FISHER

CONTROL VALVE SOURCEBOOK

PULP & PAPER

EMERSON

Process Management

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Pulp and Paper Control Valves

Introduction

This sourcebook's intent is to introduce a pulp and paper mill's processes, as well as the use of control valves in many of the processes found in the mill. It is intended to help you:

- Understand pulp and paper processes
- Learn where control valves are typically located within each process
- Identify valves commonly used for specific applications
- Identify troublesome/problem valves within the process

The information provided will follow a standard format of:

- Description of the process
- Functional drawing of the process
- Fisher® valves to be considered in each process and their associated function
- Impacts and/or considerations for troublesome/problem valves

Valve Selection

The information presented in this sourcebook is intended to assist in understanding the control valve requirements of general pulp and paper mill's processes.

Since every mill is different in technology and layout, the control valve requirements and recommendations presented by this sourcebook should be considered as general guidelines. Under no circumstances should this information alone be used to select a control valve without ensuring the proper valve construction is identified for the application and process conditions.

All valve considerations should be reviewed by the local business representative as part of any valve selection or specification activity.

Control Valves

Valves described within a chapter are labeled and numbered corresponding to the identification used in the process flow chart for that chapter. Their valve function is described, and a specification section gives added information on process conditions, names of Fisher valves that may be considered, process impact of the valve, and any special considerations for the process and valve(s) of choice.

Process Drawings

The process drawings within each chapter show major equipment items, their typical placement within the processing system, and process flow direction. Utilities and pumps are not shown unless otherwise stated.

Many original equipment manufacturers (OEMs) provide equipment to the pulp and paper industry, each with their own processes and proprietary information. Process drawings are based on general equipment configurations unless otherwise stated.

Problem Valves

Often there are references to valve-caused problems or difficulties. The list of problems include valve erosion from process media, stickiness caused by excessive friction (stiction), excessive play in valve to actuator linkages (typically found in rotary valves) that causes deadband, excessive valve stem packing leakage, and valve materials that are incompatible with the flowing medium. Any one, or a combination of these difficulties, may affect process quality and throughput with a resulting negative impact on mill profitability.

Many of these problems can be avoided or minimized through proper valve selection. Consideration should be given to valve style and size, actuator capabilities, analog versus digital instrumentation, materials of construction, etc. Although not being all-inclusive, the information found in this sourcebook should facilitate the valve selection process.

Chapter 1

Control Valve Selection

In the past, a customer simply requested a control valve and the manufacturer offered the product best-suited for the job. The choices among the manufacturers were always dependent upon obvious matters such as cost, delivery, vendor relationships, and user preference. However, accurate control valve selection can be considerably more complex, especially for engineers with limited experience or those who have not kept up with changes in the control valve industry.

An assortment of sliding-stem and rotary valve styles are available for many applications. Some are touted as “universal” valves for almost any size and service, while others are claimed to be optimum solutions for narrowly defined needs. Even the most knowledgeable user may wonder whether they are really getting the most for their money in the control valves they have specified.

Like most decisions, selection of a control valve involves a great number of variables; the everyday selection process tends to overlook a number of these important variables. The following discussion includes categorization of available valve types and a set of criteria to be considered in the selection process.

What Is A Control Valve?

Process plants consist of hundreds, or even thousands, of control loops all networked together to produce a product to be offered for sale. Each of these control loops is designed to control a critical process variable such as pressure, flow, level, temperature, etc., within a required operating range to ensure the quality of the end-product. These loops receive, and internally create, disturbances that detrimentally affect the process variable. Interaction from other loops in the network provides disturbances that influence the process variable. To reduce the effect of these load disturbances, sensors and transmitters collect information regarding the process variable and its relationship to a desired set point. A controller then processes this information and decides what must occur in order to get the process variable back to where it should be after a load disturbance occurs. When all measuring, comparing, and calculating are complete, the strategy selected by the controller is implemented via some type of final control element. The most common final control element in the process control industries is the control valve.

A control valve manipulates a flowing fluid such as gas, steam, water, or chemical compounds to compensate for the load disturbance and keep the regulated process variable as close as possible to the desired set point.

Many people who speak of “control valves” are actually referring to “control valve assemblies.” The control valve assembly typically consists of the valve body, the internal trim parts, an actuator to provide the motive power to operate the valve, and a variety of additional valve accessories, which may include positioners, transducers, supply pressure regulators, manual operators, snubbers, or limit switches.

It is best to think of a control loop as an instrumentation chain. Like any other chain, the entire chain is only as good as its weakest link. It is important to ensure that the control valve is not the weakest link.

Valve Types and Characteristics

The control valve regulates the rate of fluid flow as the position of the valve plug or disk is changed by force from the actuator. To do this, the valve must:

- Contain the fluid without external leakage.
- Have adequate capacity for the intended service.
- Be capable of withstanding the erosive, corrosive, and temperature influences of the process.
- Incorporate appropriate end connections to mate with adjacent pipelines and actuator attachment means to permit transmission of actuator thrust to the valve plug stem or rotary shaft.

Many styles of control valve bodies have been developed. Some can be used effectively in a number of applications while others meet specific service demands or conditions and are used less frequently. The subsequent text describes popular control valve body styles utilized today.

Globe Valves

Single-Port Valve Bodies

Single-port is the most common valve body style and is simple in construction. Single-port valves are available in various forms, such as globe, angle, bar stock, forged, and split constructions. Generally, single-port valves are specified for applications with stringent shutoff requirements. They use metal-to-metal seating surfaces or soft-seating with PTFE or other composition materials forming the seal.

Single-port valves can handle most service requirements. Because high pressure fluid is normally loading the entire area of the port, the unbalance force created must be considered when selecting actuators for single-port control valve bodies. Although most popular in the smaller sizes, single-port valves can often be used in NPS 4 to 8 with high thrust actuators.

Many modern single-seated valve bodies use cage or retainer-style construction to retain the seat ring cage, provide valve plug guiding, and provide a means for establishing particular valve flow

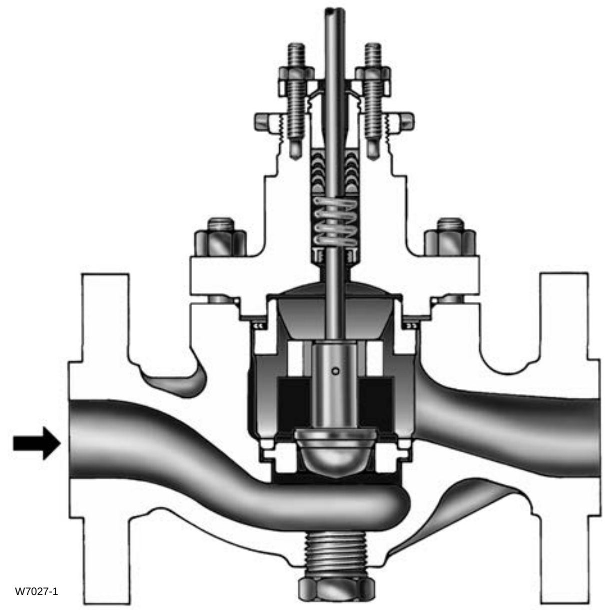

Figure 1-1*. Single-Ported Globe-Style Valve Body*

characteristics. Retainer-style trim also offers ease of maintenance with flow characteristics altered by changing the plug. Cage or retainer-style single-seated valve bodies can also be easily modified by a change of trim parts to provide reduced-capacity flow, noise attenuation, or cavitation eliminating or reducing trim (see chapter 4).

Figure 1-1 shows one of the more popular styles of single-ported or single-seated globe valve bodies. They are widely used in process control applications, particularly in sizes NPS 1 through NPS 4. Normal flow direction is most often flow-up through the seat ring.

Angle valves are nearly always single ported, as shown in figure 1-2. This valve has cage-style trim construction. Others might have screwed-in seat rings, expanded outlet connections, restricted trim, and outlet liners for reduction of erosion damage.

Bar stock valve bodies are often specified for corrosive applications in the chemical industry (figure 1-3), but may also be requested in other low flow corrosive applications. They can be machined from any metallic bar-stock material and from some plastics. When exotic metal alloys are required for corrosion resistance, a bar-stock valve body is normally less expensive than a valve body produced from a casting.

High pressure single-ported globe valves are often found in power plants due to high pressure steam (figure 1-4). Variations available include

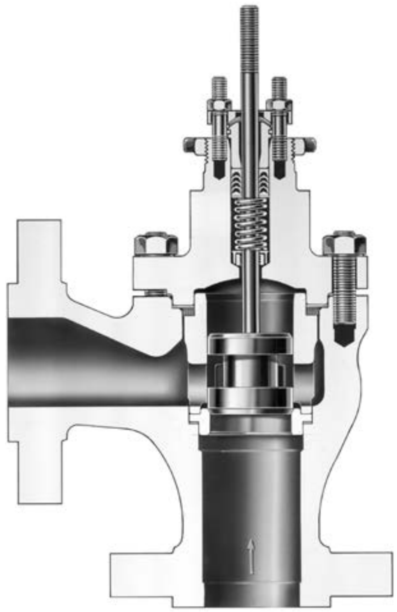

Figure 1-2*. Flanged Angle-Style Control Valve Body*

Figure 1-3*. Bar Stock Valve Body*

cage-guided trim, bolted body-to-bonnet connection, and others. Flanged versions are available with ratings to Class 2500.

Balanced-Plug Cage-Style Valve Bodies

This popular valve body style, single-ported in the sense that only one seat ring is used, provides the advantages of a balanced valve plug often

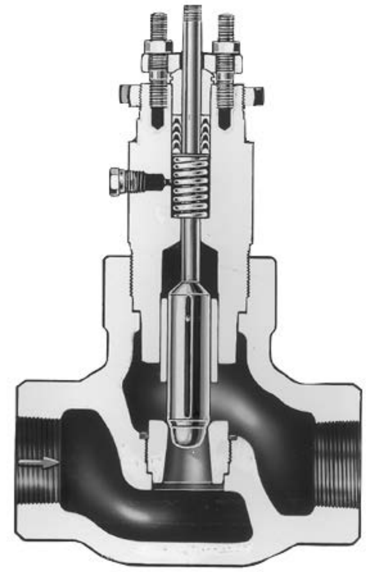

Figure 1-4*. High Pressure Globe-Style Control Valve Body*

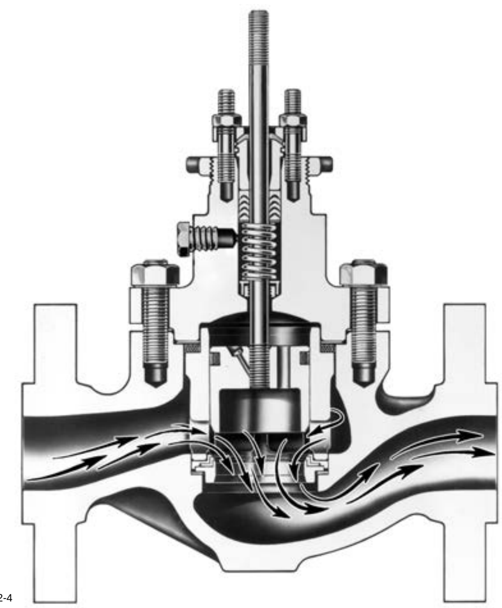

Figure 1-5*. Valve Body with Cage-Style Trim, Balanced Valve Plug, and Soft Seat*

associated only with double-ported valve bodies (figure 1-5). Cage-style trim provides valve plug guiding, seat ring retention, and flow characterization. In addition, a sliding piston ring-type seal between the upper portion of the valve plug and the wall of the cage cylinder virtually eliminates leakage of the upstream high pressure fluid into the lower pressure downstream system.

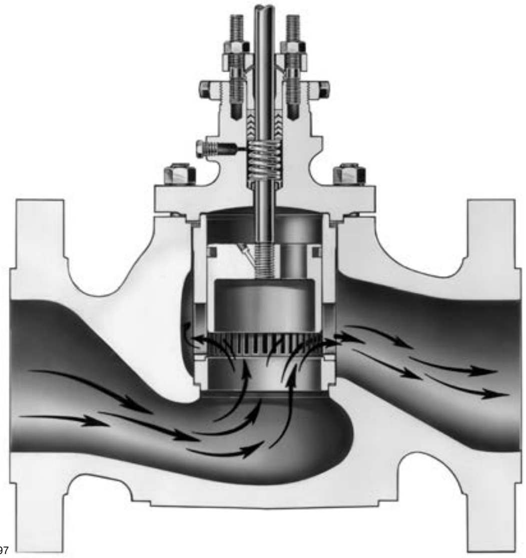

***Figure 1-6**. High Capacity Valve Body with Cage-Style Noise Abatement Trim*

Downstream pressure acts upon both the top and bottom sides of the valve plug, thereby nullifying most of the static unbalance force. Reduced unbalance permits operation of the valve with smaller actuators than those necessary for conventional single-ported valve bodies.

Interchangeability of trim permits the choice of several flow characteristics or of noise attenuation or anticavitation components. For most available trim designs, the standard direction of flow is in through the cage openings and down through the seat ring. These are available in various material combinations, sizes through NPS 20, and pressure ratings to Class 2500.

High Capacity, Cage-Guided Valve Bodies

This adaptation of the cage-guided bodies mentioned above was designed for noise applications, such as high pressure power plants, where sonic steam velocities are often encountered at the outlet of conventional valve bodies (figure 1-6).

The design incorporates oversized end connections with a streamlined flow path and the ease of trim maintenance inherent with cage-style constructions. Use of noise abatement trim reduces overall noise levels by as much as 35 decibels. The design is also available in cageless versions with a bolted seat ring, end connection sizes through NPS 20, Class 600, and versions for liquid service. The flow direction depends upon the intended service and trim selection, with unbalanced constructions normally flow-up and balanced constructions normally flow-down.

Port-Guided Single-Port Valve Bodies

- Usually limited to 150 psi (10 bar) maximum pressure drop.
- Susceptible to velocity-induced vibration.
- Typically provided with screwed in seat rings which might be difficult to remove after use.

Three-Way Valve Bodies

- Provide general converging (flow-mixing) or diverging (flow-splitting) service.
- Best designs use cage-style trim for positive valve plug guiding and ease of maintenance.
- Variations include trim materials selected for high temperature service. Standard end connections (flanged, screwed, butt weld, etc.) can be specified to mate with most any piping scheme.
- Actuator selection demands careful consideration, particularly for constructions with unbalanced valve plug.

A balanced valve plug style three-way valve body is shown with the cylindrical valve plug in the down position (figure 1-7). This position opens the bottom common port to the right-hand port and shuts off the left-hand port. The construction can be used for throttling mid-travel position control of either converging or diverging fluids.

Rotary Valves

Traditional Butterfly Valve

Standard butterfly valves are available in sizes through NPS 72 for miscellaneous control valve applications. Smaller sizes can use versions of traditional diaphragm or piston pneumatic actuators, including the modern rotary actuator styles. Larger sizes might require high output electric or long-stroke pneumatic cylinder actuators.

Butterfly valves exhibit an approximately equal percentage flow characteristic. They can be used

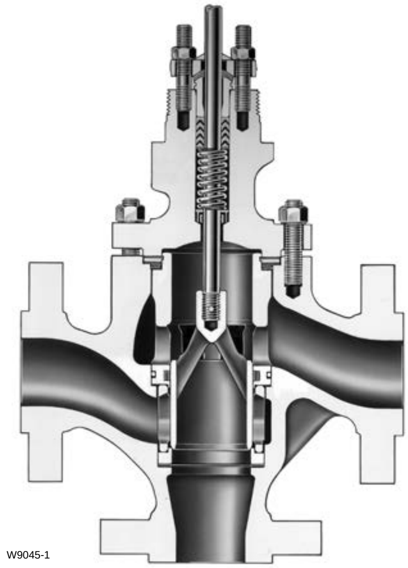

Figure 1-7*. Three Way Valve with Balanced Valve Plug*

Figure 1-8*. High-Performance Butterfly Control Valve*

for throttling service or for on-off control. Soft-seat constructions can be obtained by utilizing a liner or by including an adjustable soft ring in the body or on the face of the disk.

- Require minimum space for installation (figure 1-8).

- Provide high capacity with low pressure loss through the valves.

Figure 1-9*. Eccentric-Disk Rotary-Shaft Control Valve*

- Offer an economic advantage, particularly in larger sizes and in terms of flow capacity per dollar investment.

- Mate with standard raised-face pipeline flanges.

- Depending on size, might require high output or oversized actuators due to valve size valves or large operating torques from large pressure drops.

- Standard liner can provide precise shutoff and quality corrosion protection with nitrile or PTFE liner.

Eccentric-Disk Control Valve

Eccentric disk rotary control valves are intended for general service applications not requiring precision throttling control. They are frequently applied in applications requiring large sizes and high temperatures due to their lower cost relative to other styles of control valves. The control range for this style of valve is approximately one third as large as a ball or globe-style valves. Consequently, additional care is required in sizing and applying this style of valve to eliminate control problems associated with process load changes. They are well-suited for constant process load applications.

- Provide effective throttling control.

- Linear flow characteristic through 90 degrees of disk rotation (figure 1-9).

- Eccentric mounting of disk pulls it away from the seal after it begins to open, minimizing seal wear.

WAFER STYLE   SINGLE FLANGE STYLE

Figure 1-10*. Fisher Control-Disk Valve with 2052 Actuator and FIELDVUE DVC6200 Digital Valve Controller*

- Bodies are available in sizes through NPS 24 compatible with standard ASME flanges.

- Utilize standard pneumatic diaphragm or piston rotary actuators.

- Standard flow direction is dependent upon seal design; reverse flow results in reduced capacity.

Control-Disk Valve

The Control-Disk™ valve (figure 1-10) offers excellent throttling performance, while maintaining the size (face-to-face) of a traditional butterfly valve. The Control-Disk valve is first in class in controllability, rangeability, and tight shutoff, and it is designed to meet worldwide standards.

- Utilizes a contoured edge and unique patented disk to provide an improved control range of 15 - 70% of valve travel. Traditional butterfly valves are typically limited to 25% - 50% control range.

- Includes a tested valve sealing design, available in both metal and soft seats, to provide an unmatched cycle life while still maintaining excellent shutoff

- Spring loaded shaft positions disk against the inboard bearing nearest the actuator allowing for the disk to close in the same position in the seal, and allows for either horizontal or vertical mounting.

- Complimenting actuator comes in three, compact sizes, has nested springs and a patented lever design to increase torque range within each actuator size.

Figure 1-11*. Rotary-Shaft Control Valve with V-Notch Ball*

V-notch Ball Control Valve

This construction is similar to a conventional ball valve, but with patented, contoured V-notch in the ball (figure 1-11). The V-notch produces an equal-percentage flow characteristic. These control valves provide precise rangeability, control, and tight shutoff.

- Straight-through flow design produces little pressure drop.

- Bodies are suited to provide control of erosive or viscous fluids, paper stock, or other slurries containing entrained solids or fibers.

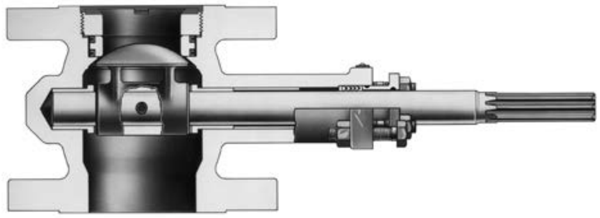

***Figure 1-12**. Sectional of Eccentric-Plug Control Valve Body*

- They utilize standard diaphragm or piston rotary actuators.

- Ball remains in contact with seal during rotation, which produces a shearing effect as the ball closes and minimizes clogging.

- Bodies are available with either heavy-duty or PTFE-filled composition ball seal ring to provide excellent rangeability in excess of 300:1.

- Bodies are available in flangeless or flanged-body end connections. Both flanged and flangeless valves mate with Class 150, 300, or 600 flanges or DIN flanges.

- Valves are capable of energy absorbing special attenuating trim to provide improved performance for demanding applications.

Eccentric-Plug Control Valve

- Valve assembly combats erosion. The rugged body and trim design handle temperatures to 800°F (427°C) and shutoff pressure drops to 1500 psi (103 bar).

- Path of eccentric plug minimizes contact with the seat ring when opening, thus reducing seat wear and friction, prolonging seat life, and improving throttling performance (figure 1-12).

- Self-centering seat ring and rugged plug allow forward or reverse-flow with tight shutoff in either direction. Plug, seat ring, and retainer are available in hardened materials, including ceramics, for selection of erosion resistance.

- Designs offering a segmented V-notch ball in place of the plug for higher capacity requirements are available.

This style of rotary control valve is well-suited for control of erosive, coking, and other hard-to-handle fluids, providing either throttling or on-off operation. The flanged or flangeless valves feature streamlined flow passages and rugged metal-trim components for dependable service in slurry applications.

Control Valve End Connections

The three common methods of installing control valves in pipelines are by means of:

- Screwed pipe threads

- Bolted gasketed flanges

- Welded end connections

Screwed Pipe Threads

Screwed end connections, popular in small control valves, are typically more economical than flanged ends. The threads usually specified are tapered female National Pipe Thread (NPT) on the valve body. They form a metal-to-metal seal by wedging over the mating male threads on the pipeline ends. This connection style, usually limited to valves not larger than NPS 2, is not recommended for elevated temperature service. Valve maintenance might be complicated by screwed end connections if it is necessary to take the body out of the pipeline. This is because the valve cannot be removed without breaking a flanged joint or union connection to permit unscrewing the valve body from the pipeline.

Bolted Gasketed Flanges

Flanged end valves are easily removed from the piping and are suitable for use through the range of working pressures for which most control valves are manufactured (figure 1-13). Flanged end connections can be used in a temperature range from absolute zero to approximately 1500°F (815°C). They are used on all valve sizes. The most common flanged end connections include flat-face, raised-face, and ring-type joint.

The flat face variety allows the matching flanges to be in full-face contact with the gasket clamped between them. This construction is commonly used in low pressure, cast iron, and brass valves, and minimizes flange stresses caused by initial bolting-up force.

The raised-face flange features a circular raised-face with the inside diameter the same as the valve opening, and the outside diameter less than the bolt circle diameter. The raised-face is

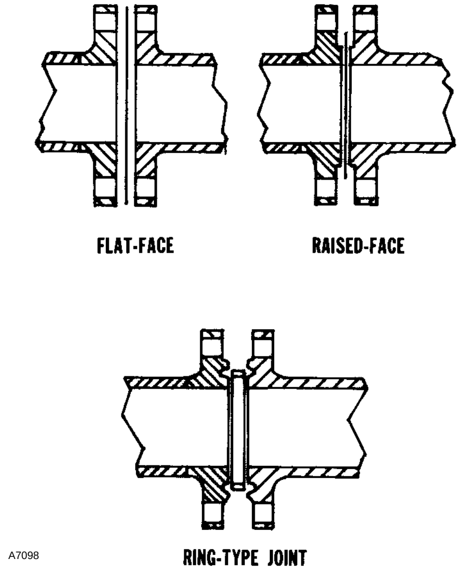

Figure 1-13*. Popular Varieties of Bolted Flange Connections*

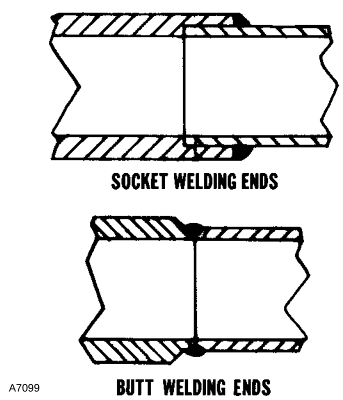

Figure 1-14*. Common Welded End Connections*

finished with concentric circular grooves for precise sealing and resistance to gasket blowout. This kind of flange is used with a variety of gasket materials and flange materials for pressures through the 6000 psig (414 bar) pressure range and for temperatures through 1500°F (815°C). This style of flanging is normally standard on Class 250 cast iron bodies and all steel and alloy steel bodies.

The ring-type joint flange is similar in looks to the raised-face flange except that a U-shaped groove is cut in the raised-face concentric with the valve opening. The gasket consists of a metal ring with either an elliptical or octagonal cross-section. When the flange bolts are tightened, the gasket is wedged into the groove of the mating flange and a tight seal is made. The gasket is generally soft iron or Monel™, but is available in almost any metal. This makes an excellent joint at high pressures and is used up to 15,000 psig (1034 bar), however, it is generally not used at high temperatures. It is furnished only on steel and alloy valve bodies when specified.

Welding End Connections

Welding ends on control valves (figure 1-14) are leak-tight at all pressures and temperatures, and are economical in first cost. Welding end valves are more difficult to take from the line and are limited to weldable materials. Welding ends come in two styles:

- Socket welding
- Buttwelding

The socket welding ends are prepared by boring in a socket at each end of the valve with an inside diameter slightly larger than the pipe outside diameter. The pipe slips into the socket where it butts against a shoulder and then joins to the valve with a fillet weld. Socket welding ends in a given size are dimensionally the same regardless of pipe schedule. They are usually furnished in sizes through NPS 2.

The buttwelding ends are prepared by beveling each end of the valve to match a similar bevel on the pipe. The two ends are then butted to the pipeline and joined with a full penetration weld. This type of joint is used on all valve styles and the end preparation must be different for each schedule of pipe. These are generally furnished for control valves in NPS 2-1/2 and larger. Care must be exercised when welding valve bodies in the pipeline to prevent excessive heat transmitted to valve trim parts. Trims with low-temperature composition materials must be removed before welding.

Valve Body Bonnets

The bonnet of a control valve is the part of the body assembly through which the valve plug stem or rotary shaft moves. On globe or angle bodies, it is the pressure retaining component for one end of the valve body. The bonnet normally provides a means of mounting the actuator to the body and houses the packing box. Generally, rotary valves do not have bonnets. (On some rotary-shaft valves, the packing is housed within an extension of the valve body itself, or the packing box is a separate component bolted between the valve body and bonnet.)

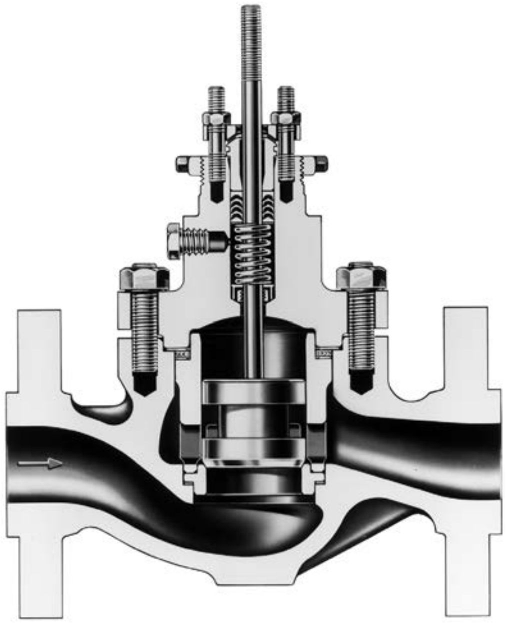

***Figure 1-15**. Typical Bonnet, Flange, and Stud Bolts*

On a typical globe-style control valve body, the bonnet is made of the same material as the valve body or is an equivalent forged material because it is a pressure-containing member subject to the same temperature and corrosion effects as the body. Several styles of valve body-to-bonnet connections are illustrated. The most common is the bolted flange type shown in figure 1-15. A bonnet with an integral flange is also illustrated in figure 1-15. Figure 1-3 illustrates a bonnet with a separable, slip-on flange held in place with a split ring. The bonnet used on the high pressure globe valve body illustrated in figure 1-4, is screwed into the valve body. Figure 1-8 illustrates a rotary-shaft control valve in which the packing is housed within the valve body and a bonnet is not used. The actuator linkage housing is not a pressure-containing part and is intended to enclose the linkage for safety and environmental protection.

On control valve bodies with cage- or retainer-style trim, the bonnet furnishes loading force to prevent leakage between the bonnet flange and the valve body, and also between the seat ring and the valve body. The tightening of the body-bonnet bolting compresses a flat sheet gasket to seal the body-bonnet joint, compresses a spiral-wound gasket on top of the cage, and compresses an additional flat sheet gasket below the seat ring to provide the seat ring-body seal. The bonnet also provides alignment for the cage, which, in turn, guides the valve plug to ensure proper valve plug stem alignment with the packing.

As mentioned previously, the conventional bonnet on a globe-type control valve houses the packing. The packing is most often retained by a packing follower held in place by a flange on the yoke boss area of the bonnet (figure 1-15). An alternate packing retention means is where the packing follower is held in place by a screwed gland (figure 1-3). This alternate is compact, thus, it is often used on small control valves, however, the user cannot always be sure of thread engagement. Therefore, caution should be used if adjusting the packing compression when the control valve is in service.

Most bolted-flange bonnets have an area on the side of the packing box which can be drilled and tapped. This opening is closed with a standard pipe plug unless one of the following conditions exists:

- It is necessary to purge the valve body and bonnet of process fluid, in which case the opening can be used as a purge connection.

- The bonnet opening is being used to detect leakage from the first set of packing or from a failed bellows seal.

Extension Bonnets

Extension bonnets are used for either high or low temperature service to protect valve stem packing from extreme process temperatures. Standard PTFE valve stem packing is useful for most applications up to 450°F (232°C). However, it is susceptible to damage at low process temperatures if frost forms on the valve stem. The frost crystals can cut grooves in the PTFE, thus, forming leakage paths for process fluid along the stem. Extension bonnets remove the packing box of the bonnet far enough from the extreme temperature of the process that the packing temperature remains within the recommended range.

Extension bonnets are either cast (figure 1-16) or fabricated (figure 1-17). Cast extensions offer better high temperature service because of greater heat emissivity, which provides better cooling effect. Conversely, smooth surfaces that can be fabricated from stainless steel tubing are preferred for cold service because heat influx is usually the major concern. In either case, extension wall thickness should be minimized to cut down heat transfer. Stainless steel is usually preferable to

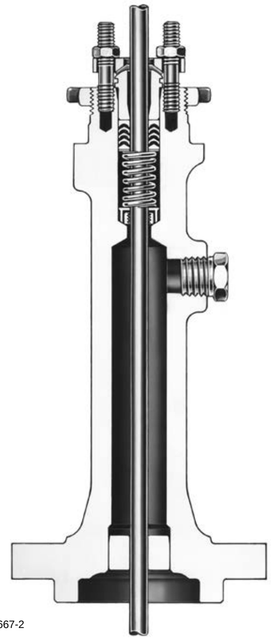
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Figure 1-16*. Extension Bonnet*


W1416

Figure 1-17*. Valve Body with Fabricated Extension Bonnet*

carbon steel because of its lower coefficient of thermal conductivity. On cold service applications, insulation can be added around the extension to protect further against heat influx.


W6434

Figure 1-18*. ENVIRO-SEAL ™ Bellows Seal Bonnet*

Bellows Seal Bonnets

Bellows seal bonnets (figure 1-18) are used when no leakage (less than 1x10−6 cc/sec of helium) along the stem can be tolerated. They are often used when the process fluid is toxic, volatile, radioactive, or highly expensive. This special bonnet construction protects both the stem and the valve packing from contact with the process fluid. Standard or environmental packing box constructions above the bellows seal unit will prevent catastrophic failure in case of rupture or failure of the bellows.

As with other control valve pressure/ temperature limitations, these pressure ratings decrease with increasing temperature. Selection of a bellows seal design should be carefully considered, and particular attention should be paid to proper inspection and maintenance after installation. The bellows material should be carefully considered to ensure the maximum cycle life.

Two types of bellows seal designs are used for control valves:

- Mechanically formed as shown in figure 1-19
- Welded leaf bellows as shown in figure 1-20

The welded-leaf design offers a shorter total package height. Due to its method of manufacture and inherent design, service life may be limited.

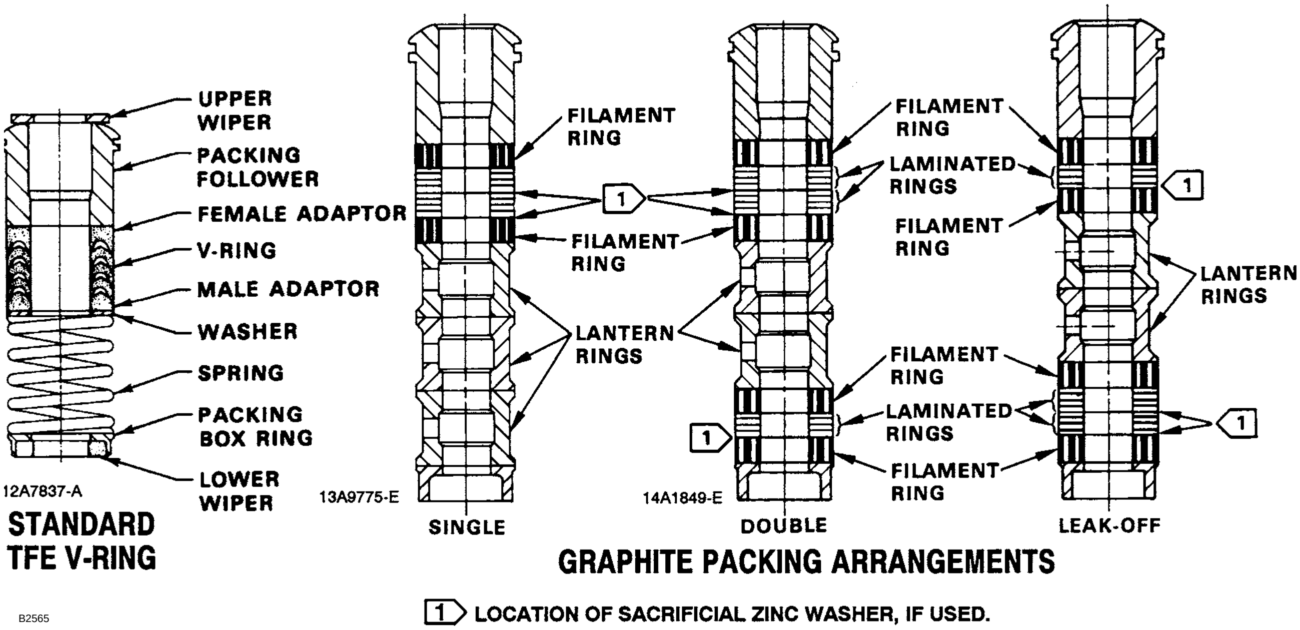

Figure 1-21*. Comprehensive Packing Material Arrangements for Globe-Style Valve Bodies*

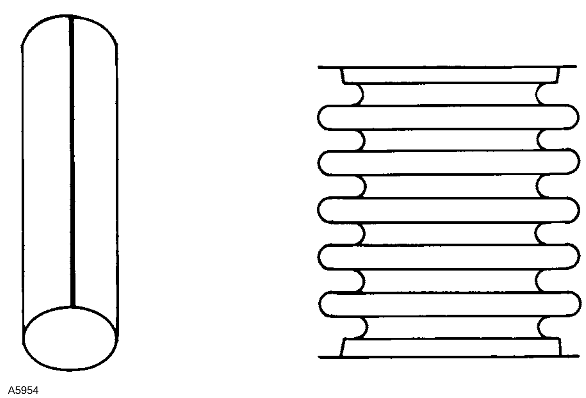

Figure 1-19*. Mechanically Formed Bellows*

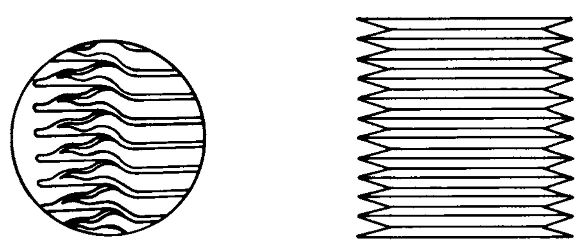

Figure 1-20*. Welded Leaf Bellows*

The mechanically formed bellows is taller in comparison and is produced with a more repeatable manufacturing process.

Control Valve Packing

Most control valves use packing boxes with the packing retained and adjusted by a flange and stud bolts (figure 1-27). Several packing materials can be used depending upon the service conditions expected and whether the application requires compliance to environmental regulations. Brief descriptions and service condition guidelines for several popular materials and typical packing material arrangements are shown in figure 1-21.

PTFE V-Ring

- Plastic material with inherent ability to minimize friction.

- Molded in V-shaped rings that are spring loaded and self-adjusting in the packing box. Packing lubrication not required.

- Resistant to most known chemicals except molten alkali metals.

- Requires extremely smooth (2 to 4 micro-inches RMS) stem finish to seal properly. Will leak if stem or packing surface is damaged.

- Recommended temperature limits: −40°F to +450°F (−40°C to +232°C)

- Not suitable for nuclear service because PTFE is easily destroyed by radiation.

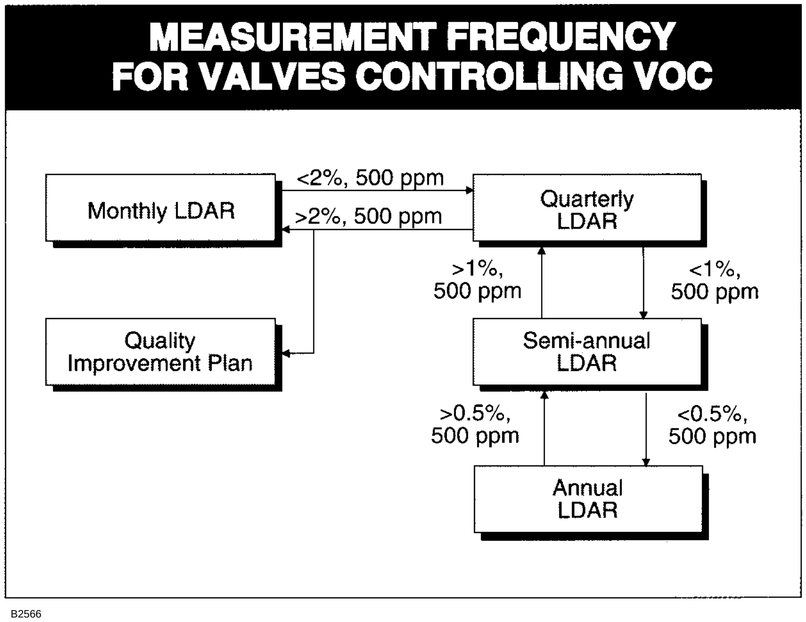

Figure 1-22. *Measurement Frequency for Valves Controlling Volatile Organic Chemicals (VOC)*

Laminated and Filament Graphite

- Suitable for high temperature nuclear service or where low chloride content is desirable (Grade GTN).

- Provides leak-free operation, high thermal conductivity, and long service life, but produces high stem friction and resultant hysteresis.

- Impervious to most hard-to-handle fluids and high radiation.

- Suitable temperature range: Cryogenic temperatures to 1200°F (649°C).

- Lubrication not required, but an extension bonnet or steel yoke should be used when packing box temperature exceeds 800°F (427°C).

USA Regulatory Requirements for Fugitive Emissions

Fugitive emissions are non-point source volatile organic emissions that result from process equipment leaks. Equipment leaks in the United States have been estimated at over 400 million pounds per year. Strict government regulations, developed by the US, dictate Leak Detection and Repair (LDAR) programs. Valves and pumps have been identified as key sources of fugitive emissions. In the case of valves, this is the leakage to atmosphere due to packing seal or gasket failures.

The LDAR programs require industry to monitor all valves (control and noncontrol) at an interval that is determined by the percentage of valves found to be leaking above a threshold level of 500 ppmv (some cities use a 100 ppmv criteria). This leakage level is so slight you cannot see or hear it. The use of sophisticated portable monitoring equipment is required for detection. Detection occurs by sniffing the valve packing area for leakage using an Environmental Protection Agency (EPA) protocol. This is a costly and burdensome process for industry.

The regulations do allow for the extension of the monitoring period for up to one year if the facility can demonstrate an extremely low ongoing percentage of leaking valves (less than 0.5% of the total valve population). The opportunity to extend the measurement frequency is shown in figure 1-22.

Packing systems designed for extremely low leakage requirements also extend packing seal life and performance to support an annual monitoring objective. The ENVIRO-SEAL™ packing system is one example. Its enhanced seals incorporate four key design principles including:

- Containment of the pliable seal material through an anti-extrusion component.

- Proper alignment of the valve stem or shaft within the bonnet bore.

- Applying a constant packing stress through Belleville springs.

- Minimizing the number of seal rings to reduce consolidation, friction, and thermal expansion.

The traditional valve selection process meant choosing a valve design based upon its pressure and temperature capabilities as well as its flow characteristics and material compatibility. Valve stem packing used in the valve was determined primarily by the operating temperature in the packing box area. The available material choices included PTFE for temperatures below 93°C (200°F) and graphite for higher temperature applications.

Today, choosing a valve packing system has become much more complex due to the number of considerations one must take into account. For example, emissions control requirements, such as those imposed by the Clean Air Act within the United States and by other regulatory bodies, place tighter restrictions on sealing performance. Constant demands for improved process output mean that the valve packing system must not hinder valve performance. Also, today's trend toward extended maintenance schedules dictates that valve packing systems provide the required sealing over longer periods.

In addition, end user specifications that have become de facto standards, as well as standards organizations specifications, are used by customers to place stringent fugitive emissions leakage requirements and testing guidelines on process control equipment vendors. Emerson Process Management and its observance of limiting fugitive emissions is evident by its reliable valve sealing (packing and gasket) technologies, global emissions testing procedures, and emissions compliance approvals.

Given the wide variety of valve applications and service conditions within industry, these variables (sealing ability, operating friction levels, operating life) are difficult to quantify and compare. A proper understanding requires a clarification of trade names.

Single PTFE V-Ring Packing (Fig. 1-23)

The single PTFE V-ring arrangement uses a coil spring between the packing and packing follower.

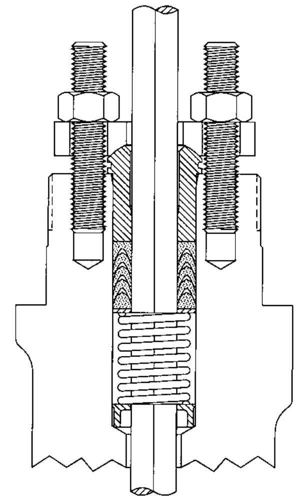

***Figure 1-23**. Single PTFE V-Ring Packing*

It meets the 100 ppmv criteria, assuming that the pressure does not exceed 20.7 bar (300 psi) and the temperature is between −18°C and 93°C (0°F and 200°F). It offers excellent sealing performance with the lowest operating friction.

ENVIRO-SEAL PTFE Packing (Fig. 1-24)

The ENVIRO-SEAL PTFE packing system is an advanced packing method that utilizes a compact, live-load spring design suited to environmental applications up to 51.7 bar and 232°C (750 psi and 450°F). While it most typically is thought of as an emission-reducing packing system, ENVIRO-SEAL PTFE packing is, also, well-suited for non-environmental applications involving high temperatures and pressures, yielding the benefit of longer, ongoing service life.

ENVIRO-SEAL Duplex Packing (Fig. 1-25)

This special packing system provides the capabilities of both PTFE and graphite components to yield a low friction, low emission, fire-tested solution (API Standard 589) for applications with process temperatures up to 232°C (450°F).

KALREZ ™ Valve Stem Packing (KVSP) systems

The KVSP pressure and temperature limits referenced are for Fisher valve applications only. KVSP with PTFE is suited to environmental use up to 24.1 bar and 204°C (350 psi and 400°F) and, to

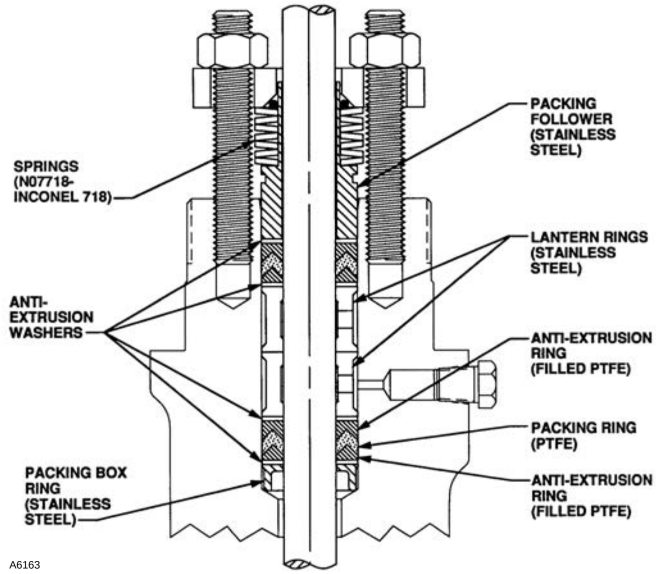

Figure 1-24. *ENVIRO-SEAL PTFE Packing System*

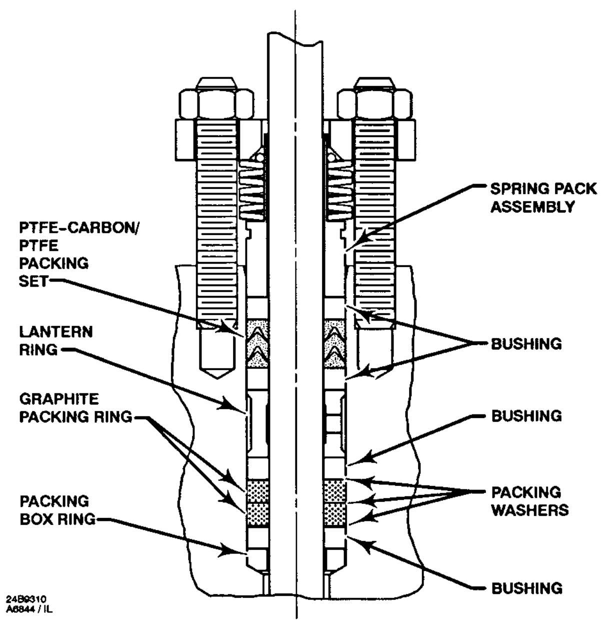

Figure 1-25. *ENVIRO-SEAL Duplex (PTFE and Graphite) Packing System*

some non-environmental services up to 103 bar (1500 psi). KVSP with ZYMAXX™, which is a carbon fiber reinforced TFE, is suited to 260°C (500°F) service.

ENVIRO-SEAL Graphite Ultra Low Friction (ULF) Packing (Fig. 1-26)

This packing system is designed primarily for environmental applications at temperatures in

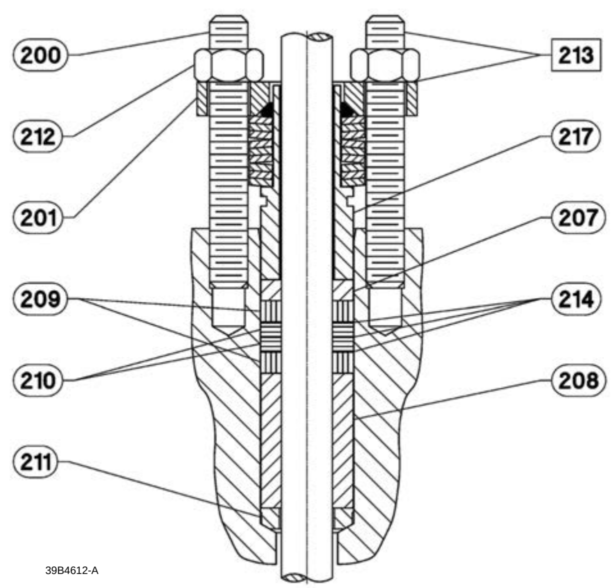

Figure 1-26. *ENVIRO-SEAL Graphite ULF Packing System*

excess of 232°C (450°F). The patented ULF packing system incorporates thin PTFE layers inside the packing rings and thin PTFE washers on each side of the packing rings. This strategic placement of PTFE minimizes control problems, reduces friction, promotes sealing, and extends the cycle life of the packing set.

HIGH-SEAL Graphite ULF Packing

Identical to the ENVIRO-SEAL graphite ULF packing system below the packing follower, the

Figure 1-28. *Characterized Cages for Globe-Style Valve Bodies*

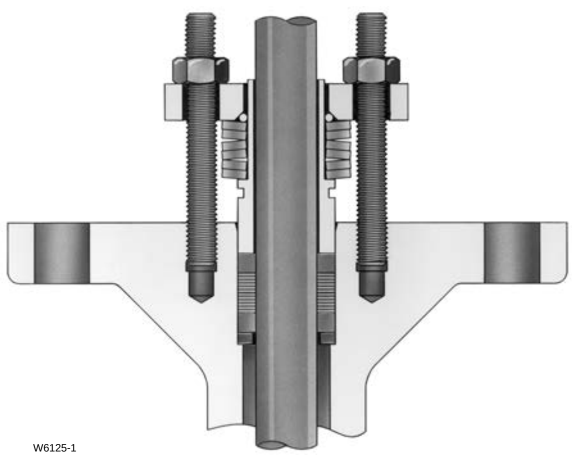

Figure 1-27. *ENVIRO-SEAL Graphite Packing System for Rotary Valves*

HIGH-SEAL system utilizes heavy-duty, large diameter Belleville springs. These springs provide additional follower travel and can be calibrated with a load scale for a visual indication of packing load and wear.

ENVIRO-SEAL Graphite Packing for Rotary Valves (Fig. 1-27)

ENVIRO-SEAL graphite packing is designed for environmental applications from −6°C to 316°C (20°F to 600°F) or for those applications where fire safety is a concern. It can be used with pressures to 103 bar (1500 psi) and still satisfy the 500 ppmv EPA leakage criteria.

Graphite Ribbon Packing for Rotary Valves

Graphite ribbon packing is designed for non-environmental applications that span a wide temperature range from −198°C to 538°C (−325°F to 1000°F).

The following table provides a comparison of various sliding-stem packing selections and a relative ranking of seal performance, service life, and packing friction for environmental applications. Braided graphite filament and double PTFE are not acceptable environmental sealing solutions.

The following applies to rotary valves. In the case of rotary valves, single PTFE and graphite ribbon packing arrangements do not perform well as fugitive emission sealing solutions.

The control of valve fugitive emissions and a reduction in industry's cost of regulatory compliance can be achieved through these stem sealing technologies.

While ENVIRO-SEAL packing systems have been designed specifically for fugitive emission applications, these technologies should also be considered for any application where seal performance and seal life have been an ongoing concern or maintenance cost issue.

Characterization of Cage-Guided Valve Bodies

In valve bodies with cage-guided trim, the shape of the flow openings or windows in the wall of the cylindrical cage determines flow characterization. As the valve plug is moved away from the seat ring, the cage windows are opened to permit flow through the valve. Standard cages have been designed to produce linear, equal-percentage, and quick-opening inherent flow characteristics. Note the differences in the shapes of the cage windows shown in figure 1-28. The flow rate/travel relationship provided by valves utilizing these

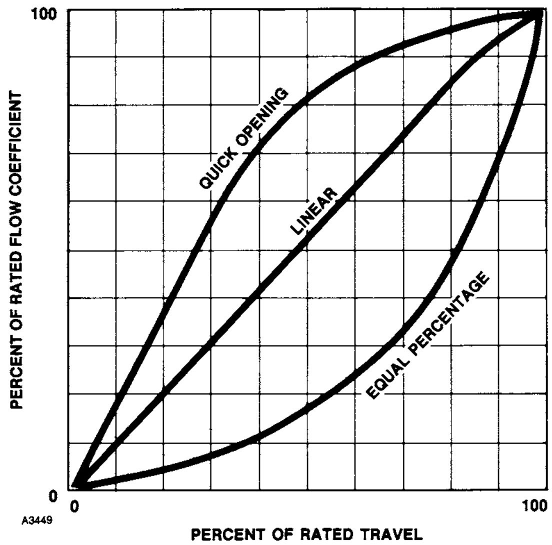

***Figure 1-29**. Inherent Flow Characteristics Curves*

cages is equivalent to the linear, quick-opening, and equal-percentage curves shown for contoured valve plugs (figure 1-29).

Cage-guided trim in a control valve provides a distinct advantage over conventional valve body assemblies in that maintenance and replacement of internal parts is simplified. The inherent flow characteristic of the valve can easily be changed by installing a different cage. Interchange of cages to provide a different inherent flow characteristic does not require changing the valve plug or seat ring. The standard cages shown can be used with either balanced or unbalanced trim constructions. Soft seating, when required, is available as a retained insert in the seat ring and is independent of cage or valve plug selection.

Cage interchangeability can be extended to specialized cage designs that provide noise attenuation or combat cavitation. These cages furnish a modified linear inherent flow characteristic, but require flow to be in a specific direction through the cage openings. Therefore, it could be necessary to reverse the valve body in the pipeline to obtain proper flow direction.

Characterized Valve Plugs

The valve plug, the movable part of a globe-style control valve assembly, provides a variable restriction to fluid flow. Valve plug styles are each designed to:

- Provide a specific flow characteristic.
- Permit a specified manner of guiding or alignment with the seat ring.
- Have a particular shutoff or damage-resistance capability.

Valve plugs are designed for either two-position or throttling control. In two-position applications, the valve plug is positioned by the actuator at either of two points within the travel range of the assembly. In throttling control, the valve plug can be positioned at any point within the travel range as dictated by the process requirements.

The contour of the valve plug surface next to the seat ring is instrumental in determining the inherent flow characteristic of a conventional globe-style control valve. As the actuator moves the valve plug through its travel range, the unobstructed flow area changes in size and shape depending upon the contour of the valve plug. When a constant pressure differential is maintained across the valve, the changing relationship between percentage of maximum flow capacity and percentage of total travel range can be portrayed (figure 1-29), and is designated as the inherent flow characteristic of the valve.

Commonly specified inherent flow characteristics include:

Linear Flow

- A valve with an ideal linear inherent flow characteristic produces a flow rate directly proportional to the amount of valve plug travel throughout the travel range. For instance, at 50% of rated travel, flow rate is 50% of maximum flow; at 80% of rated travel, flow rate is 80% of maximum; etc. Change of flow rate is constant with respect to valve plug travel. Valves with a linear characteristic are often specified for liquid level control and for flow control applications requiring constant gain.

Equal-Percentage Flow

- Ideally, for equal increments of valve plug travel, the change in flow rate regarding travel may be expressed as a constant percent of the flow rate at the time of the change. The change in flow rate observed regarding travel will be relatively small when the valve plug is near its seat, and relatively high when the valve plug is nearly wide open. Therefore, a valve with an inherent equal-percentage flow characteristic provides precise throttling control through the lower portion of the travel range and rapidly increasing capacity as the valve plug nears the wide-open position.

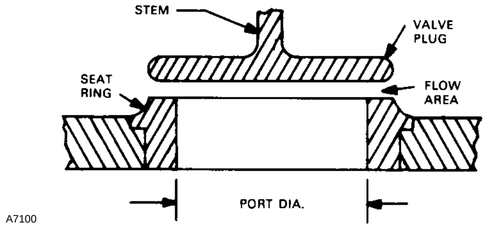

Figure 1-30*. Typical Construction to Provide Quick-Opening Flow Characteristic*

Valves with equal-percentage flow characteristics are used on pressure control applications, on applications where a large percentage of the pressure drop is normally absorbed by the system itself with only a relatively small percentage available at the control valve, and on applications where highly varying pressure drop conditions can be expected. In most physical systems, the inlet pressure decreases as the rate of flow increases, and an equal percentage characteristic is appropriate. For this reason, equal percentage flow is the most common valve characteristic.

Quick-Opening Flow

- A valve with a quick opening flow characteristic provides a maximum change in flow rate at low travels. The curve is essentially linear through the first 40 percent of valve plug travel, then flattens out noticeably to indicate little increase in flow rate as travel approaches the wide-open position. Control valves with quick-opening flow characteristics are often used for on/off applications where significant flow rate must be established quickly as the valve begins to open. As a result, they are often utilized in relief valve applications. Quick-opening valves can also be selected for many of the same applications for which linear flow characteristics are recommended. This is because the quick-opening characteristic is linear up to about 70 percent of maximum flow rate. Linearity decreases significantly after flow area generated by valve plug travel equals the flow area of the port. For a typical quick-opening valve (figure 1-30), this occurs when valve plug travel equals one-fourth of port diameter.

Valve Plug Guiding

Accurate guiding of the valve plug is necessary for proper alignment with the seat ring and efficient control of the process fluid. The common methods used are listed below.

- Cage Guiding: The outside diameter of the valve plug is close to the inside wall surface of the cylindrical cage throughout the travel range. Since the bonnet, cage, and seat ring are self-aligning upon assembly, the correct valve plug and seat ring alignment is assured when the valve closes (figure 1-15).

- Top Guiding: The valve plug is aligned by a single guide bushing in the bonnet, valve body (figure 1-4), or by packing arrangement.

- Stem Guiding: The valve plug is aligned with the seat ring by a guide bushing in the bonnet that acts upon the valve plug stem (figure 1-3, left view).

- Top-and-Bottom Guiding: The valve plug is aligned by guide bushings in the bonnet and bottom flange.

- Port Guiding: The valve plug is aligned by the valve body port. This construction is typical for control valves utilizing small-diameter valve plugs with fluted skirt projections to control low flow rates (figure 1-3, right view).

Restricted-Capacity Control Valve Trim

Most control valve manufacturers can provide valves with reduced- or restricted- capacity trim parts. The reduced flow rate might be desirable for any of the following reasons:

- Restricted capacity trim may make it possible to select a valve body large enough for increased future flow requirements, but with trim capacity properly sized for present needs.

- Valves can be selected for adequate structural strength, yet retain reasonable travel/capacity relationship.

- Large bodies with restricted capacity trim can be used to reduce inlet and outlet fluid velocities.

- Purchase of expensive pipeline reducers can be avoided.

- Over-sizing errors can be corrected by use of restricted capacity trim parts.

Conventional globe-style valve bodies can be fitted with seat rings with smaller port size than normal and valve plugs sized to fit those smaller ports. Valves with cage-guided trim often achieve the reduced capacity effect by utilizing valve plug, cage, and seat ring parts from a smaller valve size of similar construction and adapter pieces above the cage and below the seat ring to mate those smaller parts with the valve body (figure 1-28). Because reduced capacity service is not unusual, leading manufacturers provide readily available trim part combinations to perform the required function. Many restricted capacity trim combinations are designed to furnish approximately 40% of full-size trim capacity.

General Selection Criteria

Most of the considerations that guide the selection of valve type and brand are rather basic. However, there are some matters that may be overlooked by users whose familiarity is mainly limited to just one or a few valve types. Table 1-1 below provides a checklist of important criteria; each is discussed at length following the table.

Table 1-1. *Suggested General Criteria for Selecting Type and Brand of Control Valve*

Body pressure rating
High and low temperature limits
Material compatibility and durability
Inherent flow characteristic and rangeability
Maximum pressure drop (shutoff and flowing)
Noise and cavitation
End connections
Shutoff leakage
Capacity versus cost
Nature of flowing media
Dynamic performance

Pressure Ratings

Body pressure ratings ordinarily are considered according to ANSI pressure classes — the most common ones for steel and stainless steel being Classes 150, 300 and 600. (Source documents are ASME/ANSI Standards B16.34, "Steel Valves," and ANSI B16.1, "Cast Iron Pipe Flanges and Flanged Fittings.") For a given body material, each NSI Class corresponds to a prescribed profile of maximum pressures that decrease with temperature according to the strength of the material. Each material also has a minimum and maximum service temperature based upon loss of ductility or loss of strength. For most applications, the required pressure rating is dictated by the application. However, because all products are not available for all ANSI Classes, it is an important consideration for selection.

Temperature Considerations

Required temperature capabilities are also a foregone conclusion, but one that is likely to narrow valve selection possibilities. The considerations include the strength or ductility of the body material, as well as relative thermal expansion of various parts.

Temperature limits also may be imposed due to disintegration of soft parts at high temperatures or loss of resiliency at low temperatures. The soft materials under consideration include various elastomers, plastics, and PTFE. They may be found in parts such as seat rings, seal or piston rings, packing, rotary shaft bearings and butterfly valve liners. Typical upper temperature limits for elastomers are in the 200 - 350°F range, and the general limit for PTFE is 450°F.

Temperature affects valve selection by excluding certain valves that do not have high or low temperature options. It also may have some affect on the valve's performance. For instance, going from PTFE to metal seals for high temperatures generally increases the shutoff leakage flow. Similarly, high temperature metal bearing sleeves in rotary valves impose more friction upon the shaft than do PTFE bearings, so that the shaft cannot withstand as high a pressure-drop load at shutoff. Selection of the valve packing is also based largely upon service temperature.

Material Selection

The third criterion in table 1-1, "material compatibility and durability", is a more complex consideration. Variables may include corrosion by the process fluid, erosion by abrasive material, flashing, cavitation or pressure and temperature requirements. The piping material usually indicates the body material. However, because the velocity is higher in valves, other factors must be considered. When these variables are included, often valve and piping materials will differ. The trim materials, in turn, are usually a function of the body material, temperature range and qualities of the fluid. When a body material other than carbon, alloy, or stainless steel is required, use of an alternate valve type, such as lined or bar stock, should be considered.

Flow Characteristic

The next selection criterion, “inherent flow characteristic”, refers to the pattern in which the flow at constant pressure drop changes according to valve position. Typical characteristics are quick-opening, linear, and equal-percentage. The choice of characteristic may have a strong influence upon the stability or controllability of the process (see table 1-3), as it represents the change of valve gain relative to travel.

Most control valves are carefully “characterized” by means of contours on a plug, cage, or ball element. Some valves are available in a variety of characteristics to suit the application, while others offer little or no choice. To quantitatively determine the best flow characteristic for a given application, a dynamic analysis of the control loop can be performed. In most cases, however, this is unnecessary; reference to established rules of thumb will suffice.

The accompanying drawing illustrates typical flow characteristic curves (figure 1-29). The quick opening flow characteristic provides for maximum change in flow rate at low valve travels with a fairly linear relationship. Additional increases in valve travel give sharply reduced changes in flow rate, and when the valve plug nears the wide open position, the change in flow rate approaches zero. In a control valve, the quick opening valve plug is used primarily for on-off service; but it is also suitable for many applications where a linear valve plug would normally be specified.

Rangeability

Another aspect of a valve’s flow characteristic is its rangeability, which is the ratio of its maximum and minimum controllable flow rates. Exceptionally wide rangeability may be required for certain applications to handle wide load swings or a combination of start-up, normal and maximum working conditions. Generally speaking, rotary valves—especially partial ball valves—have greater rangeability than sliding-stem varieties.

Use of Positioners

A positioner is an instrument that helps improve control by accurately positioning a control valve actuator in response to a control signal. They are useful in many applications and are required with certain actuator styles in order to match actuator and instrument pressure signals, or to provide operating stability. To a certain extent, a valve with one inherent flow characteristic can also be made to perform as though it had a different characteristic by utilizing a nonlinear (i.e., characterized) positioner-actuator combination. The limitation of this approach lies in the positioner’s frequency response and phase lag compared to the characteristic frequency of the process. Although it is common practice to utilize a positioner on every valve application, each application should be reviewed carefully. There are certain examples of high gain processes where a positioner can hinder valve performance.

Pressure Drop

The maximum pressure drop a valve can tolerate at shutoff, or when partially or fully open, is an important selection criteria. Sliding-stem valves are generally superior in both regards because of the rugged nature of their moving parts. Many rotary valves are limited to pressure drops well below the body pressure rating, especially under flowing conditions, due to dynamic stresses that high velocity flow imposes on the disk or ball segment.

Noise and Cavitation

Noise and cavitation are two considerations that often are grouped together because both result from high pressure drops and large flow rates. They are treated by special modifications to standard valves. Chapter four discusses the cavitation phenomenon and its impact and treatment, while chapter six discusses noise generation and abatement.

End Connections

The three common methods of installing control valves in pipelines are by means of screwed pipe threads, bolted flanges, and welded end connections. At some point in the selection process, the valve’s end connections must be considered with the question simply being whether the desired connection style is available in the valve being considered.

In some situations, this matter can limit the selection rather narrowly. For instance, if a piping specification calls for welded connections only, the choice usually is limited to sliding-stem valves.

Screwed end connections, popular in small control valves, offer more economy than flanged ends.

The threads usually specified are tapered female NPT on the valve body. They form a metal-to-metal seal by wedging over the mating male threads on the pipeline ends. This connection style is usually limited to valves not larger than NPS 2, and is not recommended for elevated temperature service.

Valve maintenance might be complicated by screwed end connections if it is necessary to take the body out of the pipeline. Screwed connections require breaking a flanged joint or union connection to permit unscrewing the valve body from the pipeline.

Flanged end valves are easily removed from the piping and are suitable for use through the range of working pressures that most control valves are manufactured (figure 1-13).

Flanged end connections can be utilized in a temperature range from absolute zero (−273°F) to approximately 1500°F (815°C). They are utilized on all valve sizes. The most common flanged end connections include flat face, raised face, and ring type joint.

Welded ends on control valves are leak-tight at all pressures and temperatures and are economical in initial cost (figure 1-14). Welded end valves are more difficult to remove from the line and are limited to weldable materials. Welded ends come in two styles, socket weld and buttweld.

Shutoff Capability

Some consideration must be given to a valve's shutoff capability, which is usually rated in terms of classes specified in ANSI/FCI70-2 (table 1-4). In service, shutoff leakage depends upon many factors, including but not limited to, pressure drop, temperature, and the condition of the sealing surfaces. Because shutoff ratings are based upon standard test conditions that can be different from service conditions, service leakage cannot be predicted accurately. However, the shutoff class provides a good basis for comparison among valves of similar configuration. It is not uncommon for valve users to overestimate the shutoff class required.

Because tight shutoff valves generally cost more both in initial cost, as well as in later maintenance expense, serious consideration is warranted. Tight shutoff is particularly critical in high pressure valves, considering that leakage in these applications can lead to the ultimate destruction of the trim. Special precautions in seat material selection, seat preparation and seat load are necessary to ensure success.

Flow Capacity

Finally, the criterion of capacity or size can be an overriding constraint on selection. For extremely large lines, sliding-stem valves are more expensive than rotary types. On the other hand, for extremely small flows, a suitable rotary valve may not be available. If future plans call for significantly larger flow, then a sliding-stem valve with replaceable restricted trim may be the answer. The trim can be changed to full size trim to accommodate higher flow rates at less cost than replacing the entire valve body assembly.

Rotary style products generally have much higher maximum capacity than sliding-stem valves for a given body size. This fact makes rotary products attractive in applications where the pressure drop available is rather small. However, it is of little or no advantage in high pressure drop applications such as pressure regulation or letdown.

Conclusion

For most general applications, it makes sense both economically, as well as technically, to use sliding-stem valves for lower flow ranges, ball valves for intermediate capacities, and high performance butterfly valves for the very largest required flows. However, there are numerous other factors in selecting control valves, and general selection principles are not always the best choice.

Selecting a control valve is more of an art than a science. Process conditions, physical fluid phenomena, customer preference, customer experience, supplier experience, among numerous other criteria must be considered in order to obtain the best possible solution. Many applications are beyond that of general service, and as chapter 4 will present, there are of number of selection criteria that must be considered when dealing with these sometimes severe flows.

Special considerations may require out-of-the-ordinary valve solutions; there are valve designs and special trims available to handle high noise applications, flashing, cavitation, high pressure, high temperature and combinations of these conditions.

After going through all the criteria for a given application, the selection process may point to several types of valves. From there on, selection becomes a matter of price versus capability, coupled with the inevitable personal and institutional preferences. As no single control valve package is cost-effective over the full range of applications, it is important to keep an open mind to alternative choices.

Table 1-2. *Major Categories and Subcategories of Control Valves with Typical General Characteristics*

Valve Style	Main Characteristics	Typical Size Range, inches	Typical Standard Body Materials	Typical Standard End Connection	Typical Pressure Ratings	Relative Flow Capacity	Relative Shutoff Capability
Regular Sliding-stem	Heavy Duty Versatile	1 to 24	Carbon Steel Cast Iron Stainless	ANSI Flanged Welded Screwed	To ANSI 2500	Moderate	Excellent
Bar Stock	Machined from Bar Stock	½ to 3	Variety of Alloys	Flangeless Screwed	To ANSI 600	Low	Excellent
Economy Sliding-stem	Light Duty Inexpensive	½ to 2	Bronze Cast Iron Carbon Steel	Screwed	To ANSI 125	Moderate	Good
Thru-Bore Ball	On-Off Service	1 to 24	Carbon Steel Stainless	Flangeless	To ANSI 900	High	Excellent
Partial Ball	Characterized for Throttling	1 to 24	Carbon Steel Stainless	Flangeless Flanged	To ANSI 600	High	Excellent
Eccentric Plug	Erosion Resistance	1 to 8	Carbon Steel Stainless	Flanged	To ANSI 600	Moderate	Excellent
Swing-Thru Butterfly	No Seal	2 to 96	Carbon Steel Cast Iron Stainless	Flangeless Lugged Welded	To ANSI 2500	High	Poor
Lined Butterfly	Elastomer or TFE Liner	2 to 96	Carbon Steel Cast Iron Stainless	Flangeless Lugged	To ANSI 300	High	Good
High Performance Butterfly	Offset Disk General Service	2 to 72	Carbon Steel Stainless	Flangeless Lugged	To ANSI 600	High	Excellent

__Table 1-3.__ Control Valve Characteristic Recommendations

Liquid Level Systems

Control Valve Pressure Drop	Best Inherent Characteristic
Constant ΔP	Linear
Decreasing ΔP with increasing load, ΔP at maximum load > 20% of minimum load ΔP	Linear
Decreasing ΔP with increasing load, ΔP at maximum load < 20% of minimum load ΔP	Equal-percentage
Increasing ΔP with increasing load, ΔP at maximum load < 200% of minimum load ΔP	Linear
Increasing ΔP with increasing load, ΔP at maximum load > 200% of minimum load ΔP	Quick Opening

Pressure Control Systems

Application	Best Inherent Characteristic
Liquid Process	Equal-Percentage
Gas Process, Large Volume (Process has a receiver, Distribution System or Transmission Line Exceeding 100 ft. of Nominal Pipe Volume), Decreasing ΔP with Increasing Load, ΔP at Maximum Load > 20% of Minimum Load ΔP	Linear
Gas Process, Large Volume, Decreasing ΔP with Increasing Load, ΔP at Maximum Load < 20% of Minimum Load ΔP	Equal-Percentage
Gas Process, Small Volume, Less than 10 ft. of Pipe between Control Valve and Load Valve	Equal-Percentage

Flow Control Processes

Application		Best Inherent Characteristic	
Flow Measurement Signal to Controller	Location of Control Valve in Relation to Measuring Element	Wide Range of Flow Set Point	Small Range of Flow but Large ΔP Change at Valve with Increasing Load
Proportional to Flow	In Series	Linear	Equal-Percentage
	In Bypass*	Linear	Equal-Percentage
Proportional to Flow Squared	In Series	Linear	Equal-Percentage
	In Bypass*	Equal-Percentage	Equal-Percentage

*When control valve closes, flow rate increases in measuring element.

Table 1-4. *Control Valve Leakage Standards*

<table>
<tr><th>ANSI
B16.104-1976</th><th colspan="3">Maximum Leakage</th><th>Test Medium</th><th colspan="2">Pressure and Temperature</th></tr>
<tr><td>Class II</td><td colspan="3">0.5% valve capacity at full travel</td><td>Air</td><td colspan="2">Service ΔP or 50 psid (3.4 bar differential), whichever is lower, at 50° or 125°F (10° to 52°C)</td></tr>
<tr><td>Class III</td><td colspan="3">0.1% valve capacity at full travel</td><td>Air</td><td colspan="2">Service ΔP or 50 psid (3.4 bar differential), whichever is lower, at 50° or 125°F (10° to 52°C)</td></tr>
<tr><td>Class IV</td><td colspan="3">0.01% valve capacity at full travel</td><td>Air</td><td colspan="2">Service ΔP or 50 psid (3.4 bar differential), whichever is lower, at 50° or 125°F (10° to 52°C)</td></tr>
<tr><td>Class V</td><td colspan="3">5 x 10^{-4} mL/min/psid/inch port dia. (5 x 10^{-12} m^3/sec/Δbar/mm port dia)</td><td>Water</td><td colspan="2">Service ΔP at 50° or 125°F (10° to 52°C)</td></tr>
<tr><td>Class VI</td><td colspan="2">Nominal Port Diameter</td><td>Bubbles per Minute</td><td>mL per Minute</td><td>Test Medium</td><td>Pressure and Temperature</td></tr>
<tr><td rowspan="9"></td><td><u>In</u></td><td><u>mm</u></td><td></td><td></td><td rowspan="9">Air</td><td rowspan="9">Service ΔP or 50 psid (3.4 bar differential), whichever is lower, at 50° or 125°F (10° to 52°C)</td></tr>
<tr><td>1</td><td>25</td><td>1</td><td>0.15</td></tr>
<tr><td>1-1/2</td><td>38</td><td>2</td><td>0.30</td></tr>
<tr><td>2</td><td>51</td><td>3</td><td>0.45</td></tr>
<tr><td>2-1/2</td><td>64</td><td>4</td><td>0.60</td></tr>
<tr><td>3</td><td>76</td><td>6</td><td>0.90</td></tr>
<tr><td>4</td><td>102</td><td>11</td><td>1.70</td></tr>
<tr><td>6</td><td>152</td><td>27</td><td>4.00</td></tr>
<tr><td>8</td><td>203</td><td>45</td><td>6.75</td></tr>
<tr><td colspan="7">Copyright 1976 Fluid Controls Institute, Inc. Reprinted with permission.</td></tr>
</table>

Chapter 2

Actuator Selection

The actuator is the distinguishing element that differentiates control valves from other types of valves. The first actuated valves were designed in the late 19th century. Today, they would be better described as regulators since they operated directly from the process fluid. These “automatic valves” were the mainstay of industry through the early 1930s.

It was at this time that the first pneumatic controllers were used. Development of valve controllers and the adaptation of standardized control signals stimulated design of the first, true, control valve actuators.

The control valve industry has evolved to fill a variety of needs and desires. Actuators are available with an array of designs, power sources and capabilities. Proper selection involves process knowledge, valve knowledge, and actuator knowledge.

A control valve can perform its function only as well as the actuator can handle the static and dynamic loads placed on it by the valve. Therefore, proper selection and sizing are very important. Since the actuator can represent a significant portion of the total control valve price, careful selection of actuator and accessory options can lead to significant dollar savings.

The range of actuator types and sizes on the market today is so great that it seems the selection process might be highly complex. With a few rules in mind and knowledge of fundamental needs, the selection process can be simple.

The following parameters are key as they quickly narrow the actuator choices:

- Power source availability
- Fail-safe requirements
- Torque or thrust requirements
- Control functions

Power Source Availability

The power source available at the location of a valve can often point directly to what type of actuator to choose. Typically, valve actuators are powered either by compressed air or by electricity. However, in some cases water pressure, hydraulic fluid, or even pipeline pressure can be used.

Since most plants have both electricity and compressed air readily available, the selection depends upon the ease and cost of furnishing either power source to the actuator location. Reliability and maintenance requirements of the power system must also be considered. Consideration should also be given to providing backup operating power to critical plant loops.

Fail-safe Requirements

The overall reliability of power sources is quite high. However, many loops demand specific valve action should the power source ever fail. Desired action upon a signal failure may be required for safety reasons or for protection of equipment.

Fail-safe systems store energy, either mechanically in springs, pneumatically in volume tanks, or in hydraulic accumulators. When power fails, the fail-safe systems are triggered to drive the valves to the required position and to then maintain this position until returned to normal operation. In many cases, the process pressure is used to ensure or enhance this action.

Actuator designs are available with a choice of failure mode between failing open, failing closed, or holding in the last position. Many actuator systems incorporate failure modes at no extra cost. For example, spring-and-diaphragm actuators are inherently fail open or closed, while electric operators typically hold their last position.

Torque or Thrust Requirements

An actuator must have sufficient thrust or torque for the prescribed application. In some cases this requirement can dictate actuator type as well as power supply requirements.

For instance, large valves requiring a high thrust may be limited to only electric or electro-hydraulic actuators due to a lack of pneumatic actuators with sufficient thrust capability. Conversely, electro-hydraulic actuators would be a poor choice for valves with very low thrust requirements.

The matching of actuator capability with valve body requirements is best left to the control valve manufacturer as there are considerable differences in frictional and fluid forces from valve to valve.

Control Functions

Knowledge of the required actuator functions will most clearly define the options available for selection. These functions include the actuator signal (pneumatic, electric, etc.), signal range, ambient temperatures, vibration levels, operating speed, frequency, and quality of control that is required.

Signal types are typically grouped as such:

- Two-position (on-off)
- Analog (throttling)
- Digital

Two-position electric, electro-pneumatic, or pneumatic switches control on-off actuators. This is the simplest type of automatic control and the least restrictive in terms of selection.

Throttling actuators have considerably higher demands put on them from both a compatibility and performance standpoint. A throttling actuator receives its input from an electronic or pneumatic instrument that measures the controlled process variable. The actuator must then move the final control element in response to the instrument signal in an accurate and timely fashion to ensure effective control. The two primary additional requirements for throttling actuators include:

- Compatibility with instrument signal
- Better static and dynamic performance to ensure loop stability

Compatibility with instrument signals is inherent in many actuator types, or it can be obtained with add-on equipment. But, the high-performance characteristics required of a good throttling actuator cannot be bolted on; instead, low hysteresis and minimal deadband must be designed into actuators.

Stroking speed, vibration, and temperature resistance must also be considered if critical to the application. For example, on liquid loops fast-stroking speeds can be detrimental due to the possibility of water hammer.

Vibration or mounting position can be a potential problem. The actuator weight, combined with the weight of the valve, may necessitate bracing.

It is essential to determine the ambient temperature and humidity that the actuator will experience. Many actuators contain either elastomeric or electronic components that can be subject to degradation by high humidity or temperature.

Economics

Evaluation of economics in actuator selection is a combination of the following:

- Cost
- Maintenance
- Reliability

A simple actuator, such as a spring-and-diaphragm, has few moving parts and is easy to service. Its initial cost is low, and maintenance personnel understand and are comfortable working with them.

An actuator made specifically for a control valve eliminates the chance for a costly performance mismatch. An actuator manufactured by the valve vendor and shipped with the valve will eliminate separate mounting charges and ensure easier coordination of spare parts procurement. Interchangeable parts among varied actuators are also important to minimize spare-parts inventory.

Actuator Designs

There are many types of actuators on the market, most of which fall into five general categories:

- Spring-and-diaphragm
- Pneumatic piston
- Rack and Pinion
- Electric motor
- Electro-hydraulic

Each actuator design has weaknesses, strong points and optimum uses. Most actuator designs are available for either sliding stem or rotary valve bodies. They differ only by linkages or motion translators; the basic power sources are identical.

Most rotary actuators employ linkages, gears, or crank arms to convert direct linear motion of a diaphragm or piston into the 90-degree output rotation required by rotary valves. The most important consideration for control valve actuators is the requirement for a design that limits the amount of lost motion between internal linkage and valve coupling.

Rotary actuators are now available that employ tilting pistons or diaphragms. These designs eliminate most linkage points (and resultant lost motion) and provide a safe, accurate and enclosed package.

When considering an actuator design, it is also necessary to consider the method by which it is coupled to the drive shaft of the control valve. Slotted connectors mated to milled shaft flats are generally not satisfactory if any degree of performance is required. Pinned connections, if solidly constructed, are suitable for nominal torque applications. A splined connector that mates to a splined shaft end and then is rigidly clamped to the shaft eliminates lost motion, is easy to disassemble, and is capable of high torque.

Sliding stem actuators are rigidly fixed to valve stems by threaded and clamped connections. Because they don’t have any linkage points, and their connections are rigid, they exhibit no lost motion and have excellent inherent control characteristics.

Spring-and-Diaphragm Actuators

The most popular and widely used control valve actuator is the pneumatic spring-and-diaphragm style. These actuators are extremely simple and offer low cost and high reliability. They normally operate over the standard signal ranges of 3 to 15 psi or 6 to 30 psi, and therefore, are often suitable for throttling service using instrument signals directly.

Many spring-and-diaphragm designs offer either adjustable springs and/or wide spring selections to allow the actuator to be tailored to the particular application. Because they have few moving parts that may contribute to failure, they are extremely reliable. Should they ever fail, maintenance is extremely simple. Improved designs now include mechanisms to control the release of spring compression, eliminating possible personnel injury during actuator disassembly.

Use of a positioner or booster with a spring-and-diaphragm actuator can improve control, but when improperly applied, can result in poor control. Follow the simple guidelines available for positioner applications and look for:

- Rugged, vibration-resistant construction
- Calibration ease
- Simple, positive feedback linkages

The overwhelming advantage of the spring-and-diaphragm actuator is the inherent provision for fail-safe action. As air is loaded on the actuator casing, the diaphragm moves the valve and compresses the spring. The stored energy in the spring acts to move the valve back to its original position as air is released from the casing. Should there be a loss of signal pressure to the instrument or the actuator, the spring can move the valve to its initial (fail-safe) position.

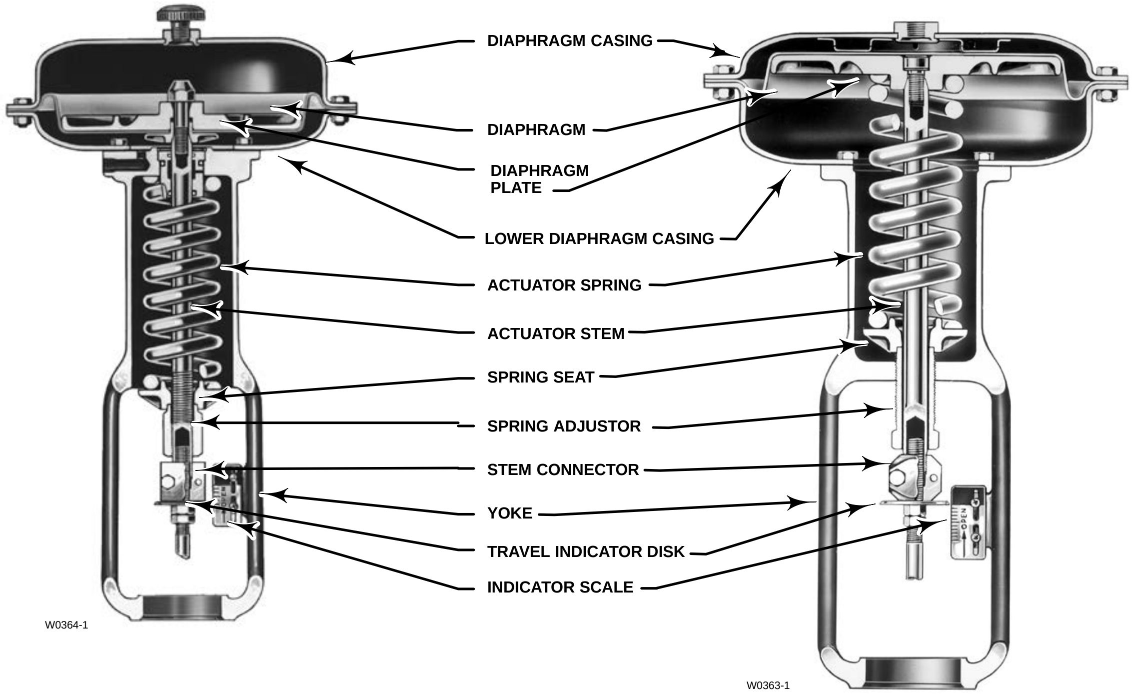

Figure 2-1. *Spring-and-diaphragm actuators offer an excellent first choice for most control valves. They are inexpensive, simple and have built-in, fail-safe action. Pictured above are cutaways of the popular Fisher 667 (left) and Fisher 657 (right) actuators.*

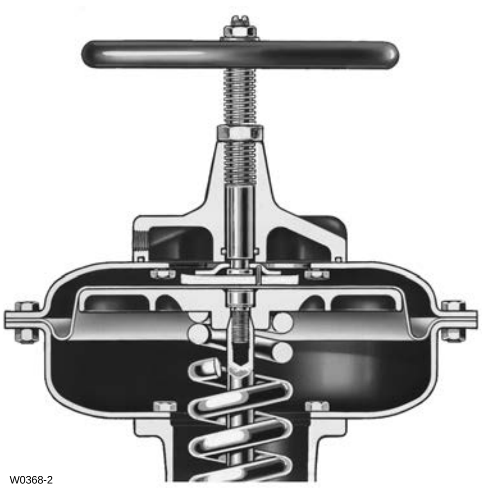

Figure 2-2. *Spring-and-diaphragm actuators can be supplied with a top-mounted handwheel. The handwheel allows manual operation and also acts as a travel stop or means of emergency operation.*

Actuators are available for either fail-open or fail-closed action. The only drawback to the spring-and-diaphragm actuator is a relatively limited output capability. Much of the thrust created by the diaphragm is taken up by the spring and thus does not result in output to the valve.

Therefore, the spring-and-diaphragm actuator is used infrequently for high force requirements. It is not economical to build and use very large spring-and-diaphragm actuators because the size, weight and cost grow exponentially with each increase in output force capability.

Piston Actuators

Piston actuators are generally more compact and provide higher torque or force outputs than spring-and-diaphragm actuators. Fisher piston styles normally work with supply pressures between 50 and 150 psi and can be equipped with spring returns (however, this construction has limited application).

Piston actuators used for throttling service must be furnished with double-acting positioners that simultaneously load and unload opposite sides of the piston. The pressure differential created across the piston causes travel toward the lower pressure side. The positioner senses the motion, and when the required position is reached, the positioner equalizes the pressure on both sides of the piston.

The pneumatic piston actuator is an excellent choice when a compact unit is required to produce high torque or force. It is also easily adapted to

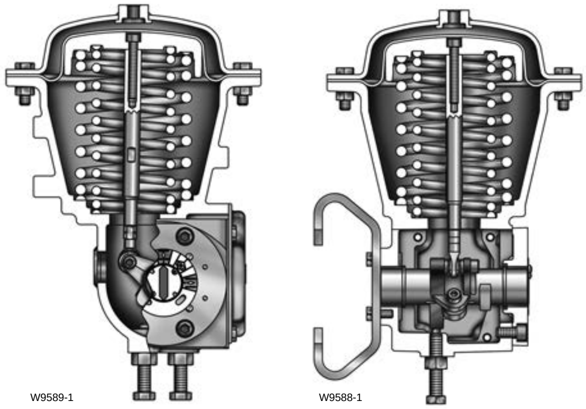

Figure 2-3. *The Fisher 2052 spring-and-diaphragm actuator has many features to provide precise control. The splined actuator connection features a clamped lever and single-joint linkage to help eliminate lost motion.*

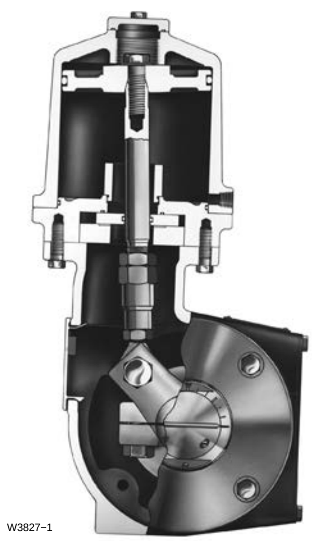

Figure 2-4. *Double-acting piston actuators such as the Fisher 1061 rotary actuator are a good choice when thrust requirements exceed the capability of spring-and-diaphragm actuators. Piston actuators require a higher supply pressure, but have benefits such as high stiffness and small size. The 1061 actuator is typically used for throttling service.*

services where high ambient temperatures are a concern.

The main disadvantages of piston actuators are the high supply pressures required for positioners when used in throttling service and the lack of fail-safe systems.

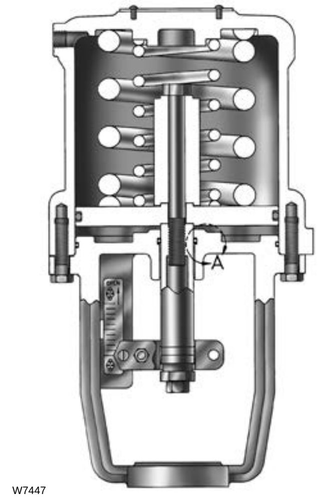

Figure 2-5*. Spring fail-safe is present in this piston design. The Fisher 585C is an example of a spring-bias piston actuator. Process pressure can aid fail-safe action, or the actuator can be configured for full spring-fail closure.*

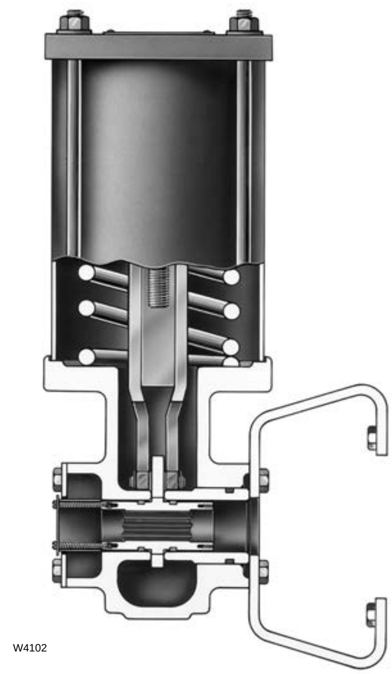

Figure 2-6. *Since the requirements for accuracy and minimal lost motion are unnecessary for on-off service, cost savings can be achieved by simplifying the actuator design. The Fisher 1066SR incorporates spring-return capability.*

There are two types of spring-return piston actuators available. The variations are subtle, but significant. It is possible to add a spring to a piston actuator and operate it much like a spring-and-diaphragm. These designs use a single-acting positioner that loads the piston chamber to move the actuator and compress the spring. As air is unloaded, the spring forces the piston back. These designs use large, high output springs that are capable of overcoming the fluid forces in the valve.

The alternative design uses a much smaller spring and relies on valve fluid forces to help provide the fail-safe action. In normal operation they act like a double action piston. In a fail-safe situation the spring initiates movement and is helped by unbalance forces on the valve plug. These actuators can be sized and set up to provide full spring closure action without process assistance.

An alternative to springs is a pneumatic trip system which often proves to be complex in design, difficult to maintain and costly. While a trip system is completely safe, any fail-safe requirement consideration should be given first to spring-and-diaphragm operators if they are feasible.

Special care should be given during the selection of throttling piston actuators to specify a design that has minimal hysteresis and deadband. As the number of linkage points in the actuator increases, so does the deadband. As the number of sliding parts increases, so does the hysteresis. An actuator with high hysteresis and deadband can be quite suitable for on-off service; however, caution is necessary when attempting to adapt this actuator to throttling service by merely bolting on a positioner.

The cost of a spring-and-diaphragm actuator is generally less than a comparable piston actuator. Part of this cost saving is a result of the ability to use instrument output air directly, thereby eliminating the need for a positioner. The inherent provision for fail-safe action in the spring-and-diaphragm actuator is also a consideration.

Rack and Pinion Actuators

Rack and pinion actuators may come in a double-acting design, or spring return, and are a compact and economical solution for rotary shaft valves. They provide high torque outputs and are typically used for on-off applications with high cycle life. They may also be used in processes where higher variability is not a concern.

Figure 2-7. *The FieldQ ™ actuator is a quarter turn pneumatic rack and pinion actuator. It comes with an integrated module combining the solenoid and switchbox into a low profile, compact package.*

Electric Actuators

Electric actuators can be applied successfully in many situations. Most electric operators consist of motors and gear trains and are available in a wide range of torque outputs, travels, and capabilities. They are suited for remote mounting where no other power source is available, for use where there are specialized thrust or stiffness requirements, or when highly precise control is required.

Electric operators are economical versus pneumatic actuators for applications in small size ranges only. Larger units operate slowly and weigh considerably more than pneumatic equivalents. Available fail action is typically lock in last position.

One key consideration in choosing an electric actuator is its capability for continuous closed-loop control. In applications where frequent changes are made in control-valve position, the electric actuator must have a suitable duty cycle.

High performance electric actuators using continuous rated DC motors and ball screw output devices are capable of precise control and 100% duty cycles.

Compared to other actuator designs, the electric actuator generally provides the highest output available within a given package size. Additionally, electric actuators are stiff, that is, resistant to valve forces. This makes them an excellent choice for good throttling control of large, high-pressure valves.

Actuator Sizing

The last step in the selection process is to determine the required actuator size. Fundamentally, the process of sizing is to match as closely as possible the actuator capabilities to the valve requirements.

In practice, the mating of actuator and valve requires the consideration of many factors. Valve forces must be evaluated at the critical positions of valve travel (usually open and closed) and compared to actuator output. Valve force calculation varies considerably between valve styles and manufacturers. In most cases it is necessary to consider a complex summation of forces including:

- Static fluid forces
- Dynamic fluid forces and force gradients
- Friction of seals, bearings, and packing
- Seat loading

Although actuator sizing is not difficult, the great variety of designs on the market and the ready availability of vendor expertise (normally at no cost) make detailed knowledge of the procedures unnecessary.

Actuator Spring for Globe Valves

The force required to operate a globe valve includes:

A. Force to overcome static unbalance of the valve plug

B. Force to provide a seat load

C. Force to overcome packing friction

D. Additional forces required for certain specific applications or constructions

Total force required = A + B + C + D

A. Unbalance Force

The unbalance force is that resulting from fluid pressure at shutoff, and in the most general sense can be expressed as:

Unbalance force = net pressure differential X net unbalance area

Frequent practice is to take the maximum upstream gauge pressure as the net pressure differential unless the process design always ensures a back pressure at the maximum inlet pressure. Net unbalance area is the port area on a single seated flow up design. Unbalance area may have to take into account the stem area depending on configuration. For balanced valves there is still a small unbalance area. This data can be obtained from the manufacturer. Typical port areas for balanced valves flow up and unbalanced valves in a flow down configuration are listed in table 2-1.

Table 2-1. *Typical Unbalance Areas of Control Valves*

Port Diameter, Inches	Unbalance Area Single-Seated Unbalanced Valves, In^2	Unbalance Area Balanced Valves, In^2
1/4	0.049	– – –
3/8	0.110	– – –
1/2	0.196	– – –
3/4	0.441	– – –
1	0.785	– – –
1 5/16	1.35	0.04
1 7/8	2.76	0.062
2 5/16	4.20	0.27
3 7/16	9.28	0.118
4 3/8	15.03	0.154
7	38.48	0.81
8	50.24	0.86

B. Force to Provide Seat Load

Seat load, usually expressed in pounds per lineal inch or port circumference, is determined by shutoff requirements. Use the guidelines in table 2-2 to determine the seat load required to meet the factory acceptance tests for ANSI/FCI 70-2 and IEC 534-4 leak Classes II through VI.

Because of differences in the severity of service conditions, do not construe these leak classifications and corresponding leakage rates as indicators of field performance. To prolong seat life and shutoff capabilities, use a higher than recommended seat load. If tight shutoff is not a prime consideration, use a lower leak class.

Table 2-2. *Recommended Seat Load Per Leak Class for Control Valves*

Class I	As required by customer specification, no factory leak test required
Class II	20 pounds per lineal inch of port circumference
Class III	40 pounds per lineal inch of port circumference
Class IV	Standard (Lower) Seat only—40 pounds per lineal inch of port circumference (up through a 4–3/8 inch diameter port) Standard (Lower) Seat only—80 pounds per lineal inch of port circumference (larger than 4–3/8 inch diameter port)
Class V	Metal Seat—determine pounds per lineal inch of port circumference from figure 2-9

C. Packing Friction

Packing friction is determined by stem size, packing type, and the amount of compressive load placed on the packing by the process or the bolting. Packing friction is not 100% repeatable in its friction characteristics. Newer live loaded packing designs can have significant friction forces especially if graphite packing is used. Table 2-3 lists typical packing friction values.

D. Additional Forces

Additional forces to consider may include bellows stiffness, unusual frictional forces resulting from seals or special seating forces for soft metal seals. The manufacturer should either supply this information or take it into account when sizing an actuator.

Actuator Force Calculations

Pneumatic spring-and-diaphragm actuators provide a net force with the additional air pressure after compressing the spring in air-to-close, or with the net pre-compression of the spring in air-to-open. This may be calculated in pounds per square inch of pressure differential.

For example, suppose 275 pound-force (lbf) is required to close the valve as calculated per the process described earlier. An air-to-open actuator with 100 square inches of diaphragm area and a bench set of 6 to 15 psig is one available option. The expected operating range is 3 to 15 psig. The

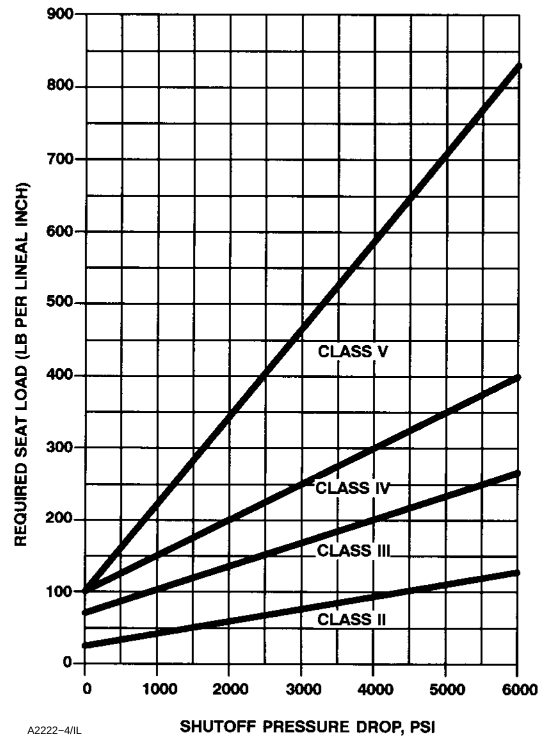

Figure 2-8. *Recommended Seat Load*

pre-compression can be calculated as the difference between the lower end of the bench set (6 psig) and the beginning of the operating range (3 psig). This 3 psig is used to overcome the pre-compression so the net pre-compression force must be:

3 psig X 100 sq. in. = 300 lbf.

This exceeds the force required and is an adequate selection.

Piston actuators with springs are sized in the same manner. The thrust from piston actuators without springs can be calculated as:

Piston area X minimum supply pressure = minimum available thrust
(maintain compatibility of units)

In some circumstances an actuator could supply too much force and cause the stem to buckle, to bend sufficiently to cause a leak, or to damage valve internals.

The manufacturer normally takes responsibility for actuator sizing and should have methods documented to check for maximum stem loads. Manufacturers also publish data on actuator thrusts, effective diaphragm areas, and spring data.

Table 2-3. *Typical Packing Friction Values (Lb)*

Stem Size (Inches)	ANSI Class	PTFE Packing		Graphite Ribbon/ Filament
		Single	Double	
5/16	All	20	30	– – –
3/8	125 150 250 300	38	56	– – – 125 – – – 190
	600 900 1500			250 320 380
1/2	125 150 250 300	50	75	– – – 180 – – – 230
	600 900 1500 2500			320 410 500 590
5/8	125 150 250 300 600	63	95	– – – 218 – – – 290 400
3/4	125 150 250 300	75	112.5	– – – 350 – – – 440
	600 900 1500 2500			660 880 1100 1320
1	300 600 900 1500 2500	100	150	610 850 1060 1300 1540
1–1/4	300 600 900 1500 2500	120	180	800 1100 1400 1700 2040
2	300 600 900 1500 2500	200	300	1225 1725 2250 2750 3245
Values shown are frictional forces typically encountered when using standard packing flange bolt-torquing procedures.				

Actuator Sizing for Rotary Valves

In selecting the most economical actuator for a rotary valve, the determining factors are the torque required to open and close the valve and the torque output of the actuator.

This method assumes the valve has been properly sized for the application and the application does not exceed pressure limitations for the valve.

Torque Equations

Rotary valve torque equals the sum of a number of torque components. To avoid confusion, a number of these have been combined, and a number of calculations have been performed in advance. Thus, the torque required for each valve type can be represented with two simple and practical equations.

Breakout Torque

$$T_B=A(\Delta P_{shutoff})+B$$

Dynamic Torque

$$T_D=C(\Delta P_{eff})$$

Specific A, B, and C factors, for example, rotary valve designs are included in tables 2-4 and 2-5.

Maximum Rotation

Maximum rotation is defined as the angle of valve disk or ball in the fully open position.

Normally, maximum rotation is 90 degrees. The ball or disk rotates 90 degrees from the closed position to the wide-open position.

Some of the pneumatic spring-return piston and pneumatic spring-and-diaphragm actuators are limited to 60 or 75 degrees rotation.

For pneumatic spring-and-diaphragm actuators, limiting maximum rotation allows for higher initial spring compression, resulting in more actuator breakout torque. Additionally, the effective length of each actuator lever changes with valve rotation. Published torque values, particularly for pneumatic piston actuators, reflect this changing lever length.

The Selection Process

In choosing an actuator type, the fundamental requirement is to know your application. Control signal, operating mode, power source available, thrust/torque required, and fail-safe position can make many decisions for you. Keep in mind simplicity, maintainability and lifetime costs.

Safety is another consideration that must never be overlooked. Enclosed linkages and controlled compression springs available in some designs are important for safety reasons. Table 2-6 lists the pros and cons of the various actuator styles.

Table 2-4. *Typical Rotary Shaft Valve Torque Factors V-Notch Ball Valve with Composition Seal*

Fisher TCM™ Plus Ball Seal							
Valve Size, NPS	**Valve Shaft Diameter, Inches**	**A**	**B**	**C**		**Maximum T_D, Lbf•In.**
		Composition Bearings(1)		**60 Degrees**	**70 Degrees**	
1	1/2	0.07	50	0.38	0.48	515
1-1/2	5/8	0.12	100	1.10	1.10	1225
2	5/8	0.19	175	1.30	2.40	1225
3	3/4	0.10	280	0.15	3.80	2120
4	3/4	0.10	380	1.10	18.0	2120
6	1	1.80	500	1.10	36.0	4140
8	1-1/4	1.80	750	3.80	60.0	9820
10	1-1/4	1.80	1250	3.80	125	9820
12	1-1/2	4.00	3000	11.0	143	12,000
14	1-3/4	42	2400	75	413	23,525
16	2	60	2800	105	578	23,525
16	2-1/8	60	2800	105	578	55,762
20	2-1/2	97	5200	190	1044	55,762

1. PEEK/PTFE or metal/PTFE bearings.

Table 2-5. *Typical High Performance Butterfly Torque Factors for Valve with Composition Seal*

PEEK/PTFE Bearings with PTFE Seal							
Valve Size	**Shaft Diameter**	**A**	**B**	**C**		**Maximum Allowable Torque**	
				ANGLE OF OPENING		**S17400 H1075**	**S20910**
NPS	**Inch**			**60° (K)**	**90° (θ)**	**lbf•in**	**lbf•in**
2	1/2	0.30	100	1.05	2.45	515	515
3	5/8	0.56	150	3.59	10.8	1087	1028
4	3/4	0.99	232	7.65	21.2	1640	1551
6	1	2.30	438	17.5	46.7	4140	4140
8	1-1/4	4.80	705	33.4	223	7988	7552
10	1-1/4	8.10	1056	82.2	358	9792	9258
12	1-1/2	12.5	1470	106	626	12000	12000

Table 2-6. *Actuator Feature Comparison*

Actuator Type	**Advantages**	**Disadvantages**
Spring-and-Diaphragm	Lowest cost Ability to throttle without positioner Simplicity Inherent fail-safe action Low supply pressure requirement Adjustable to varying conditions Ease of maintenance	Limited output capability Larger size and weight
Pneumatic Piston	High thrust capability Compact Lightweight Adaptable to high ambient temperatures Fast stroking speed Relatively high actuator stiffness	Higher cost Fail-safe requires accessories or addition of a spring Positioner required for throttling High supply pressure requirement
Electric Motor	Compactness Very high stiffness High output capability	High cost Lack of fail-safe action Limited duty cycle Slow stroking speed
Electro-Hydraulic	High output capability High actuator stiffness Excellent throttling ability Fast stroking speed	High cost Complexity and maintenance difficulty Large size and weight Fail-safe action only with accessories

Actuator Selection Summary

- Actuator selection must be based upon a balance of process requirements, valve requirements and cost.

- Simple designs such as the spring-and-diaphragm are simpler, less expensive and easier to maintain. Consider them first in most situations.

- Piston actuators offer many of the advantages of pneumatic actuators with higher thrust capability than spring-and-diaphragm styles. They are especially useful where compactness is desired or long travel is required.

- Electric and electro-hydraulic actuators provide excellent performance. They are, however, much more complex and difficult to maintain.

- Actuator sizing is not difficult, but the wide variety of actuators and valves make it difficult to master. Vendor expertise is widely available.

- Systems such as control valves are best purchased, assembled and tested by one source.

Figure 2-9*. The FIELDVUE Digital Valve Controller brings increased control accuracy and flexibility. When utilized with AMS ValveLink ™ software, FIELDVUE instruments provide valuable diagnostic data that helps to avoid maintenance problems.*

Use of actuators and accessories of the same manufacturer will eliminate many problems.

Chapter 3

Liquid Valve Sizing

Valves are selected and sized to perform a specific function within a process system. Failure to perform that given function in controlling a process variable results in higher process costs. Thus, valve sizing becomes a critical step to successful process operation. The following sections focus on correctly sizing valves for liquid service: the liquid sizing equation is examined, the nomenclature and procedures are explained, and sample problems are solved to illustrate their use.

Valve Sizing Background

Standardization activities for control valve sizing can be traced back to the early 1960s when a trade association, the Fluids Control Institute, published sizing equations for use with both compressible and incompressible fluids. The range of service conditions that could be accommodated accurately by these equations was quite narrow, and the standard did not achieve a high degree of acceptance.

In 1967, the International Society of America (ISA™) established a committee to develop and publish standard equations. The efforts of this committee culminated in a valve sizing procedure that has achieved the status of American National Standards Institute (ANSI). Later, a committee of the International Electrotechnical Commission (IEC) used the ISA works as a basis to formulate international standards for sizing control valves.* Except for some slight differences in nomenclature and procedures, the ISA and IEC standards have been harmonized. ANSI/ISA Standard S75.01 is harmonized with IEC Standards 534-2-1 and 534-2-2 (IEC Publications 534-2, Sections One and Two for incompressible and compressible fluids, respectively).

Liquid Sizing Equation Background

This section presents the technical substance of the liquid sizing equations. The value of this lies in not only a better understanding of the sizing equations, but also in knowledge of their intrinsic limitations and relationship to other flow equations and conditions.

The flow equations used for sizing have their roots in the fundamental equations, which describe the behavior of fluid motion. The two principle equations include the:

- Energy equation
- Continuity equation

The energy equation is equivalent to a mathematical statement of the first law of thermodynamics. It accounts for the energy transfer and content of the fluid. For an incompressible fluid (e.g. a liquid) in steady flow, this equation can be written as:

$$\left(\frac{V^2}{2g_c} + \frac{P}{\rho} + gZ\right) - w + q + U = constant \quad (1)$$

The three terms† in parenthesis are all mechanical, or available, energy terms and carry a special significance. These quantities are all capable of directly doing work. Under certain conditions more thoroughly described later, this quantity may also remain constant:

$$\frac{V^2}{2g_c} + \frac{P}{\rho} + gZ = constant \quad (2)$$

This equation can be derived from purely kinematic methods (as opposed to thermodynamic methods) and is known as “Bernoulli’s equation”.

The other fundamental equation, which plays a vital role in the sizing equation, is the continuity

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*Some information in this introductory material has been extracted from ANSI/ISA S75.01 standard with the permission of the publisher, the ISA.
†All terms are defined in the nomenclature section.

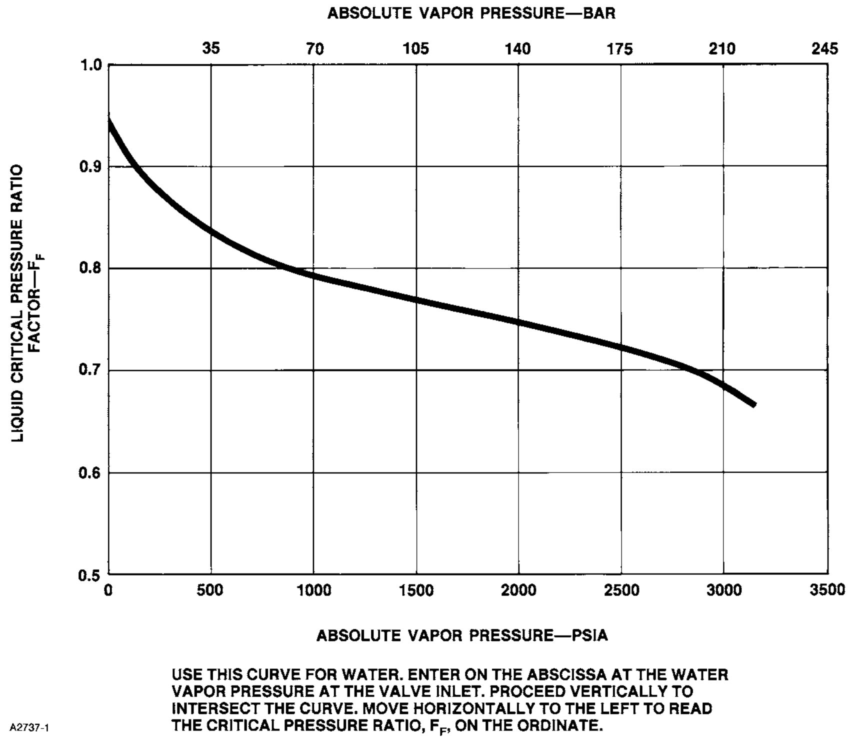

Figure 3-1. *Liquid Critical Pressure Ratio Factor for Water*

equation. This is the mathematical statement of conservation of the fluid mass. For steady flow conditions (one-dimensional) this equation is written as follows:

$$\rho VA = constant \quad (3)$$

Using these fundamental equations, we can examine the flow through a simple, fixed restriction such as that shown in figure 3-1. We will assume the following for the present:

1. The fluid is incompressible (a liquid)
2. The flow is steady
3. The flow is one-dimensional
4. The flow can be treated as inviscid (having no viscosity)
5. No change of fluid phase occurs

As seen in figure 3-1, the flow stream must contract to pass through the reduced flow area. The point along the flow stream of minimum cross sectional flow area is the vena contracta. The flow processes upstream of this point and downstream of this point differ substantially, thus it is convenient to consider them separately.

The process from a point several pipe diameters upstream of the restriction to the vena contracta is very nearly ideal for practical intents and purposes (thermodynamically isentropic, thus having constant entropy). Under this constraint, Bernoulli's equation applies and we see that no mechanical energy is lost — it merely changes from one form to the other. Furthermore, changes in elevation are negligible since the flow stream centerline changes very little, if at all. Thus, energy contained in the fluid simply changes from pressure to kinetic. This is quantified when considering the continuity equation. As the flowstream passes through the restriction, the velocity must increase inversely proportional to the change in area. For example, from equation 4 below:

$$V_{VC} = \frac{(constant)}{A_{VC}} \quad (4)$$

Using upstream conditions as a reference, this becomes:

$$V_{VC} = V_1\left(\frac{A_1}{A_{VC}}\right) \quad (5)$$

Thus, as the fluid passes through the restriction, the velocity increases. Below, equation 2 has been applied and elevation changes have been neglected (again using upstream conditions as a reference):

$$\frac{\rho V_1{}^2}{2g_c} + P_1 = \frac{\rho V_{VC}{}^2}{2g_c} + P_{VC} \qquad (6)$$

In the equation below, equation 5 has been inserted and rearranged:

$$P_{VC} = P_1 - \frac{\rho V_1{}^2}{2g_c}\left[\left(\frac{A_1}{A_{VC}}\right)^2 - 1\right] \qquad (7)$$

Thus, at the point of minimum cross sectional area, we see that fluid velocity is at a maximum (from equation 5 above) and fluid pressure is at a minimum (from equation 6 above).

The process from the vena contracta point to a point several diameters downstream is not ideal, and equation 2 no longer applies. By arguments similar to the above, it can be reasoned (from the continuity equation) that, as the original cross sectional area is restored, the original velocity is also restored. Because of the non-idealities of this process, however, the total mechanical energy is not restored. A portion of it is converted into heat that is either absorbed by the fluid itself, or dissipated to the environment.

Let us consider equation 1 applied from several diameters upstream of the restriction to several diameters downstream of the restriction:

$$\begin{aligned} U_1 + \frac{V_1{}^2}{2g_c} + \frac{P_1}{\rho} + \frac{gZ_1}{g_C} + q &= \\ U_2 + \frac{V_2{}^2}{2g_c} + \frac{P_2}{\rho} + \frac{gZ_2}{g_C} + w & \end{aligned} \qquad (8)$$

No work is done across the restriction, thus the work term drops out. The elevation changes are negligible and as a result, the respective terms cancel each other. We can combine the thermal terms into a single term, H_I:

$$\frac{\rho V_1{}^2}{2g_c} + P_1 = \frac{\rho V_2{}^2}{2g_c} + P_2 + H_I \qquad (9)$$

The velocity was restored to its original value so that equation 9 reduces to:

$$P_1 = P_2 + H_I \qquad (10)$$

Consequently, the pressure decreases across the restriction, and the thermal terms (internal energy and heat lost to the surroundings) increase.

Losses of this type are generally proportional to the square of the velocity (references one and two), so it is convenient to represent them by the following equation:

$$H_I = K_I \frac{\rho V^2}{2} \qquad (11)$$

In this equation, the constant of proportionality, K_I, is called the available head loss coefficient, and is determined by experiment.

From equations 10 and 11, it can be seen that the velocity (at location two) is proportional to the square root of the pressure drop. Volume flow rate can be determined knowing the velocity and corresponding area at any given point so that:

$$Q = V_2 A_2 \quad \sqrt{\frac{2(P_1 - P_2)}{\rho K_I}}\; A_2 \qquad (12)$$

Now, letting:

$$\rho = G\rho_W$$

and, defining:

$$C_V = A_2 \quad \sqrt{\frac{2}{\rho_W K_I}} \qquad (13)$$

Where G is the liquid specific gravity, equation 12 may be rewritten as:

$$Q = C_V \quad \sqrt{\frac{P_1 - P_2}{G}} \qquad (14)$$

Equation 14 constitutes the basic sizing equation used by the control valve industry, and provides a measure of flow in gallons per minute (GPM) when pressure in pounds per square inch (PSI) is used. At times, it may be desirable to work with other units of flow or independent flow variables (pressure, density, etc). The equation fundamentals are the same for such cases, and only constants are different.

Determination of Flow Coefficients

Rather than experimentally measure K_I and calculate C_V, it is more straightforward to measure C_V directly.

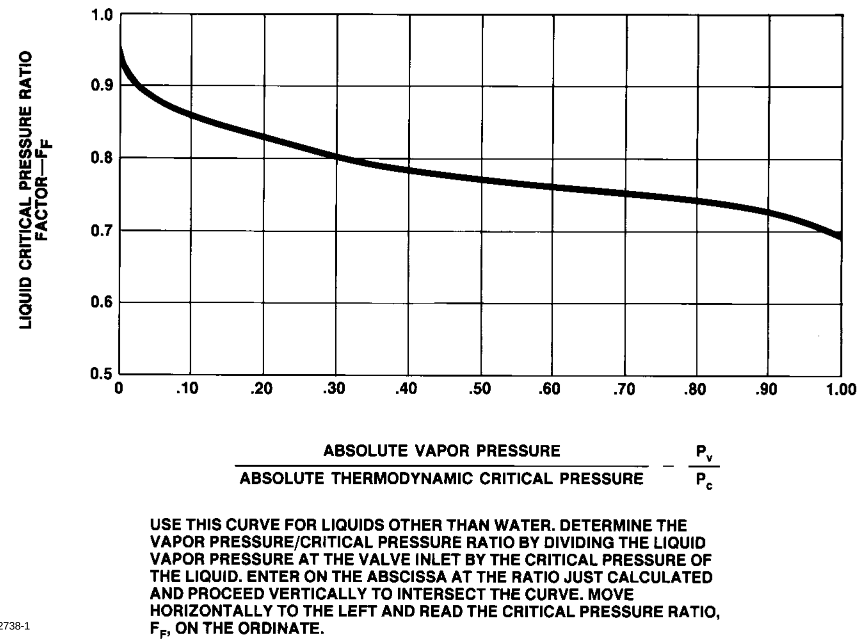

Figure 3-2. *Liquid Critical Pressure Ratio Factor for Liquids Other Than Water*

In order to assure uniformity and accuracy, the procedures for both measuring flow parameters and use in sizing are addressed by industrial standards. The currently accepted standards are sponsored by the ISA.

The basic test system configuration is shown in figure 3-2. Specifications, accuracies, and tolerances are given for all hardware installation and data measurements such that coefficients can be calculated to an accuracy of approximately 5%. Fresh water at approximately 68°F is circulated through the test valve at specified pressure differentials and inlet pressures. Flow rate, fluid temperature, inlet and differential pressure, valve travel, and barometric pressure are all measured and recorded. This yields sufficient information to calculate the following sizing parameters:

- Flow coefficient (C_V)
- Pressure recovery coefficient (F_L)
- Piping correction factor (F_p)
- Reynolds number factor (F_R)

In general, each of these parameters depends on the valve style and size, so multiple tests must be performed accordingly. These values are then published by the valve manufacturer for use in sizing.

Basic Sizing Procedure Overview

The procedure by which valves are sized for normal, incompressible flow is straightforward. Again, to ensure uniformity and consistency, a standard exists that delineates the equations and correction factors to be employed for a given application.

The simplest case of liquid flow application involves the basic equation developed earlier. Rearranging equation thirteen so that all of the fluid and process related variables are on the right side of the equation, we arrive at an expression for the valve C_V required for the particular application:

$$C_v = \frac{Q}{\sqrt{\frac{P_1 - P_2}{G}}} \qquad (15)$$

It is important to realize that valve size is only one aspect of selecting a valve for a given application. Other considerations include valve style and trim characteristic. Discussion of these features can be referenced in chapter 2, chapter 4, and other thorough resources.

Once a valve has been selected and C_V is known, the flow rate for a given pressure drop, or the pressure drop for a given flow rate, can be predicted by substituting the appropriate quantities into equation 16.

Many applications fall outside the bounds of the basic liquid flow applications just considered. Rather than develop special flow equations for all of the possible deviations, it is possible (and preferred) to account for different behavior with the use of simple correction factors. These factors, when incorporated, change the form of equation 14 to the following:

$$Q = (N_1 F_P F_R) C_V \sqrt{\frac{P_1 - P_2}{G}} \qquad (16)$$

All of the additional factors in this equation are explained in the following sections.

Sizing Valves for Liquids

Following is a step-by-step procedure for the sizing of control valves for liquid flow using the IEC procedure. Each of these steps is important and must be considered during any valve sizing procedure. Steps three and four concern the determination of certain sizing factors that may, or may not, be required in the sizing equation depending upon the service conditions of the sizing problem. If one, two, or all three of these sizing factors are to be included in the equation for a particular sizing problem, please refer to the appropriate factor determination section(s) located in the text proceeding step six.

1. Specify the variables required to size the valve as follows:

- Desired design
- Process fluid (water, oil, etc.)
- Appropriate service conditions Q or w, P_1, P_2 or ΔP, T_1, G_f, P_v, P_c, and υ*

2. Determine the equation constant, N.

N is a numerical constant contained in each of the flow equations to provide a means for using different systems of units. Values for these various constants and their applicable units are given in the Equation Constants Table (table 3-2).

Use N_1 if sizing the valve for a flow rate in volumetric units (gpm or m^3/h).

Use N_6 if sizing the valve for a flow rate in mass units (lb/h or kg/h).

3. Determine F_p, the piping geometry factor.

F_p is a correction factor that accounts for pressure losses due to piping fittings such as reducers, elbows, or tees that might be attached directly to the inlet and outlet connections of the control valve to be sized. If such fittings are attached to the valve, the F_p factor must be considered in the sizing procedure. If, however, no fittings are attached to the valve, F_p has a value of 1.0 and simply drops out of the sizing equation.

For rotary valves with reducers (swaged installations), and other valve designs and fitting styles, determine the F_p factors by using the procedure for determining F_p, the piping geometry factor.

4. Determine q_{max} (the maximum flow rate at given upstream conditions) or ΔP_{max} (the allowable sizing pressure drop).

The maximum or limiting flow rate (q_{max}), commonly called choked flow, is manifested by no additional increase in flow rate with increasing pressure differential with fixed upstream conditions. In liquids, choking occurs as a result of vaporization of the liquid when the static pressure within the valve drops below the vapor pressure of the liquid.

The IEC standard requires the calculation of an allowable sizing pressure drop (ΔP_{max}) to account for the possibility of choked flow conditions within the valve. The calculated ΔP_{max} value is compared with the actual pressure drop specified in the service conditions, and the lesser of these two values is used in the sizing equation. If it is desired to use ΔP_{max} to account for the possibility of choked flow conditions it can be calculated using the procedure for determining q_{max}, the maximum flow rate, or ΔP_{max}, the allowable sizing pressure drop. If it can be recognized that choked flow conditions will not develop within the valve ΔP_{max} need not be calculated.

* The ability to recognize which terms are appropriate for a specific sizing procedure can only be acquired through experience with different valve sizing problems. If any of the above terms appears to be new or unfamiliar, refer to the Abbreviations and Terminology Table (table 3-1) for a complete definition.

Table 3-1. Abbreviations and Terminology

Symbol		Symbol	
C_v	Valve sizing coefficient	P_1	Upstream absolute static pressure
d	Nominal valve size	P_2	Downstream absolute static pressure
D	Internal diameter of the piping	P_c	Absolute thermodynamic critical pressure
F_d	Valve style modifier, dimensionless	P_v	Vapor pressure absolute of liquid at inlet temperature
F_F	Liquid critical pressure ratio factor, dimensionless	ΔP	Pressure drop (P_1-P_2) across the valve
F_k	Ratio of specific heats factor, dimensionless	$\Delta P_{max(L)}$	Maximum allowable liquid sizing pressure drop
F_L	Rated liquid pressure recovery factor, dimensionless	$\Delta P_{max(LP)}$	Maximum allowable sizing pressure drop with attached fittings
F_{LP}	Combined liquid pressure recovery factor and piping geometry factor of valve with attached fittings (when there are no attached fittings, F_{LP} equals F_L), dimensionless	q	Volume rate of flow
F_P	Piping geometry factor, dimensionless	q_{max}	Maximum flow rate (choked flow conditions) at given upstream conditions
G_f	Liquid specific gravity (ratio of density of liquid at flowing temperature to density of water at 60°F), dimensionless	T_1	Absolute upstream temperature (degree K or degree R)
G_g	Gas specific gravity (ratio of density of flowing gas to density of air with both at standard conditions[1], i.e., ratio of molecular weight of gas to molecular weight of air), dimensionless	w	Mass rate of flow
k	Ratio of specific heats, dimensionless	x	Ratio of pressure drop to upstream absolute static pressure ($\Delta P/P_1$), dimensionless
K	Head loss coefficient of a device, dimensionless	x_T	Rated pressure drop ratio factor, dimensionless
M	Molecular weight, dimensionless	Y	Expansion factor (ratio of flow coefficient for a gas to that for a liquid at the same Reynolds number), dimensionless
N	Numerical constant	Z	Compressibility factor, dimensionless
		γ_1	Specific weight at inlet conditions
		υ	Kinematic viscosity, centistokes

1. Standard conditions are defined as 60°F (15.5°C) and 14.7 psia (101.3kPa).

Table 3-2. *Equation Constants*[1]

		N	w	q	p[2]	γ	T	d, D
N_1		0.0865 0.865 1.00	- - - - - - - - -	m^3/h m^3/h gpm	kPa bar psia	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -
N_2		0.00214 890	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	mm inch
N_5		0.00241 1000	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	mm inch
N_6		2.73 27.3 63.3	kg/h kg/h lb/h	- - - - - - - - -	kPa bar psia	kg/m^3 kg/m^3 lb/ft^3	- - - - - - - - -	- - - - - - - - -
N_7[3]	Normal Conditions $T_N = 0°C$	3.94 394	- - - - - -	m^3/h m^3/h	kPa bar	- - - - - -	deg K deg K	- - - - - -
	Standard Conditions $T_s = 15.5°C$	4.17 417	- - - - - -	m^3/h m^3/h	kPa bar	- - - - - -	deg K deg K	- - - - - -
	Standard Conditions $T_s = 60°F$	1360	- - -	scfh	psia	- - -	deg R	- - -
N_8		0.948 94.8 19.3	kg/h kg/h lb/h	- - - - - - - - -	kPa bar psia	- - - - - - - - -	deg K deg K deg R	- - - - - - - - -
N_9[3]	Normal Conditions $T_N = 0°C$	21.2 2120	- - - - - -	m^3/h m^3/h	kPa bar	- - - - - -	deg K deg K	- - - - - -
	Standard Conditions Ts = 15.5°C	22.4 2240	- - - - - -	m^3/h m^3/h	kPa bar	- - - - - -	deg K deg K	- - - - - -
	Standard Conditions $T_S = 60°F$	7320	- - -	scfh	psia	- - -	deg R	- - -

1. Many of the equations used in these sizing procedures contain a numerical constant, N, along with a numerical subscript. These numerical constants provide a means for using different units in the equations. Values for the various constants and the applicable units are given in the above table. For example, if the flow rate is given in U.S. gpm and the pressures are psia, N_1 has a value of 1.00. If the flow rate is m^3/hr and the pressures are kPa, the N_1 constant becomes 0.0865.
2. All pressures are absolute.
3. Pressure base is 101.3 kPa (1.013 bar)(14.7 psia).

5. Solve for required C_v, using the appropriate equation.

For volumetric flow rate units:

$$C_v = \frac{q}{N_1 \; F_P \sqrt{\frac{P_1 - P_2}{G_f}}} \qquad (17)$$

For mass flow rate units:

$$C_v = \frac{w}{N_6 \; F_P \; \sqrt{(P_1 - \; P_2)\,\gamma}} \qquad (18)$$

In addition to C_v, two other flow coefficients, K_v and A_v, are used, particularly outside of North America. The following relationships exist:

$$K_V = (0.865)(C_V)$$

$$A_V = (2.40 \times 10^{-5})(C_V)$$

6. Select the valve size using the appropriate flow coefficient table and the calculated C_v value.

Determining Piping Geometry Factor (F_p)

Determine an F_p factor if any fittings such as reducers, elbows, or tees will be directly attached to the inlet and outlet connections of the control valve that is to be sized. When possible, it is recommended that F_p factors be determined experimentally by using the specified valve in actual tests.

Calculate the F_p factor using the following equation:

$$F_p = \left[1 + \frac{\Sigma K}{N_2}\left(\frac{C_v}{d^2}\right)^2 \right]^{-1/2} \qquad (19)$$

where,

N_2 = Numerical constant found in the Equation Constants table

d = Assumed nominal valve size

C_v = Valve sizing coefficient at 100% travel for the assumed valve size

In the above equation, the "K" term is the algebraic sum of the velocity head loss coefficients of all of the fittings that are attached to the control valve.

$$\Sigma K = K_1 + K_2 + K_{B1} - K_{B2} \qquad (20)$$

where,

K_1 = Resistance coefficient of upstream fittings

K_2 = Resistance coefficient of downstream fittings

K_{B1} = Inlet Bernoulli coefficient

K_{B2} = Outlet Bernoulli coefficient

The Bernoulli coefficients, K_{B1} and K_{B2}, are used only when the diameter of the piping approaching the valve is different from the diameter of the piping leaving the valve, whereby:

$$K_{B1} \ or \ K_{B2} = 1 - \left(\frac{d}{D}\right)^4 \qquad (21)$$

where,

d = Nominal valve size

D = Internal diameter of piping

If the inlet and outlet piping are of equal size, then the Bernoulli coefficients are also equal, $K_{B1} = K_{B2}$, and therefore they are dropped from the equation.

The most commonly utilized fitting in control valve installations is the short-length concentric reducer. The equations for this fitting are as follows:

For an inlet reducer:

$$K_1 = 0.5\left(1 - \frac{d^2}{D^2}\right)^2 \qquad (22)$$

For an outlet reducer:

$$K_2 = 1.0\left(1 - \frac{d^2}{D^2}\right)^2 \qquad (23)$$

For a valve installed between identical reducers:

$$K_1 + K_2 = 1.5\left(1 - \frac{d^2}{D^2}\right)^2 \qquad (24)$$

Determining Maximum Flow Rate (q_{max})

Determine either q_{max} or ΔP_{max} if it is possible for choked flow to develop within the control valve that is to be sized. The values can be determined by using the following procedures:

$$q_{\max} = N_1 \ F_L \ C_v \ \sqrt{\frac{P_1 - \ F_F \, P_v}{G_f}} \qquad (25)$$

Values for F_F, the liquid critical pressure ratio factor, can be obtained from figure 3-3, or from the following equation:

$$F_F = 0.96 - 0.28 \ \sqrt{\frac{P_v}{P_c}} \qquad (26)$$

Values of F_L, the recovery factor for rotary valves installed without fittings attached, can be found in published coefficient tables. If the given valve is to be installed with fittings such as reducer attached to it, F_L in the equation must be replaced by the quotient F_{LP}/F_p, where:

$$F_{LP} = \left[\frac{K_1}{N_2}\left(\frac{C_v}{d^2}\right)^2 + \frac{1}{F_L{}^2}\right]^{-1/2} \qquad (27)$$

and

$K_1 = K_1 + K_{B1}$

where,

K_1 = Resistance coefficient of upstream fittings

K_{B1} = Inlet Bernoulli coefficient

Note: See the procedure for determining F_p, the piping geometry factor, for definitions of the other constants and coefficients used in the above equations.)

Determining Allowable Sizing Pressure Drop (ΔP_{max})

ΔP_{max} (the allowable sizing pressure drop) can be determined from the following relationships:

For valves installed without fittings:

$$\Delta P_{\max(L)} = F_L{}^2 \left(P_1 - F_F \ P_v\right) \qquad (28)$$

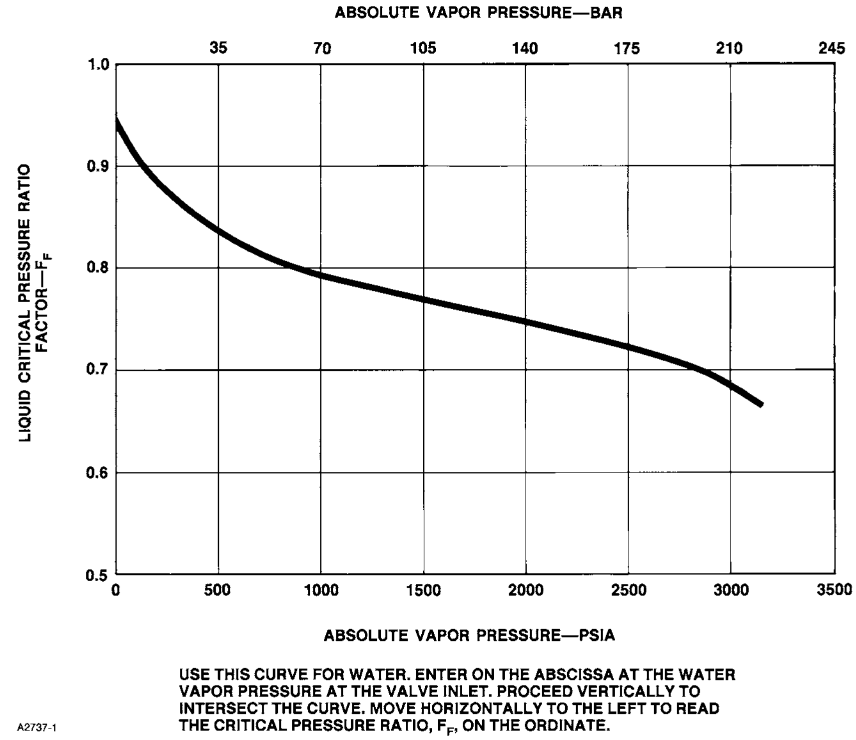

Figure 3-3. *Liquid Critical Pressure Ratio Factor for Water*

For valves installed with fittings attached:

$$\Delta P_{\max(LP)} = \left(\frac{F_{LP}}{F_P}\right)^2 (P_1 - F_F\ P_V) \qquad (29)$$

where,

P_1 = Upstream absolute static pressure

P_2= Downstream absolute static pressure

P_V = Absolute vapor pressure at inlet temperature

Values of F_F, the liquid critical pressure ratio factor, can be obtained from figure 3-3 or from the following equation:

$$F_F = 0.96 - 0.28\sqrt{\frac{P_v}{P_c}} \qquad (30)$$

An explanation of how to calculate values of F_{LP}, the recovery factor for valves installed with fittings attached, is presented in the preceding procedure determining q_{max} (the maximum flow rate).

Once the ΔP_{max} value has been obtained from the appropriate equation, it should be compared with the actual service pressure differential ($\Delta P = P_1 - P_2$). If ΔP_{max} is less than ΔP, this is an indication that choked flow conditions will exist under the service conditions specified. If choked flow conditions do exist ($\Delta P_{max} < P_1 - P_2$), then step five of the procedure for sizing valves for liquids must be modified by replacing the actual service pressure differential ($P_1 - P_2$) in the appropriate valve sizing equation with the calculated ΔP_{max} value.

Note: Once it is known that choked flow conditions will develop within the specified valve design (ΔP_{max} is calculated to be less than ΔP), a further distinction can be made to determine whether the choked flow is caused by cavitation or flashing. The choked flow conditions are caused by flashing if the outlet pressure of the given valve is less than the vapor pressure of the flowing liquid. The choked flow conditions are caused by cavitation if the outlet pressure of the valve is greater than the vapor pressure of the flowing liquid.

Liquid Sizing Sample Problem

Assume an installation that, at initial plant start-up, will not be operating at maximum design capability. The lines are sized for the ultimate system capacity, but there is a desire to install a control valve now which is sized only for currently anticipated requirements. The line size is 8-inches, and an ANSI Class 300 globe valve with an equal percentage cage has been specified. Standard concentric reducers will be used to install the valve into the line. Determine the appropriate valve size.

1. Specify the necessary variables required to size the valve:

- Desired valve design is an ANSI Class 300 globe valve with equal percentage cage and an assumed valve NPS 3.
- Process fluid is liquid propane
- Service conditions are q = 800 gpm

P_1 = 300 psig = 314.7 psia

P_2 = 275 psig = 289.7 psia

ΔP = 25 psi

T_1 = 70°F

G_f = 0.50

P_v = 124.3 psia

P_c = 616.3 psia

2. Use an N_1 value of 1.0 from the Equation Constants table.

3. Determine F_p, the piping geometry factor.

Because it is proposed to install a NPS 3 valve in an 8-inch line, it will be necessary to determine the piping geometry factor, F_p, which corrects for losses caused by fittings attached to the valve.

From Equation 19,

$$Fp = \left[1 + \frac{\Sigma K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

where,

N_2 = 890, from the Equation Constants Table

d = 3 inches, from step one

C_v = 121, from the flow coefficient table for an ANSI Class 300, NPS 3 globe valve with equal percentage cage.

To compute ΣK for a valve installed between identical concentric reducers:

$$\begin{aligned} \Sigma K &= K_1 + K_2 \\ &= 1.5\left(1 - \frac{d^2}{D^2}\right)^2 \\ &= 1.5\left(1 - \frac{(3)^2}{(8)^2}\right)^2 \\ &= 1.11 \end{aligned}$$

where,

D = 8 inches, the internal diameter of the piping so,

$$F_p = \left[1 + \frac{1.11}{890}\left(\frac{121}{3^2}\right)^2\right]^{-1/2}$$

$$= 0.90$$

4. Determine ΔP_{max} (the allowable sizing pressure drop)

Based upon the small required pressure drop, the flow will not be choked ($\Delta P_{max} > \Delta P$).

5. Solve for C_v, using equation 17.

$$\begin{aligned} C_v &= \frac{q}{N_1 F_P \sqrt{\frac{P_1 - P_2}{G_f}}} \\ &= \frac{800}{(1.0)(0.90)\sqrt{\frac{25}{0.5}}} \\ &= 125.7 \end{aligned}$$

6. Select the valve size using the flow coefficient table and the calculated C_v value.

The required C_v of 125.7 exceeds the capacity of the assumed valve, which has a C_v of 121.

Although, for this example, it may be obvious that the next larger size (NPS 4) would be the correct valve size, this may not always be true, and a repeat of the above procedure should be carried out. This is assuming that a NPS 4 valve, C_v = 203. This value was determined from the flow coefficient table for an ANSI Class 300, NPS 4 globe valve with an equal percentage cage.

Recalculate the required C_v using an assumed C_v value of 203 in the F_p calculation.

where,

$$\Sigma K = K_1 + K_2$$

$$= 1.5\left(1 - \frac{d^2}{D^2}\right)^2$$

$$= 1.5\left(1 - \frac{16}{64}\right)^2$$

$$= 0.84$$

and

$$F_p = \left[1 + \frac{\Sigma K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

$$= \left[1 + \frac{0.84}{890}\left(\frac{203}{4^2}\right)^2\right]^{-1/2}$$

$$= 0.93$$

and

$$C_v = \frac{q}{N_1 F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

$$= \frac{800}{(1.0)(0.93)\sqrt{\frac{25}{0.5}}}$$

$$= 121.7$$

This solution indicates only that the NPS 4 valve is large enough to satisfy the service conditions given. There may be cases, however, where a more accurate prediction of the C_v is required. In such cases, the required C_v should be determined again using a new F_p value based on the C_v value obtained above. In this example, C_v is 121.7, which leads to the following result:

$$F_p = \left[1 + \frac{\Sigma K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

$$= \left[1 + \frac{0.84}{890}\left(\frac{121.7}{4^2}\right)^2\right]^{-1/2}$$

$$= 0.97$$

The required C_v then becomes:

$$C_v = \frac{q}{N_1 F_p \sqrt{\frac{P_1 - P_2}{G_f}}}$$

$$= \frac{800}{(1.0)(0.97)\sqrt{\frac{25}{0.5}}}$$

$$= 116.2$$

Because this newly determined C_v is close to the C_v used initially for this recalculation (116.2 versus 121.7), the valve sizing procedure is complete, and the conclusion is that a NPS 4 valve opened to about 75% of total travel should be adequate for the required specifications.

Sizing for Pulp Stock

The behavior of flowing pulp stock is different from water or viscous Newtonian fluids. It is necessary to account for this behavior when determining the required valve size. Methods have been developed to aid in determining correct valve size for these types of applications.

The pulp stock sizing calculation uses the following modified form of the basic liquid sizing equation (equation thirteen, above):

$$Q = C_v K_p \sqrt{\Delta P}$$

where,

ΔP = sizing pressure drop, psid

C_v = valve flow coefficient

K_p = pulp stock correction factor

Q = volumetric flow rate, gpm

The root of this calculation is the pulp stock correction factor, K_p. This factor is the ratio of the pulp stock flow rate to water flow rate under the same flowing conditions. It, therefore, modifies the relationship between Q, C_v, and ΔP to account for the effects of the pulp stock relative to that for water. The value of this parameter, in theory, depends on many factors such as pulp stock type, consistency, freeness, fiber length, valve type and pressure drop. However, in practice, it appears that the dominant effects are due to three primary factors: pulp type, consistency and pressure differential. Values of K_p for three different pulp stock types are shown in figure 3-4 through 3-6.

Once the value of the pulp stock correction factor is known, determining the required flow coefficient or flow rate is equivalent to basic liquid sizing. For example, consider the following:

Q = 1000 gpm of 8% consistency Kraft pulp stock

ΔP = 16 psid

P_1 = 150 psia

K_p = 0.83 from figure 3-5

therefore, $C_v = \frac{Q}{K_p \sqrt{\Delta P}} = \frac{1000}{0.83 \sqrt{16}} = 301$

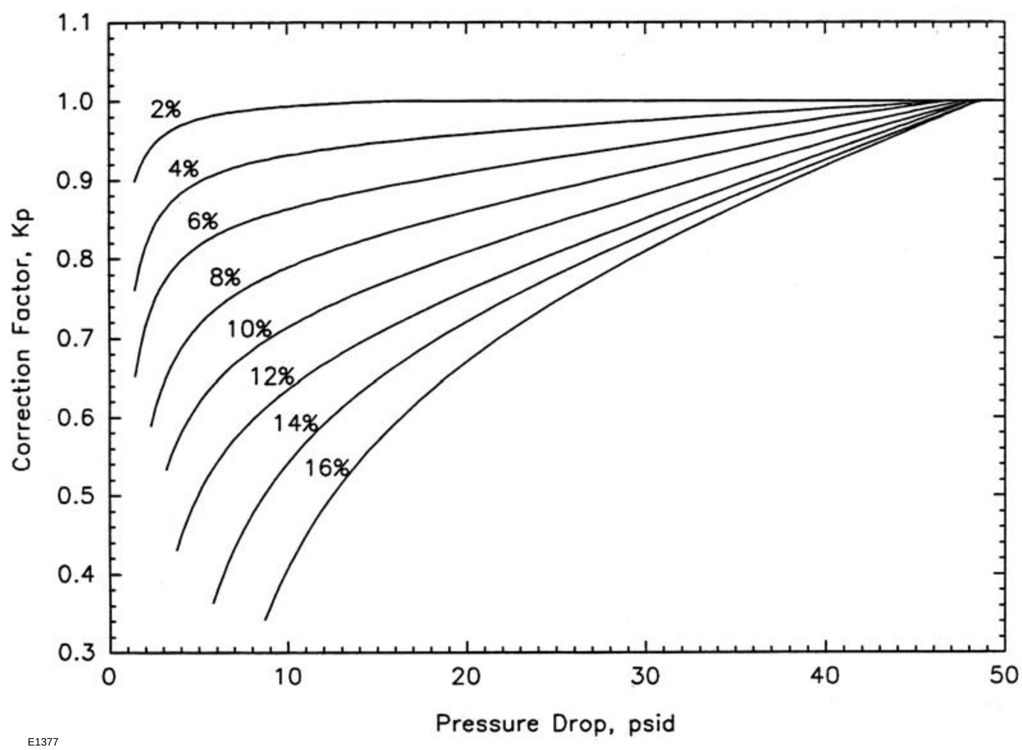

Figure 3-4. *Pulp Stock Correction Factors for Kraft Pulp*

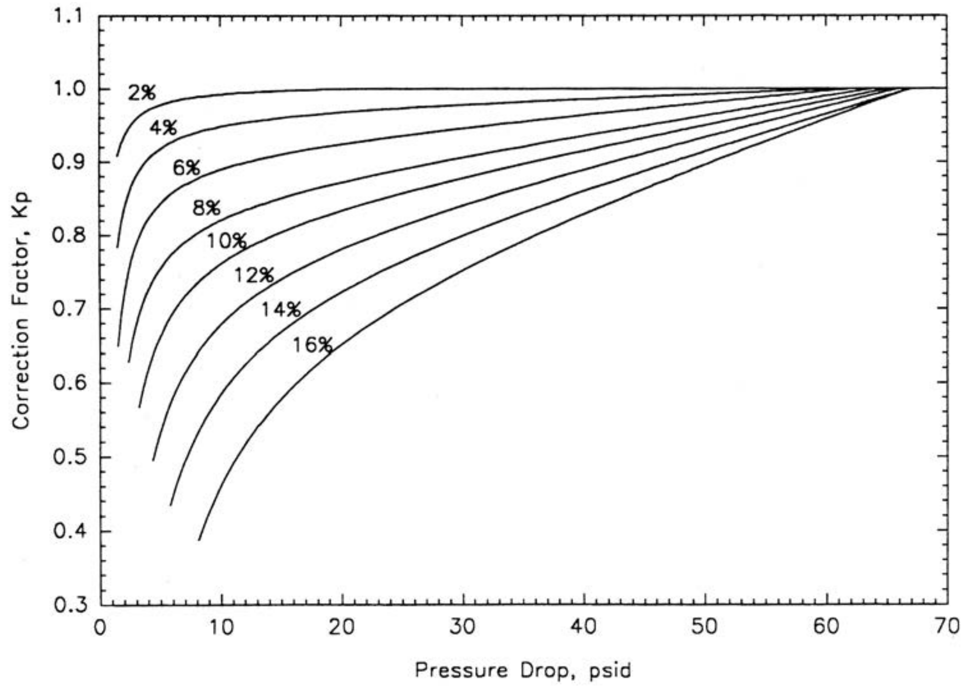

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Figure 3-5. *Pulp Stock Correction Factors for Mechanical Pulp*

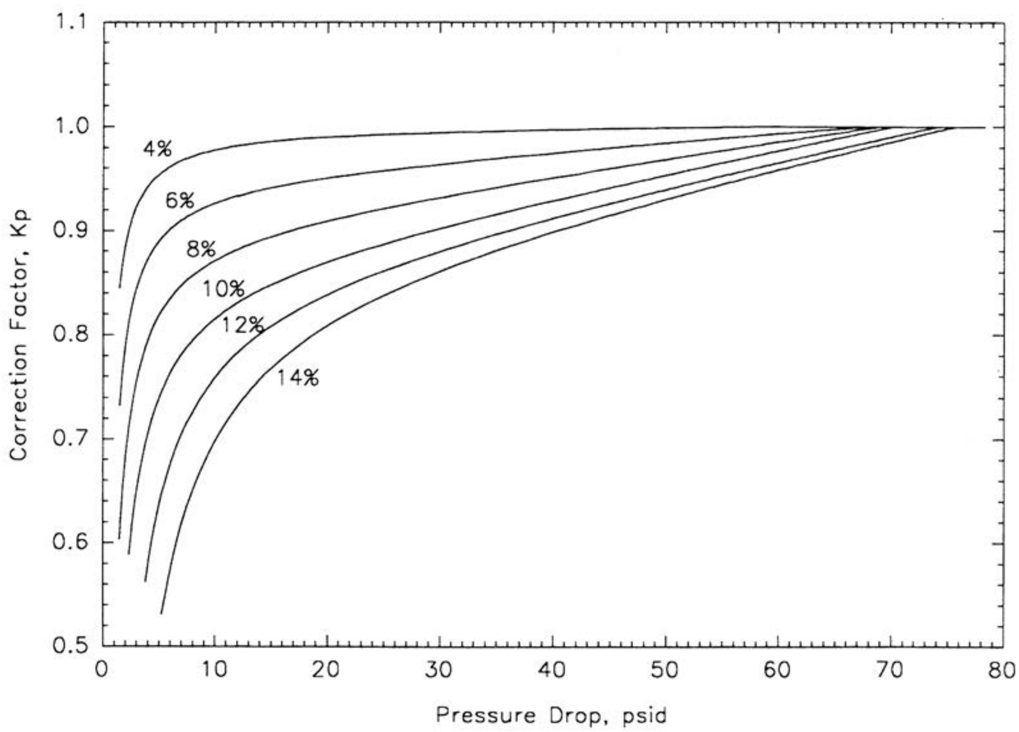

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Figure 3-6. *Pulp Stock Correction Factors for Recycled Pulp*

Chapter 4

Cavitation and Flashing

Severe Liquid Flow Sizing

Proper control valve sizing is important to successful plant operation. However, sizing is not always straightforward. At times, it involves considering phenomena beyond that of general service. Selecting the appropriate control valve can be extremely critical to the complete process loop. Liquid sizing for severe flow service, including events involving cavitation or flashing, must be closely examined in order to obtain successful plant operation.

Sizing for severe flow service applications can be explained by expanding upon base liquid sizing knowledge. The following sections will build upon the basic liquid sizing equations presented in chapter 3 in order to study liquid fluid behaviors involved with choked flow, cavitation, flashing, viscous flow, and sizing for pulp stock. In addition, discussion of considerations in selecting the appropriate control valves for cavitating and flashing services will take place.

Choked Flow

The equation illustrated below (chapter 3, equation 14) would imply that, for a given valve, flow could be continually increased to infinity by simply increasing the pressure differential across the valve.

$$Q = C_v \sqrt{\frac{P_1 - P_2}{G}} \tag{31}$$

In reality, the relationship given by this equation holds for only a limited range. As the pressure differential is increased a point is reached where the realized mass flow increase is less than expected. This phenomenon continues until no additional mass flow increase occurs in spite of increasing the pressure differential (figure 4-1). This condition of limited maximum mass flow is known as choked flow. To understand more about what is occurring, and how to correct it when sizing valves, it is necessary to revisit some of the fluid flow basics discussed in chapter 3.

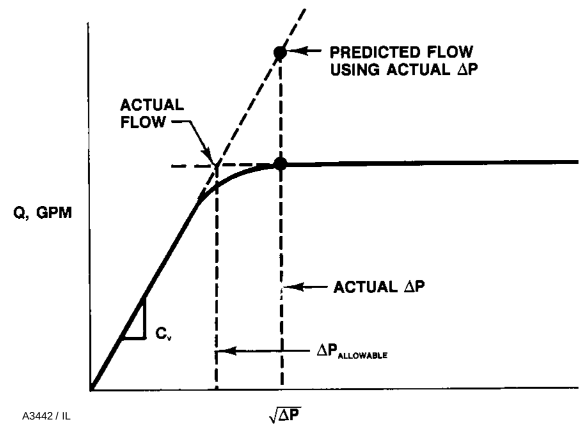

Figure 4-1. *Typical Flow Curve Showing Relationship Between Flow Rate Q and Imposed Pressure Differential ΔP*

Recall that, as a liquid passes through a reduced cross-sectional area, velocity increases to a maximum and pressure decreases to a minimum. As the flow exits, velocity is restored to its original value while the pressure is only partially restored thus creating a pressure differential across the device. As this pressure differential is increased, the velocity through the restriction increases (increasing flow) and the vena contracta pressure decreases. If a sufficiently large pressure differential is imposed upon the device, the minimum pressure may decrease to, or below, the vapor pressure of the liquid under these conditions. When this occurs the liquid becomes thermodynamically unstable and partially vaporizes. The fluid now consists of a liquid and vapor mixture that is no longer incompressible.

While the exact mechanisms of liquid choking are not fully confirmed, there are parallels between this and critical flow in gas applications. In gas flows, the flow becomes critical (choked) when the fluid velocity is equal to the acoustic wave speed at that point in the fluid. Pure incompressible fluids have high wave speeds and, practically speaking, they do not choke. Liquid-to-gas or liquid-to-vapor mixtures, however, typically have low acoustic wave speeds (actually lower than that for a pure gas or vapor), so it is possible for the mixture velocity to equal the sonic velocity and choke the flow.

Another way of viewing this phenomenon is to consider the density of the mixture at the vena contracta. As the pressure decreases, so does the density of the vapor phase, hence, the density of the mixture decreases. Eventually, this decrease in density of the fluid offsets any increase in the velocity of the mixture to the point where no additional mass flow is realized.

It is necessary to account for the occurrence of choked flow during the sizing process so that undersizing of a valve does not occur. In other words, knowing the maximum flow rate a valve can handle under a given set of conditions is necessary. To this end, a procedure was developed which combines the control valve pressure recovery characteristics with the thermodynamic properties of the fluid to predict the maximum usable pressure differential, i.e. the pressure differential at which the flow chokes.

A pressure recovery coefficient can be defined as:

$$K_m = \frac{P_1 - P_2}{P_1 - P_{vc}} \tag{32}$$

Under choked flow conditions, it is established that:

$$P_{vc} = r_c P_v \tag{33}$$

The vapor pressure, P_V, is determined at inlet temperature because the temperature of the liquid does not change appreciably between the inlet and the vena contracta. The term "r_c" is known as the critical pressure ratio, and is another thermodynamic property of the fluid. While it is actually a function of each fluid and the prevailing conditions, it has been established that data for a variety of fluids can be generalized, according to figure 4-2 or the following equation, without significantly compromising overall accuracy:

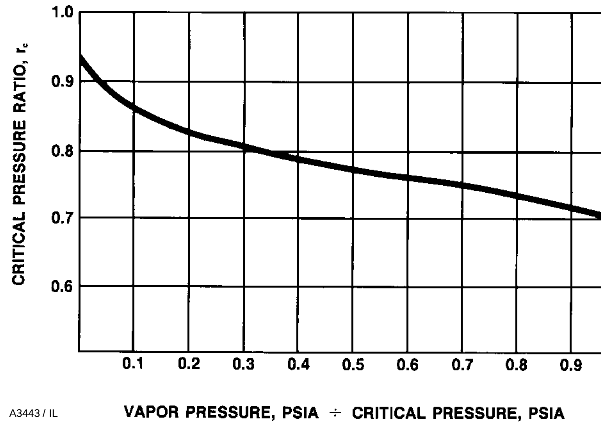

Figure 4-2. *Generalized r_c Curve*

$$r_c = F_F = 0.96 - 0.28\sqrt{\frac{P_{vc}}{P_c}} \tag{34}$$

The value of K_m is determined individually by test for each valve style and accounts for the pressure recovery characteristics of the valve.

By rearranging equation sixteen, the pressure differential at which the flow chokes can be determined is known as the allowable pressure differential:

$$(P_1 - P_2)_{allowable} = K_m(P_1 - r_c\ P_v) \tag{35}$$

When this allowable pressure differential is used in the equation below (equation 14 from chapter 3), the choked flow rate for the given valve will result.

$$Q = C_v\sqrt{\frac{P_1 - P_2}{G}}$$

If this flow rate is less than the required service flow rate, the valve is undersized. It is then necessary to select a larger valve, and repeat the calculations using the new values for C_v and K_m.

The equations supplied in the sizing standard are, in essence, the same as those presented in this chapter, except the nomenclature has been changed. In this case:

$$Q_{\max} = N_1 F_L C_v\sqrt{\frac{P_1 - F_F P_v}{G}} \tag{36}$$

Figure 4-3. *Typical Cavitation Damage*

where:

F_L = $\sqrt{K_m}$

F_F = rc

N_1 = units factor

Cavitation

Closely associated with the phenomenon of choked flow is the occurrence of cavitation. Simply stated, cavitation is the formation and collapse of cavities in the flowing liquid. It is of special concern when sizing control valves because if left unchecked, it can produce unwanted noise, vibration, and material damage.

As discussed earlier, vapor can form in the vicinity of the vena contracta when the local pressure falls below the vapor pressure of the liquid. If the outlet pressure of the mixture is greater than the vapor pressure as it exits the valve, the vapor phase will be thermodynamically unstable and will revert to a liquid. The entire liquid-to-vapor-to-liquid phase change process is known as "cavitation," although it is the vapor-to-liquid phase change that is the primary source of the damage. During this phase change a mechanical attack occurs on the material surface in the form of high velocity micro-jets and shock waves. Given sufficient intensity, proximity, and time, this attack can remove material to the point where the valve no longer retains its functional or structural integrity. figure 4-3 shows an example of such damage.

Cavitation and the damage it causes are complex processes and accurate prediction of key events such as damage, noise, and vibration level is difficult. Consequently, sizing valves for cavitation conditions requires special considerations.

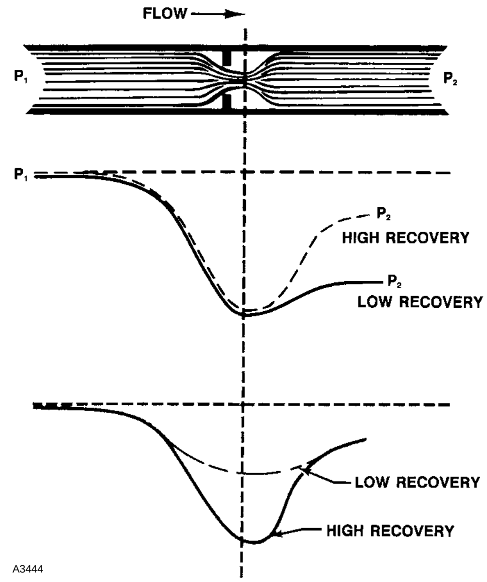

Figure 4-4. *Comparison of High and Low Recovery Valves*

The concept of pressure recovery plays a key role in characterizing a valve's suitability for cavitation service. A valve that recovers a significant percentage of the pressure differential from the inlet to the vena contracta is appropriately termed a high recovery valve. Conversely, if only a small percent is recovered, it is classified as a low recovery valve. These two are contrasted in figure 4-4. If identical pressure differentials are imposed upon a high recovery valve and a low recovery valve, all other things being equal, the high recovery valve will have a relatively low vena contracta pressure. Thus, under the same conditions, the high recovery valve is more likely to cavitate. On the other hand, if flow through each valve is such that the inlet and vena contracta pressures are equal, the low recovery valve will have the lower collapse potential (P_2–P_{VC}), and cavitation intensity will generally be less.

Therefore, it is apparent that the lower pressure recovery devices are more suited for cavitation service.

The possibility of cavitation occurring in any liquid flow application should be investigated by checking for the following two conditions:

1. The service pressure differential is approximately equal to the allowable pressure differential.

2. The outlet pressure is greater than the vapor pressure of the fluid.

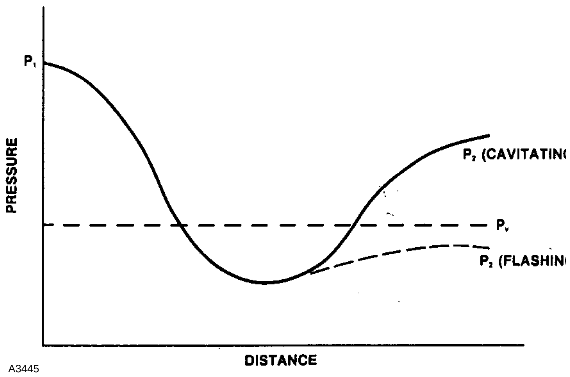

Figure 4-5. *Pressure Profiles for Flashing and Cavitating Flows*

If both of these conditions are met, the possibility exists that cavitation will occur. Because of the potentially damaging nature of cavitation, sizing a valve in this region is not recommended. Special purpose trims and products to control cavitation should be considered. Because of the great diversity in the design of this equipment, it is not possible to offer general guidelines for sizing valves with those specialized trims. Please refer to specific product literature for additional information.

Cavitation in Pulp Stock

Cavitation behavior in low consistency pulp stock (less than 4%) is treated as equivalent to that of water. Generally, pulp stock consistency greater than 4% is not known to be problematic, as the stock itself absorbs the majority of the energy produced by the cavitating microjets.

Flashing

Flashing shares some common features with choked flow and cavitation in that the process begins with vaporization of the liquid in the vicinity of the vena contracta. However, in flashing applications, the pressure downstream of this point never recovers to a value that exceeds the vapor pressure of the fluid. Thus, the fluid remains in the vapor phase. Schematic pressure profiles for flashing and cavitating flow are contrasted in figure 4-5.

Flashing is of concern not only because of its ability to limit flow through the valve, but also because of the highly erosive nature of the liquid-vapor mixture. Typical flashing damage is smooth and polished in appearance (figure 4-6) in stark contrast to the rough, cinder-like appearance of cavitation (figure 4-3).

Figure 4-6. *Typical Flashing Damage*

If $P_2 < P_v$, or there are other service conditions to indicate flashing, the standard sizing procedure should be augmented with a check for choked flow. Furthermore, suitability of the particular valve style for flashing service should be established with the valve manufacturer. Selection guidelines will be discussed later in the chapter.

Viscous Flow

One of the assumptions implicit in the sizing procedures presented to this point is that of fully developed, turbulent flow. Turbulent flow and laminar flow are flow regimes that characterize the behavior of flow. In laminar flow, all fluid particles move parallel to one another in an orderly fashion and with no mixing of the fluid. Conversely, turbulent flow is highly random in terms of local velocity direction and magnitude. While there is certainly net flow in a particular direction, instantaneous velocity components in all directions are superimposed on this net flow. Significant fluid mixing occurs in turbulent flow. As is true of many physical phenomena, there is no distinct line of demarcation between these two regimes. Thus, a third regime of transition flow is sometimes recognized.

The physical quantities which govern this flow regime are the viscous and inertial forces; this ratio is known as the Reynolds number. When the viscous forces dominate (a Reynolds number below 2,000) the flow is laminar, or viscous. If the inertial forces dominate (a Reynolds number above 3,000) the flow is turbulent, or inviscid.

Consideration of these flow regimes is critical because the macroscopic behavior of the flow changes when the flow regime changes. The primary behavior characteristic of concern in sizing is the nature of the available energy losses. In earlier discussion it was asserted that, under the assumption of inviscid flow, the available energy

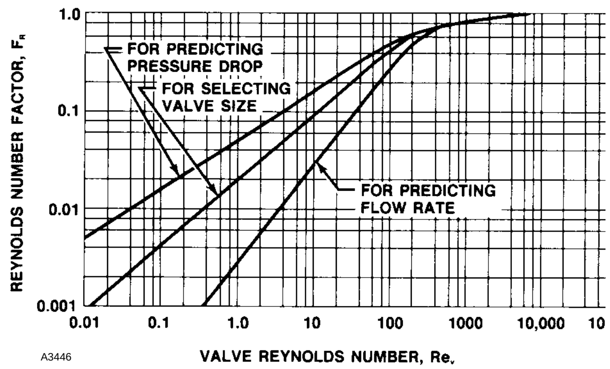

Figure 4-7. *Viscous Flow Correction Factors*

losses were proportional to the square of the velocity.

In the laminar flow regime, these same losses are linearly proportional to the velocity; in the transitional regime, these losses tend to vary. Thus, for equivalent flow rates, the pressure differential through a conduit or across a restriction will be different for each flow regime.

To compensate for this effect (the change in resistance to flow) in sizing valves, a correction factor was developed. The required C_v can be determined from the following equation:

$$C_{v_{req'd}} = F_R \ C_{v_{rated}} \tag{37}$$

The factor F_R is a function of the Reynolds number and can be determined from a simple nomograph procedure, or by calculating the Reynolds number for a control valve from the following equation and determining F_R from figure 4-7.

$$\mathrm{Re}_v = \frac{N_4 F_d Q}{\nu F_L 1/2 \ \ C_v 1/2}\left[\frac{1}{N_2}(F_L)^2\left(\frac{C_v}{d^2}\right)^2 + 1\right]^{1/4} \tag{38}$$

To predict flow rate, or resulting pressure differential, the required flow coefficient is used in place of the rated flow coefficient in the appropriate equation.

When a valve is installed in a field piping configuration which is different than the specified test section, it is necessary to account for the effect of the altered piping on flow through the valve. (Recall that the standard test section consists of a prescribed length of straight pipe up and downstream of the valve.) Field installation may require elbows, reducers, and tees, which will induce additional losses immediately adjacent to the valve. To correct for this situation, two factors are introduced:

- F_p
- F_{lp}

Factor F_p is used to correct the flow equation when used in the incompressible range, while factor F_{lp} is used in the choked flow range. The expressions for these factors are:

$$F_p = \left[\frac{\Sigma K}{N_2}\left(\frac{C_v}{d^2}\right)^2 + 1\right]^{-1/2} \tag{39}$$

$$F_{lp} = F_L\left[\frac{F_L{}^2 K_I}{N_2}\left(\frac{C_v}{d^2}\right)^2 + 1\right]^{-1/2} \tag{40}$$

The term K in equation 39 is the sum of all loss coefficients of all devices attached to the valve and the inlet and outlet Bernoulli coefficients. Bernoulli coefficients account for changes in the kinetic energy as a result of a cross-sectional flow area change. They are calculated from the following equations.

$$K_{B_{inlet}} = 1 - (d/D)^4 \tag{41a}$$

$$K_{B_{outlet}} = (d/D)^4 - 1 \tag{41b}$$

Thus, if reducers of identical size are used at the inlet and outlet, these terms cancel out.

The term “K_I” in equation 40 includes the loss coefficients and Bernoulli coefficient on the inlet side only.

In the absence of test data or knowledge of loss coefficients, loss coefficients may be estimated from information contained in other resources.

The factors F_p and F_l would appear in flow equations 31 and 36 respectively as follows:

For incompressible flow:

$$Q = F_p C_v \sqrt{\frac{P_1 - P_2}{G}} \tag{42}$$

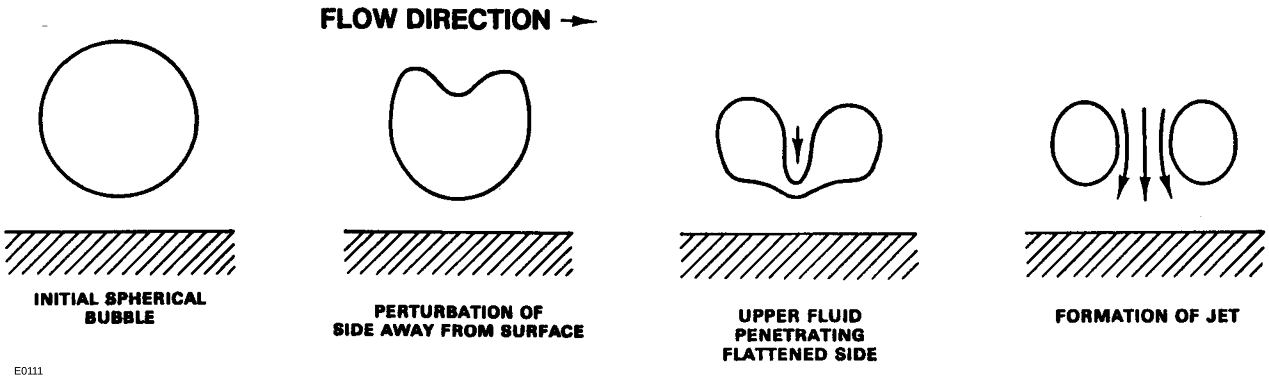

Figure 4-8. *The implosion of cavitation vapor cavities is rapid, asymmetric and very energetic. The mechanics of collapse give rise to high velocity liquid jets, which impinge on metallic surfaces. Ultimately, the metal fatigues and breaks away in small pieces.*

For choked flow:

$$Q_{\max} = F_I C_v \sqrt{\frac{P_1 - F_F P_v}{G}} \qquad (43)$$

Valve Material Damage

Cavitation damage is usually the most troublesome side effect plaguing the control valve industry. It does not take many examples of such damage to fully demonstrate the destructive capabilities of cavitation.

Typically, cavitation damage is characterized by an irregular, rough surface. The phrase “cinder-like appearance” is used frequently to describe cavitation damage. It is discernible from other types of flow damage such as erosion and flashing damage which are usually smooth and shiny in appearance. This next section will deal with cavitation damage, although most of the comments can also apply to flashing damage. A comparison of figures 4-3 and 4-6 illustrates these differences.

While the results of cavitation damage are all too familiar, the events and mechanisms of the cavitation damage process are not known or understood completely in spite of extensive study over the years. There is general agreement, however, on a number of aspects of the process and consistency in certain observations.

Cavitation damage has been observed to be associated with the collapse stage of the bubble dynamics. Furthermore, this damage consists of two primary events or phases:

1. An attack on a material surface as a result of cavitation in the liquid.
2. The response or reaction of the material to the attack.

Any factor that influences either of these events will have some sort of final effect on the overall damage characteristics.

The attack stage of the damage process has been attributed to various mechanisms, but none of them account for all the observed results. It appears that this attack involves two factors that interact in a reinforcing manner:

1. Mechanical attack
2. Chemical attack

There is evidence indicating the almost universal presence of a mechanical attack component which can occur in either of two forms:

1. Erosion resulting from high-velocity microjets impinging upon the material surface.
2. Material deformation and failure resulting from shock waves impinging upon the material surface.

In the first type of mechanical attack a small, high-velocity liquid jet is formed during the asymmetrical collapse of a vapor bubble. If orientation and proximity of the jets is proper, a damaging attack occurs on the metal surface as shown in figure 4-8. This is the most probable form of mechanical attack. High-speed cinematography, liquid drop impingement comparisons, and various analytical studies support its presence.

The second type of mechanical attack, shock wave impingement, does not appear to be as dominant. Analytical estimations of vapor bubble collapse pressures do not suggest that the shock waves are on a damaging order of magnitude — at least during the initial collapse. Experimental studies bear this out. They also reveal that resulting collapse pressures increase in magnitude with subsequent rebound collapses and become potentially damaging.

The other primary component of attack, chemical attack, is perhaps more significant because it interacts with the mechanical component rather than acting by itself. After a period of mechanical attack, many of the protective coatings of a material (films, oxides, etc.) are physically removed, making the base material more vulnerable to chemical attack.

Just as a number of variables have an affect on the behavior of individual cavities, a number of variables influence the degree and extent of material damage. The principal variables that influence cavitation damage include air content, pressure, velocity and temperature.

Air content impacts cavitation damage primarily through its effect on cavity mechanics. Again, two opposing trends are evident on increasing the amount of air. Adding air supplies more entrained air nuclei which, in turn, produce more cavities that can increase the total damage. After a point, however, continued increases in air content disrupt the mechanical attack component and effectively reduce the total damage.

Pressure effects also exhibit two opposing trends. Given a fixed inlet pressure P_1, decreasing the backpressure P_2 tends to increase the number of cavities formed, which creates a worse situation. However, a lower backpressure also creates a lower collapse pressure differential ($P_2 - P_v$), resulting in a decrease in the intensity of the cavitation.

An additional pressure effect, unrelated to the above, concerns the location of damage. As the backpressure is changed, the pressure required to collapse the cavities moves upstream or downstream depending upon whether the pressure is increased or decreased, respectively. In addition to a change in the severity of the total damage, there may be an accompanying change in the physical location of the damage when pressure conditions are altered.

It should now be apparent that the cavitation and flashing damage process is a complex function of:

1. Intensity and degree of cavitation (cavitation attack)
2. Material of construction (material response)
3. Time of exposure

While the above-mentioned influences have been observed, they remain to be quantified. Often, experience is the best teacher when it comes to trying to quantify cavitation damage.

Noise

Although the noise associated with a cavitating liquid can be quite high, it is usually of secondary concern when compared to the material damage that can exist. Therefore, high intensity cavitation should be prevented to decrease the chance of material damage. If cavitation is prevented, the noise associated with the liquid flow will be less than 90 dBA.

For a flashing liquid, studies and experience have shown that the noise level associated with the valve will be less than 85 dBA, regardless of the pressure drop involved to create the flashing.

Cavitation / Flashing Damage Coefficients and Product Selection

Cavitation in control valves can be an application challenge. It is important to understand the guidelines when selecting an appropriate valve and trim. Experience, knowledge of where cavitation problems begin, and the effect of valve size and type, are all useful in deciding which valve and trim can be used.

Terminology

F_L: Pressure recovery coefficient. A valve parameter used to predict choked flow.

ΔP_{max}: Allowable sizing pressure drop. The limiting pressure drop beyond which any increase in pressure drop brought about by decreasing P_2 will not generate additional flow through the valve. Therefore the valve is “choked”. Per equation 28 of chapter 3:

$$\Delta P_{max(L)} = F_L{}^2(P_1 - F_F P_v)$$

where,

P_1 = Upstream absolute static pressure

P_v = Absolute vapor pressure at inlet temperature

F_F = the liquid critical pressure ratio factor. Can be obtained from the following equation:

$$F_F = 0.96 - 0.28\sqrt{\frac{P_v}{P_c}}$$

K_c: Cavitation coefficient. A valve parameter dependent upon valve style and trim. It predicts the beginning of cavitation related damage and vibration problems for a particular valve/trim style.

$$\Delta P_{Cavitation} = K_c\,(P_1 - P_v)$$

A_r: Application ratio. A cavitation index which is dependent upon the actual service conditions. It indicates the presence of flashing or potentially cavitating services.

$$A_r = (\Delta P_{Flow})\,/\,(P_1 - P_v)$$

K_i: Incipient cavitation coefficient. A valve parameter which predicts the point of initial generation and collapse of vapor bubbles. (Specific values of K_i are generally not available).

$$\Delta P_{Incipient\ Cav.} = K_i\,(P_1 - P_v)$$

Valve Selection Coefficient Criteria and Selection Procedure

1. Determine $\Delta P_{Flowing}$ (ΔP_{Flow})
2. Calculate A_r

   a. If $A_r \geq 1.0$, the service is flashing.

   b. If $A_r \leq 1.0$, the service is potentially cavitating.

3. Use ΔP_{Flow} and A_r in conjunction with the K_c values of valve trim ΔP limits and K_c indices, as well as other valve selection criteria (P_1, temp., style, etc.), to make a valve selection.

The cavitation coefficient (K_c) is based upon valve type and pressure drop limit. Select a valve/trim that has a ΔP limit higher than the service ΔP_{Flow} and a K_c higher that the service A_r.

Application Guidelines

Guidelines (including A_r and K_c ratios) were developed to help select the proper valve construction when cavitation is present. These guidelines are intended to provide valve selections free of cavitation related material and vibration damage over the long term. The guidelines do not indicate an absence of cavitation. Thus, noise due to cavitation may still be present. If noise is a concern, use hydrodynamic noise prediction to assist in selecting a valve.

The following restrictions apply to these guidelines:

- Water only
- Customer requirements that may require use of different guidelines

Examples:

- Long maintenance intervals
- Very low noise requirements
- Different fluids
- Corrosive an/or erosive environment
- Installation limitations
- Valve usage rate

These guidelines will aid in selecting a valve and trim designed to help prevent cavitation damage and thus offer long term valve life in potentially cavitating services.

For detailed cavitating service valve selection guidelines, please contact your local sales office.

Additional Guidelines

- For all valve styles and sizes, applying backpressure to the valve can eliminate cavitation. This solution is most effective when the service conditions do not vary widely.
- Fluids information:

  — Cold water is the most common problem fluid.

  — Pure component fluids, similar to water, can also cause problems.

  — Fluid mixtures, like that of pulp stock, can be less damaging even when the numbers indicate cavitation is present. Experience is most useful here.

These guidelines have been constructed from a broad base of experience. There are undoubtedly exceptions to these guidelines and, as always, recent experience should be used to select the best valve for specific applications.

Hardware Choices for Flashing Applications

It was stated previously that flashing is a liquid flow phenomenon that is defined by the system, and not by the valve design. Therefore, since flashing cannot be prevented by the control valve, all that can be done is to prevent flashing damage. There are three main factors that affect the amount of flashing damage in a control valve:

1. Valve design
2. Materials of construction
3. System design

Valve Design

While valve design has no bearing upon whether flashing does or does not occur, it can have a large impact on the intensity of flashing damage. Generally, there are two valve designs that are more resistant to flashing damage.

An angle valve with standard trim in the flow down direction and with a downstream liner is perhaps the best solution to preventing flashing damage. figure 4-9 shows a typical angle valve for flashing service.

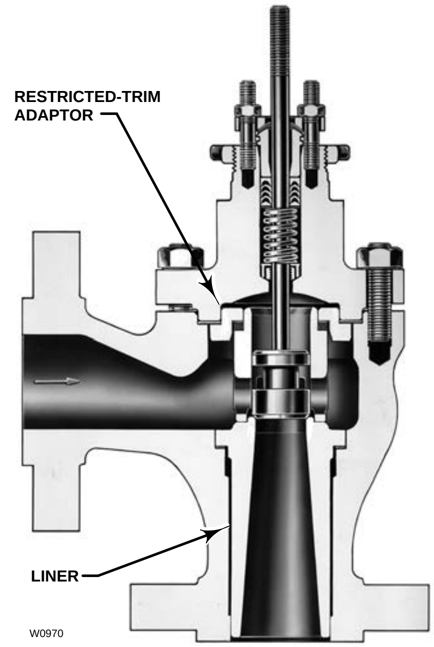

Figure 4-9. *Fisher EAS valve with outlet liner is used for flashing service. The liner resists erosion and protects the body.*

This construction is an excellent choice because flashing damage occurs when high velocity vapor bubbles impinge on the surface of a valve. An angle valve reduces the impingement by directing flow into the center of the downstream pipe, not into the valve body. If damage does occur, the downstream liner can be replaced much more economically than the valve body.

A rotary plug style of valve is also an excellent choice for medium to low pressure flashing applications. This valve can be installed with the plug facing the downstream side of the body (figure 4-10) so when flashing occurs, it does so downstream of the valve. In some cases, a spool piece of sacrificial pipe is used to absorb the flashing damage.

Materials of Construction

There are several factors that determine the performance of a given material in a particular flashing and/or cavitating situation including the materials' toughness, hardness, and its corrosion resistance in the application environment. Within a given material family (e.g. the 400-series stainless steels), hardness is a fairly accurate method for ranking materials. However, when comparing materials from different families, hardness does not correlate with overall resistance to damage. For example, cobalt-chromium-tungsten based alloy 6 has much more resistance to cavitation and flashing than either hardened type 410 or 17-4 stainless steels, even though they all exhibit roughly the same hardness. In fact, alloy 6 equals or exceeds the performance of many materials with a hardness of 60 HRC and higher. The superior performance of alloy 6 is attributed to a built-in "energy-absorbing" mechanism shared by a number of cobalt-base alloys.

Materials commonly used for flashing and cavitating services are alloy 6 (solid and overlays), nickel-chromium-boron alloys (solid and overlays), hardened 440C stainless steel, hardened 17-4 stainless steel, and hardened 410/416 stainless steel.

Because the standard materials used in valve bodies are relatively soft, selection for cavitation and flashing resistance must rely upon factors other than hardness. In general, as the chromium and molybdenum contents increase, the resistance to damage by both cavitation and flashing increase. Thus, the chromium-molybdenum alloy steels have

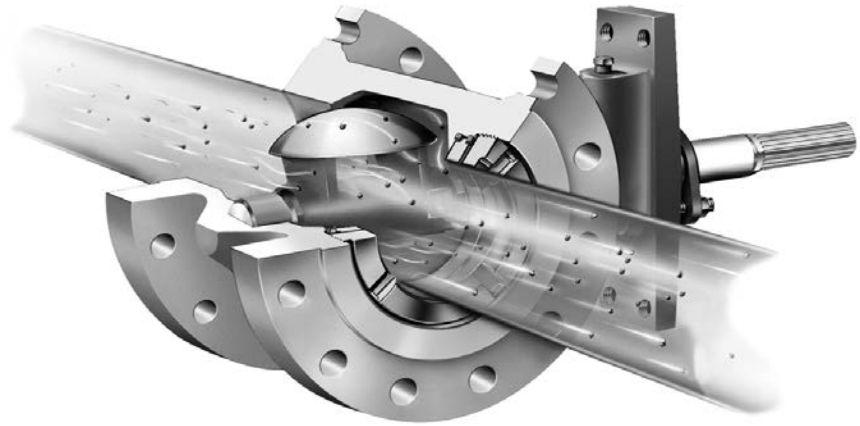

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***Figure 4-10**. Rotary plug valves, such as the V500 Vee-Ball valve(reverse flow trim direction, trim level 3) have excellent erosion resistance and perform well in flashing service*

better resistance than the carbon steels, and the stainless steels have even better resistance than the chromium-molybdenum alloy steels.

In the past, ASME SA217 grade C5 was the most commonly specified chromium-molybdenum alloy steel. However, because of the poor casting, welding, and manufacturing characteristics of C5, ASME SA217 grade WC9 has become a more popular alternative. Experience indicates that WC9 performs on par with C5 in cavitation and flashing services despite its lower chromium content (2-1/4% vs. 5%). This is apparently because its higher molybdenum content (1% vs. 1/2%) makes up for the lower chromium content.

ASTM A217 grade C12A is becoming more common in the power industry. This material has excellent high temperature properties, and is typically used at temperatures exceeding 1000°F (538°C). Its higher chromium and molybdenum contents (9% Cr, 1% Mo) would indicate excellent cavitation resistance.

While angle bodies are a better choice for flashing applications than globe bodies, they are also a more economical choice in most cases. This is because carbon steel bodies can be used in an angle valve with an optional hardened downstream liner (17-4PH SST or alloy 6) because only the downstream portion of the valve will experience the flashing liquid (see figure 4-9). If a globe valve is used, it is better to use a chromium-molybdenum alloy steel body because the flashing will occur within the body itself.

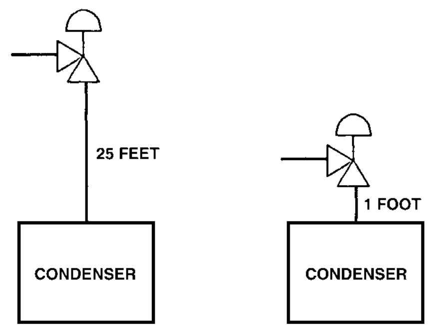

***Figure 4-11**. Location of a control valve can often be changed to lengthen its life or allow use of less expensive products. Mounting a heater drain valve near the condenser is a good example.*

System Design

This section discusses system design where it is assumed flashing will occur. The optimum position of the valve in a flashing service can have a great impact on the success of that valve installation.

Figure 4-11 shows the same application with the exception of the location of the control valve. These figures are fairly representative of a valve that controls flow to a condenser. In the top illustration, the flashing will occur in the downstream pipe between the control valve and the tank. Any damage that occurs will do so in that downstream piping area. In the bottom illustration, the flashing will occur downstream of the valve within the tank.

Because the tank has a much larger volume compared to the pipe, high velocity fluid impingement on a material surface will not occur as there is essentially no material surface. This system design will help prevent flashing damage.

Hardware Choices for Cavitating Applications

The design of a control valve greatly affects the ability of a valve to control cavitation. This section discusses the theories behind each type of trim design that is used for cavitation control and also reviews each type of Fisher trim used to control cavitation.

The design theories or ideas behind the various trim designs include:

- Tortuous path
- Pressure drop staging
- Expanding flow area
- Drilled hole design
- Characterized cage
- Separation of seating and throttling locations
- Cavitation control in lieu of prevention

Tortuous Path

Providing a tortuous path for the fluid through the trim is one way to lower the amount of pressure recovery of that trim. Although this tortuous path can be in the form of drilled holes, axial flow passages or radial flow passages, the effect of each design is essentially the same. The use of a tortuous path design concept is used in virtually every cavitation control style of hardware.

Pressure Drop Staging

This approach to damage control routes flow through several restrictions in series, as opposed to a single restriction. Each restriction dissipates a certain amount of available energy and presents a lower inlet pressure to the next stage.

A well-designed pressure-staging device will be able to take a large pressure differential while maintaining the vena contracta pressure above the vapor pressure of the liquid, which prevents the liquid from cavitating.

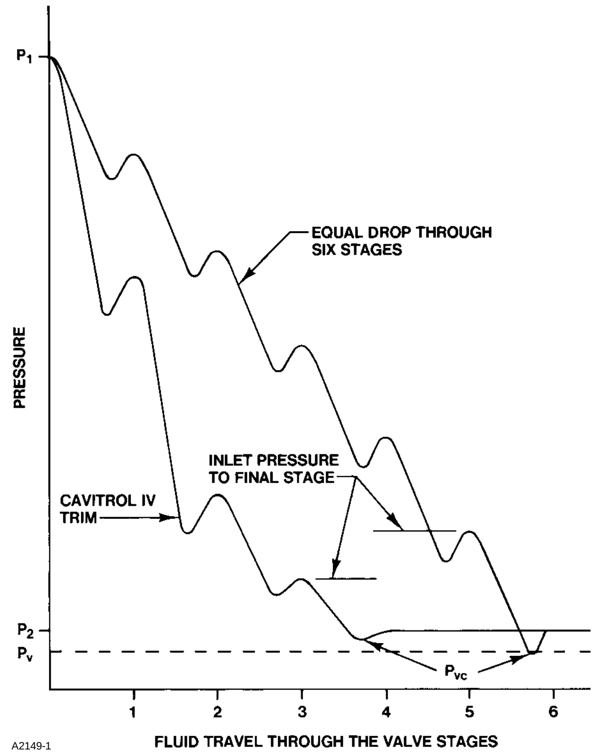

Figure 4-12. *In Cavitrol trim, the pressure drop is staged in two or more unequal steps. Staging is accomplished by increasing the flow area from stage to stage. This stepped reduction allows full pressure drop without the vena contracta pressure falling below the vapor pressure of the liquid.*

For the same pressure differential then, the vena contracta pressure in conventional trim will be lower than for the staged trim, and the liquid will be more prone to cavitate.

Trims that dissipate available energy have an additional advantage. If the design pressure differential is exceeded and cavitation does occur, the intensity will be less. This is because the pressure that causes the collapse of cavities (i.e., the recovered pressure) will be less.

Expanding Flow Areas

The expanding flow area concept of damage control is closely related to the pressure drop staging concept. Figure 4-12 shows a pressure versus distance curve for flow through a series of fixed restrictions where the area of each succeeding restriction is larger than the previous. Notice that the first restriction takes the bulk of the pressure drop, and the pressure drop through successive sections decreases.

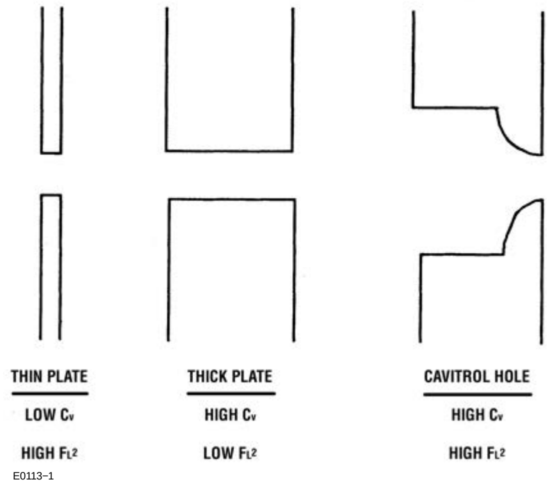

Figure 4-13. *By combining the geometric effects of thick plates and thin plates, it is possible to design a flow passage that optimizes capacity and recovery coefficient values. These carefully designed passages are used exclusively in Cavitrol cages.*

In the last restriction, where cavitation is most likely to occur, the pressure drop is only a small percentage of the total drop, and the pressure recovery is substantially lowered.

The expanding flow area concept requires fewer pressure drop stages to provide the same cavitation protection as the equal area concept. Because the pressure drop of the last stage is rather low compared to the total pressure drop, if cavitation does occur, the intensity and cavitation damage will be much less.

Drilled Hole Design

Drilled hole cages are used in the Fisher Cavitrol™ cavitation control trim line to provide a tortuous path, pressure drop staging, and expanding flow area. The design of each particular drilled hole has a significant impact on the overall pressure recovery of the valve design.

Figure 4-13 illustrates a cross section of three types of drilled holes that could be used in a cavitation control cage. The thin plate design is an inefficient flow device, but it does provide a high F_L^2 and, therefore, a low pressure recovery. The thick plate design provides an efficient design, but also provides a high pressure recovery as denoted by a low F_L^2 value.

The Cavitrol trim hole design is a balance between the thick plate and the thin plate hole designs. It provides relatively high flow efficiency while maintaining a high F_L^2, which results in a low pressure recovery. This design represents the optimal choice between capacity and cavitation control.

Another benefit of this type of drilled hole design is that the vena contracta point is further from the exit of the hole when compared to a straight through drilled hole. Consequently, if pressure recovery above the vapor pressure occurs (cavitation), it will do so further away from the external wall of the cage, and the amount of damage will be smaller.

One disadvantage of cavitation control trims is the potential for flow passages to become plugged with sand, dirt or other debris. Particulate laden flow is common to water injection applications. The flowing media often times contains small particulate that can plug the passages, restricting or totally stopping flow through the valve. If this potential exists, the particles must be removed from the flow stream, usually by filtration or an alternative approach to cavitation should be taken.

An alternative is to use a trim that is designed to allow the particulate to pass, but still control cavitation. The Fisher Dirty Service Trim (DST) has been designed to allow particles up to 3/4” to be passed and to control cavitation up to pressure drops of 4000 psi. This trim has been used extensively in produced water injection, water injection pump recirculation, and other liquid flow, particulate containing, high pressure drop applications.

Characterized Cage

The characterized cage design theory has evolved from the fact that “capacity is inversely related to a design’s ability to prevent cavitation.” In those applications where the pressure drop decreases as the flow rate increases, characterized cages can be used to optimize cavitation prevention and capacity.

For a Cavitrol III trim design, as the travel increases, the cage design changes. It begins as a pressure-staging design and then develops into a straight-through hole design. Consequently, the cavitation control ability of this trim design is greatest at low travels and decreases with increasing valve plug travel.

Care should be taken to employ characterized cages only in applications where the pressure drop decreases as travel increases.

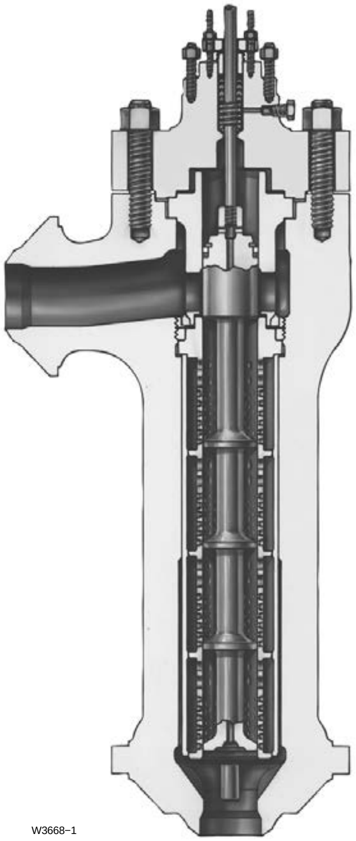

Figure 4-14. *Cavitrol IV trim provides cavitation protection at pressures to 6500 psi. It uses expanding flow areas to affect a four-stage pressure drop. All significant pressure drop is taken downstream of the shutoff seating surface.*

Separate Seating and Throttling Locations

In a modern power plant, most cavitating applications require a control valve to not only provide cavitation control, but also provide tight shutoff. The best way to accomplish this is to separate the throttling location from the seating location as shown in figure 4-14. The seating surface of the plug is upstream of the throttling location, and the upper cage is designed such that it takes very little pressure drop. The seating surface experiences relatively low flow velocities as velocity is inversely related to pressure. A recent technological advancement has been to implement the use of a softer seating material relative to the material of the plug. This allows for a slight deformation of the seating material, which provides much better plug/seat contact and, as a result, greatly enhanced shutoff capability. Valves utilizing this soft seating material are capable of providing Class VI shutoff.

Cavitation Control Hardware Alternatives

In the previous sections, theories behind modern types of cavitation control hardware were discussed. This section presents alternatives to the, sometimes, costly cavitation hardware. Guidelines are also presented to help determine when cavitation control hardware is required or when other alternatives can be employed.

System Design

Correct liquid system design is the most economical way to prevent the damaging effects caused by cavitation without applying cavitation prevention control valves. Unfortunately, even the best system design is likely to need cavitation type control valves, but by applying certain design features, the complexity of these control valves may be simplified.

The most common and oldest method of designing a liquid flow system where large pressure drops must occur is to use a standard trim control valve with a downstream backpressure device. Although these devices come in various sizes, shapes, and designs, they all perform the same function of lowering the pressure drop across the control valve by raising its downstream pressure.

Because the downstream pressure of the valve is increased, the vena contracta pressure is increased. If the backpressure device is sized correctly, the vena contract pressure will not fall below the vapor pressure, and cavitation will not occur.

While this is a simple and cost-effective way to prevent cavitation damage in the control valve, there are several serious considerations to look at before using a downstream backpressure device.

- A larger valve may be required to pass the required flow as the pressure drop is lowered.
- Although cavitation may not occur at the control valve, it may occur at the backpressure device.
- The backpressure device can only be sized for one condition. If other conditions exist, the

backpressure provided may allow cavitation to occur.

- If the backpressure device becomes worn, the backpressure will decrease and cavitation in the valve may occur.

Another disadvantage that is rarely mentioned occurs when a valve is opened against a high upstream pressure. Until the flow reaches the backpressure device and stabilizes, the valve will experience the entire pressure drop of the system. Although this may only occur for a short period of time, the potential for damage exists.

In the instance of rotary valves, air injection (known as aspiration) also can be used to minimize the effects of cavitation in a system. With this method, air is injected upstream of the vena contracta. The dispersed air acts as a buffer when the vapor bubbles implode so that the intensity of the cavitation is lowered. Unfortunately, the location of the vena contracta, the amount of air to be injected, etc. are hard to quantify.

Because air is being injected into the system, this method of cavitation control is usually used on large valves dumping to a tank or pond or where solids in the system prevent the use of other cavitation control devices.

Cavitation is an interesting but destructive phenomenon. Preventing cavitation is the most acceptable way of limiting potential for damage. Proper application of available products, based upon sizing equations and field experience, will provide long term success.

Summary

The past two chapters have indicated that a fundamental relationship exists between key variables (P_1, P_2, P_v, G, C_v, Q) for flow through a device such as a control valve. Knowledge of any four of these allows the fifth to be calculated or predicted. Furthermore, adjustments to this basic relationship are necessary to account for special considerations such as installed piping configuration, cavitation, flashing, choked flow, and viscous flow behavior. Adherence to these guidelines will ensure correct sizing and optimum performance.

It is important to understand that pulp stock flow exhibits characterizations that closely resemble those of water. Guidelines for hindering the effects of cavitation are based upon process testing using water. One must consider that a pulp stock multi-phase flow may result in less severe damage when compared to that of water for flashing, cavitation, or turbulent flow. However, it must be noted that pulp stock can lead to other issues such as erosion and corrosion, depending on process make-up and the materials used in the process. Therefore, it is important to understand the process media, as well as firm process conditions, in order to ensure the correct valve is properly sized and selected for the given severe service application.

As noted throughout the chapter, it is evident that severe flow phenomena through a control valve can occur under the proper conditions. In general, the most common liquid severe service applications involve either cavitation or flashing. It is important to have a basic understanding of both liquid service incidents as presented in this chapter.

Chapter 5

Gas Sizing

This chapter addresses the six-step procedure for sizing control valves for compressible flow using the standardized ISA procedure. All six steps are outlined below, and must be accounted for when sizing a valve for compressible flow. Steps three and four are involved in determining specific sizing factors that may or may not be required in the sizing equation depending on the service conditions of the application. When steps three and/or four are required, refer to the appropriate section of the book referenced below.

Standardized ISA Procedure

1. Specify the necessary variables required to size the valve as follows:

- Desired valve design (globe, butterfly, ball)
- Process fluid (air, natural gas, steam, etc.)
- Appropriate service conditions (q, or w, P_1, P_2 or ΔP, T_1, G_g, M, k, Z, and γ_1)

The ability to recognize the appropriate terms for a specific valve sizing application is gained through experience sizing valves for different applications. Refer to the notations table in chapter three for any new or unfamiliar terms.

2. Determine the equation constant, N.

N is a numerical constant contained in each of the flow equations to provide a means for using different systems of units. Values for these various constants and their applicable units are given in the equation constants table 5-2 at the end of this chapter.

Use N_7 or N_9 when sizing a valve with a specified flow rate in volumetric units (scfh or m^3/h). Selecting the appropriate constant depends upon the specified service conditions. N_7 is used only when specific gravity, G_g, has been specified along with the other required service conditions. N_9 is used only when the molecular weight, M, of the gas has been specified.

Use N_6 or N_8 when sizing a valve with a specified flow rate in mass units (lb/h or kg/h). In this case, N_6 is used only when specific weight, γ_1, has been specified along with the other required service conditions. N_8 is used only when the molecular weight, M, of the gas has been specified.

3. Determine F_p, the piping geometry factor.

F_p is a correction factor that accounts for any pressure losses due to piping fittings such as reducers, elbows, or tees that might be attached directly to the inlet and outlet connections of the control valve. If such fittings are attached to the valve, the F_p factor must be considered in the sizing procedure. If no fittings are attached to the valve, F_p has a value of one and drops out of the sizing equation.

For rotary valves with reducers, other valve designs and fitting styles refer to the determining piping geometry section of chapter three to determine the appropriate F_p value.

4. Determine Y, the expansion factor.

$$Y = 1 - \frac{x}{3F_k\ x_T}$$

where,

F_k = k/1.4, the ratio of specific heats factor

k = Ratio of specific heats

x = $\Delta P/P_1$

x_T = The pressure drop ratio factor for valves installed without attached fittings. More definitively, x_T is the pressure drop ratio required to produce critical, or maximum, flow through the valve when $F_k = 1.0$

When the control valve to be installed has fittings, such as reducers or elbows attached to it, their effect is accounted for in the expansion factor equation by replacing the x_T term with a new factor x_{TP}. A procedure for determining the x_{TP} factor is described in the following section: Determining x_{TP}, the Pressure Drop Ratio Factor.

> **Note: Conditions of critical pressure drop are realized when the value of x becomes equal to or exceeds the appropriate value of the product of either F_k*x_T or F_k*x_{TP} at which point::**

$$y = 1 - \frac{x}{3F_k\ x_T} = 1 - 1/3 = 0.667$$

In actual service, pressure drop ratios can, and often will exceed the indicated critical values. At this point, critical flow conditions develop. Thus, for a constant P_1, decreasing P_2 (i.e., increasing ΔP) will not result in an increase in the flow rate through the valve. Therefore, the values of x greater than the product of either F_k*x_T or F_k*x_{TP} must never be substituted in the expression for Y. This means that Y can never be less than 0.667. This same limit on values of x also applies to the flow equations introduced in the next section.

5. Solve for the required C_V using the appropriate equation.

For volumetric flow rate units —

- when specific gravity, G_g, of the gas has been specified:

$$C_v = \frac{q}{N_7\ F_p\ P_1\ Y\sqrt{\frac{x}{G_g\ T_1\ Z}}}$$

- when molecular weight, M, of the gas has been specified:

$$C_v = \frac{q}{N_9\ F_p\ P_1\ Y\sqrt{\frac{x}{M\ T_1\ Z}}}$$

For mass flow rate units —

- when specific weight, γ_1, of the gas has been specified:

$$C_v = \frac{w}{N_6 F_p Y\sqrt{x\ P_1\ \gamma_1}}$$

- when molecular weight, M, of the gas has been specified:

$$C_v = \frac{M}{N_8\ F_p\ P_1\ Y\sqrt{\frac{x\ M}{T_1\ Z}}}$$

6. Select the valve size using the appropriate flow coefficient table using the calculated C_V value.

Determining x_{TP}, the Pressure Drop Ratio Factor

When the control valve is to be installed with attached fittings such as reducers or elbows, their affect is accounted for in the expansion factor equation by replacing the x_T term with a new factor, x_{TP}.

$$x_{TP} = \frac{x_T}{F_p{}^2}\left[1 + \frac{x_T\ K_i}{N_5}\left(\frac{C_v}{d^2}\right)^2\right]^{-1}$$

where,

N_5 = numerical constant found in the equation constants table

d = assumed nominal valve size

C_V = valve sizing coefficient from flow coefficient table at 100% travel for the assumed valve size

F_p = piping geometry factor

x_T = pressure drop ratio for valves installed without fittings attached. x_T values are included in the flow coefficient tables.

In the above equation, K_i is the inlet head loss coefficient, which is defined as:

$$K_i = K_1 + K_{B1}$$

where,

K_1 = resistance coefficient of upstream fittings (see the procedure: *Determining F_p, the Piping Geometry Factor,* which is contained in Chapter 3: Liquid Valve Sizing

K_{B1} = Inlet Bernoulli coefficient (see the procedure: *Determining F_p, the Piping Geometry Factor,* which is contained in chapter three: Liquid Valve Sizing

Compressible Fluid Sizing Sample Problem No. 1

Assume steam is to be supplied to a process designed to operate at 250 psig. The supply source is a header maintained at 500 psig and 500°F. A 6-inch line from the steam main to the process is being planned. Also, make the assumption that if the required valve size is less than 6 inches, it will be installed using concentric reducers. Determine the appropriate ED valve with a linear cage.

1. Specify the necessary variables required to size the valve.

- Desired valve design—ANSI Class 300 ED valve with a linear cage. Assume valve size is 4 inches.
- Process fluid—superheated steam
- Service conditions—

w = 125,000 lb/h

P_1 = 500 psig = 514.7 psia

P_2 = 250 psig = 264.7 psia

ΔP = 250 psi

$x = \Delta P/P_1$ = 250/514.7 = 0.49

T_1 = 500°F

γ_1 = 1.0434 lb/ft^3 (from properties of saturated steam table)

k= 1.28 (from properties of saturated steam table)

2. Determine the appropriate equation constant, N, from the equation constants table 3-2 in chapter three.

Because the specified flow rate is in mass units, (lb/h), and the specific weight of the steam is also specified, the only sizing equation that can be used is that which contains the N_6 constant.

Therefore, N_6 = 63.3

3. Determine F_p, the piping geometry factor.

$$F_p = \left[1 + \frac{\Sigma K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right]^{-1/2}$$

where,

N_2 = 890, determined from the equation constants table

d = 4 in.

C_v = 236, which is the value listed in the flow coefficient table 4-2 for a NPS 4 ED valve at 100% total travel.

and

$$\begin{aligned}\Sigma K &= K_1 + K_2\\ &= 1.5\left(1 - \frac{d^2}{D^2}\right)^2\\ &= 1.5\left(1 - \frac{4^2}{6^2}\right)^2\\ &= 0.463\end{aligned}$$

Finally:

$$F_p = \left[1 + \frac{0.463}{890}\left(\frac{(1.0)(236)}{(4)^2}\right)^2\right]^{-1/2}$$

$$= 0.95$$

4. Determine Y, the expansion factor.

$$Y = 1 - \frac{x}{3F_k\ x_{TP}}$$

where,

$$\begin{aligned}F_k &= \frac{k}{1.40}\\ &= \frac{1.28}{1.40}\\ &= 0.91\end{aligned}$$

$$x = 0.49\ (\textit{As calculated in step } 1.)$$

Because the size 4 valve is to be installed in a 6-inch line, the x_T term must be replaced by x_{TP}.

$$x_{TP} = \frac{x_T}{F_p{}^2}\left[1 + \frac{x_T\ K_i}{N_5}\left(\frac{C_v}{d^2}\right)^2\right]^{-1}$$

where,

N_5 = 1000, from the equation constants table

d = 4 inches

F_p = 0.95, determined in step three

x_T = 0.688, a value determined from the appropriate listing in the flow coefficient table

C_V = 236, from step three

and

$$K_i = K_1 + K_{B1}$$

$$= 0.5\left(1 - \frac{d^2}{D^2}\right)^2 + \left[1 - \left(\frac{d}{D}\right)^4\right]$$

$$= 0.5\left(1 - \frac{4^2}{6^2}\right)^2 + \left[1 - \left(\frac{4}{6}\right)^4\right]$$

$$= 0.96$$

where D = 6 inches

so:

$$X_{TP} = \frac{0.69}{0.95^2}\left[1 + \frac{(0.69)(0.96)}{1000}\left(\frac{236}{4^2}\right)^2\right]^{-1} = 0.67$$

Finally:

$$Y = 1 - \frac{x}{3\ F_k\ x_{TP}}$$

$$= 1 - \frac{0.49}{(3)\ (0.91)\ (0.67)} = 0.73$$

Table 5-1. *Abbreviations and Terminology*

Symbol		Symbol	
C_v	Valve sizing coefficient	P_1	Upstream absolute static pressure
d	Nominal valve size	P_2	Downstream absolute static pressure
D	Internal diameter of the piping	P_c	Absolute thermodynamic critical pressure
F_d	Valve style modifier, dimensionless	P_v	Vapor pressure absolute of liquid at inlet temperature
F_F	Liquid critical pressure ratio factor, dimensionless	ΔP	Pressure drop (P_1-P_2) across the valve
F_k	Ratio of specific heats factor, dimensionless	$\Delta P_{max(L)}$	Maximum allowable liquid sizing pressure drop
F_L	Rated liquid pressure recovery factor, dimensionless	$\Delta P_{max(LP)}$	Maximum allowable sizing pressure drop with attached fittings
F_{LP}	Combined liquid pressure recovery factor and piping geometry factor of valve with attached fittings (when there are no attached fittings, F_{LP} equals F_L), dimensionless	q	Volume rate of flow
F_P	Piping geometry factor, dimensionless	q_{max}	Maximum flow rate (choked flow conditions) at given upstream conditions
G_f	Liquid specific gravity (ratio of density of liquid at flowing temperature to density of water at 60°F), dimensionless	T_1	Absolute upstream temperature (degree K or degree R)
G_g	Gas specific gravity (ratio of density of flowing gas to density of air with both at standard conditions[1], i.e., ratio of molecular weight of gas to molecular weight of air), dimensionless	w	Mass rate of flow
k	Ratio of specific heats, dimensionless	x	Ratio of pressure drop to upstream absolute static pressure ($\Delta P/P_1$), dimensionless
K	Head loss coefficient of a device, dimensionless	x_T	Rated pressure drop ratio factor, dimensionless
M	Molecular weight, dimensionless	Y	Expansion factor (ratio of flow coefficient for a gas to that for a liquid at the same Reynolds number), dimensionless
N	Numerical constant	Z	Compressibility factor, dimensionless
		γ_1	Specific weight at inlet conditions
		υ	Kinematic viscosity, centistokes

1. Standard conditions are defined as 60°F (15.5°C) and 14.7 psia (101.3kPa).

Table 5-2. *Equation Constants(1)*

		N	w	q	p(2)	γ	T	d, D
N_1		0.0865	- - -	m^3/h	kPa	- - -	- - -	- - -
		0.865	- - -	m^3/h	bar	- - -	- - -	- - -
		1.00	- - -	gpm	psia	- - -	- - -	- - -
N_2		0.00214	- - -	- - -	- - -	- - -	- - -	mm
		890	- - -	- - -	- - -	- - -	- - -	inch
N_5		0.00241	- - -	- - -	- - -	- - -	- - -	mm
		1000	- - -	- - -	- - -	- - -	- - -	inch
N_6		2.73	kg/h	- - -	kPa	kg/m^3	- - -	- - -
		27.3	kg/h	- - -	bar	kg/m^3	- - -	- - -
		63.3	lb/h	- - -	psia	lb/ft^3	- - -	- - -
N_7(3)	Normal Conditions $T_N = 0°C$	3.94	- - -	m^3/h	kPa	- - -	deg K	- - -
		394	- - -	m^3/h	bar	- - -	deg K	- - -
	Standard Conditions $T_s = 15.5°C$	4.17	- - -	m^3/h	kPa	- - -	deg K	- - -
		417	- - -	m^3/h	bar	- - -	deg K	- - -
	Standard Conditions $T_s = 60°F$	1360	- - -	scfh	psia	- - -	deg R	- - -
N_8		0.948	kg/h	- - -	kPa	- - -	deg K	- - -
		94.8	kg/h	- - -	bar	- - -	deg K	- - -
		19.3	lb/h	- - -	psia	- - -	deg R	- - -
N_9(3)	Normal Conditions $T_N = 0°C$	21.2	- - -	m^3/h	kPa	- - -	deg K	- - -
		2120	- - -	m^3/h	bar	- - -	deg K	- - -
	Standard Conditions Ts = 15.5°C	22.4	- - -	m^3/h	kPa	- - -	deg K	- - -
		2240	- - -	m^3/h	bar	- - -	deg K	- - -
	Standard Conditions $T_S = 60°F$	7320	- - -	scfh	psia	- - -	deg R	- - -

1. Many of the equations used in these sizing procedures contain a numerical constant, N, along with a numerical subscript. These numerical constants provide a means for using different units in the equations. Values for the various constants and the applicable units are given in the above table. For example, if the flow rate is given in U.S. gpm and the pressures are psia, N_1 has a value of 1.00. If the flow rate is m^3/hr and the pressures are kPa, the N_1 constant becomes 0.0865.
2. All pressures are absolute.
3. Pressure base is 101.3 kPa (1.013 bar)(14.7 psia).

Table 5-3. *Flow Coefficient Table*

Gas or Liquid Flow

Modified Equal Percentage Characteristic

Valve Size, Inches	Minimum Throttling C_V[1]	Coefficients	Valve Rotation, Degrees								
			10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
8	86.7	C_V	47.3	126	236	382	604	972	1600	3000	4960
		K_V	40.9	109	204	330	522	841	1380	2600	4290
		F_L	0.79	0.87	0.91	0.91	0.85	0.81	0.73	0.63	0.63
		F_d	0.37	0.64	0.78	0.88	0.94	0.97	0.98	0.99	1.00
		X_T	0.44	0.64	0.77	0.77	0.67	0.51	0.38	0.20	0.13
10	136	C_V	74.1	197	369	598	946	1520	2510	4700	7770
		K_V	64.1	171	320	517	818	1320	2170	4060	6720
		F_L	0.79	0.87	0.91	0.91	0.85	0.81	0.73	0.63	0.63
		F_d	0.37	0.64	0.78	0.87	0.94	0.97	0.99	0.99	1.00
		X_T	0.44	0.64	0.77	0.77	0.67	0.51	0.38	0.20	0.13
12	196	C_V	107	284	532	861	1360	2190	3610	6760	11 200
		K_V	92.2	246	460	745	1180	1890	3120	5850	9670
		F_L	0.79	0.87	0.91	0.91	0.85	0.81	0.73	0.63	0.63
		F_d	0.39	0.67	0.79	0.87	0.93	0.97	0.99	1.00	1.00
		X_T	0.44	0.64	0.77	0.77	0.67	0.51	0.38	0.20	0.13
16	347	C_V	189	505	945	1530	2420	3890	6410	12 000	19 900
		K_V	164	437	818	1320	2090	3370	5540	10 400	17 200
		F_d	0.38	0.64	0.79	0.87	0.93	0.97	0.99	0.99	1.00
		F_L	0.79	0.87	0.91	0.91	0.85	0.81	0.73	0.63	0.63
		X_T	0.44	0.64	0.77	0.77	0.67	0.51	0.38	0.20	0.13
20	542	C_V	296	788	1480	2390	3780	6080	10 000	18 800	31 000
		K_V	256	681	1280	2070	3270	5260	8660	16 200	26 800
		F_d	0.42	0.66	0.79	0.87	0.93	0.97	0.99	1.00	1.00
		F_L	0.79	0.87	0.91	0.91	0.85	0.81	0.73	0.63	0.63
		X_T	0.44	0.63	0.76	0.76	0.66	0.50	0.38	0.20	0.13

1. Valves should not be required to throttle at a Cv less than the minimum throttling Cv.

Table 5-4. *Representative Sizing Coefficients for ED Single-Ported Globe Style Valve Bodies*

Valve Size (inches)	Valve Plug Style	Flow Characteristic	Port Dia. (in.)	Rated Travel (in.)	C_V	F_L	X_T	F_D
1/2	Post Guided	Equal Percentage	0.38	0.50	2.41	0.90	0.54	0.61
3/4	Post Guided	Equal Percentage	0.56	0.50	5.92	0.84	0.61	0.61
1	Micro Form	Equal Percentage	3/8	3/4	3.07	0.89	0.66	0.72
			1/2	3/4	4.91	0.93	0.80	0.67
			3/4	3/4	8.84	0.97	0.92	0.62
	Cage Guided	Linear	1 5/16	3/4	20.6	0.84	0.64	0.34
		Equal Percentage	1 5/16	3/4	17.2	0.88	0.67	0.38
1 1/2	Micro-Form	Equal Percentage	3/8	3/4	3.20	0.84	0.65	0.72
			1/2	3/4	5.18	0.91	0.71	0.67
			3/4	3/4	10.2	0.92	0.80	0.62
	Cage Guided	Linear	1 7/8	3/4	39.2	0.82	0.66	0.34
		Equal Percentage	1 7/8	3/4	35.8	0.84	0.68	0.38
2	Cage Guided	Linear	2 5/16	1 1/8	72.9	0.77	0.64	0.33
		Equal Percentage	2 5/16	1 1/8	59.7	0.85	0.69	0.31
3	Cage Guided	Linear	3 7/16	1 1/2	148	0.82	0.62	0.30
		Equal Percentage			136	0.82	0.68	0.32
4	Cage Guided	Linear	4 3/8	2	236	0.82	0.69	0.28
		Equal Percentage			224	0.82	0.72	0.28
6	Cage Guided	Linear	7	2	433	0.84	0.74	0.28
		Equal Percentage			394	0.85	0.78	0.26
8	Cage Guided	Linear	8	3	846	0.87	0.81	0.31
		Equal Percentage			818	0.86	0.81	0.26

Chapter 6

Control Valve Noise

Noise has always been present in control valves. It is a natural side effect of the turbulence and energy absorption inherent in control valves. This chapter will address how noise is created, why it can be a problem, and methods to attenuate noise created in control valves.

The major problem with industrial noise is its affect on humans. Companies usually build town border stations on sites remote from residential developments. Isolation, however, is not always possible, and noise prevention is a must.

The U.S. Occupational Safety and Health Act (OSHA) establishes maximum permissible noise levels for all industries whose business affects interstate commerce. These standards relate allowable noise levels to the permissible exposure time. Notice in table 6-1 that the maximum permissible levels depend upon the duration of exposure. For example, the maximum sound level a person should be exposed to for an eight hour day is 90 dBA. These maximum sound levels have become the accepted noise exposure standard for most regulatory agencies. Thus, they have become the standard by which much noise generating equipment has been specified and measured.

Table 6-1. *Maximum Permissible Noise Levels*

Duration of Exposure (Hours)	Maximum Sound Pressure (dBA)
16	85
8	90
4	95
2	100
1	105
1/2	110
1/4	115

Decibels (dB) are a measure to give an indication of loudness. The “A” added to the term indicates the correction accounting for the response of the human ear. The sensitivity of our ears to sound varies at different frequencies. Applying this “A” correction is called weighting, and the corrected noise level is given in dBA.

The A-weighting factor at any frequency is determined by how loud noise sounds to the human ear at that particular frequency compared to the apparent loudness of sound at 1000 hertz. At 1000 hertz the A-weighting factor is zero, so if the sound pressure level is 105 dB, we say it sounds like 105 dB.

On the other hand, if we listen to a sound at 200 hertz with a sound pressure level of 115 dB, it sounds more like 105 dB. Therefore, we say that the A-weighted loudness of the noise with a sound pressure level of 115 dB is 105 dBA.

Essentially, if two or more sounds with different sound pressure levels and frequencies sound like the same loudness, they have the same dBA, regardless of what their individual, unweighted sound pressure levels may be.

The effect of A-weighting on control valve noise depends upon the flowing medium since each develops its own characteristic spectrum. Noise levels for hydrodynamic noise, or liquid flow noise, have appreciable energy at frequencies below 600 hertz. When the levels are A-weighted, it makes the low frequency terms more meaningful and the government standards somewhat more difficult to meet.

On the other hand, aerodynamic noise levels produced by steam or gas flow are the same in either dB or dBA. This is because aerodynamic noise occurs primarily in the 1000 to 8000 hertz frequency range. The human ear has a fairly flat response in the frequency range of 600 to 10,000 hertz, and the A-weighting factor is essentially zero in this range. Thus, there is negligible difference between the dB and dBA ratings.

Sound Characteristics

Analyzing noise, in the context of piping and control valves, requires consideration of its origin. This indicates how the noise will propagate. Generally speaking, noise originates from either a line source or a point source.

A sound level meter is used to determine sound pressure levels. Readings for line source noise levels are normally measured one meter from the pipe's surface and at a point one meter downstream from the valve outlet. Measurements should be made in an unobstructed free field area with no sound reflecting surfaces nearby.

Line source noise levels are radiated from the piping in the form of an imaginary cylinder, the pipe centerline as the axis. As you move away from the pipeline, the sound pressure level decreases inversely to the changes in surface area of the imaginary cylinder. The following equation defines the sound pressure level (L_pA) at distances other than one meter from the pipeline surface:

$$L_pA = F + 10\log\frac{1 + r}{R + r}$$

where,

L_pA = sound pressure level
F = noise level at one meter from the pipe surface
r = pipe radius in meters based on the pipe outside diameter
R = distance in meters from the pipe surface

What this equation tells us is that the sound pressure level decreases dramatically as the distance from the pipeline increases. Keep in mind that this equation determines the noise level radiated only by the pipeline. Other noise sources could combine with the pipeline noise source to produce greater overall sound pressure level.

The other type of noise source needed to be discussed is point source. Point source noise measurements are taken at a three meter distance in the horizontal plane through the source. Vent applications are typical examples of point source noise. Point source noise levels are radiated in the form of an imaginary sphere with the source at the center of the sphere. As you move away from a point source, the sound pressure level decreases inversely in proportion to the changes in the surface area of the imaginary sphere. The equation that defines the sound pressure level at distances other than three meters from the point source and below a horizontal plane through the point source is:

$$L_pA = F + 20\log\frac{3}{R}$$

where,

L_pA = the sound pressure level
F = the noise level at three meters from the source
R = the distance in meters from the source

This procedure determines the noise level radiated only by the point source. Other noise sources could combine with the point source noise to produce a greater overall sound pressure level.

Combining Noise Sources

The noise level in a certain area is the result of combining all of the noise generated by every noise source in the vicinity. The methodology of combining sources is important to prediction and actually lies at the root of noise abatement technology.

To determine the resultant noise level of two noise sources, it is necessary to combine two sources of energy. The energy, or power, of two sources combines directly by addition. The power levels must be calculated separately and then logarithmically combined as one overall noise source. The sources can be line, point, or a combination of both. Table 6-2 simplifies the process of combining two known noise levels.

Table 6-2. Combined Noise Corrections

dBA_1 - dBA_2	dBA Adder to Loudest Noise Source
0	3.01
1	2.54
2	2.12
3	1.76
4	1.46
5	1.2
6	<1

To use table 6-2:
1. Determine the noise level of each source at the point where you want to determine the combined noise level.
2. Determine the arithmetic dB difference between the two sources at the location of interest.
3. Find the difference between the two sources in the table.
4. Read across the table to find the dB factor to be used. Add this factor to the louder of the two sources. This value is the combined dB of the two sources.

Let's put this table to work to illustrate how noise sources combine. Two interesting examples help illustrate how sound levels combine:

1. When two noise sources with equal sound pressure levels of 90 dB are combined, the correction factor is 3.01. Therefore, the resultant combined noise level is 93 dB.

2. If two sources have considerably different noise levels, say 95 dB and 65 dB, the correction factor is nearly zero. Therefore, the combined noise level is essentially the same as the louder of the two sources, that is, 95 dB. This leads us to the first rule of noise control: Preventing or controlling the loudest noise sources first.

While this appears obvious, in practice it is not the easiest path.

Sources of Valve Noise

Control valves have long been recognized as a contributor to excessive noise levels in many fluid process and transmission systems. The major sources of control valve noise are mechanical vibration noise, aerodynamic noise, and hydrodynamic noise.

Mechanical noise generally results from valve plug vibration. Vibration of valve components is a result of random pressure fluctuations within the valve body and/or fluid impingement upon the movable or flexible parts. The most prevalent source of noise resulting from mechanical vibration is the lateral movement of the valve plug relative to the guiding surfaces. The sound produced by this type of vibration normally has a frequency less than 1500 hertz and is often described as a metallic rattling. In these situations, the physical damage incurred by the valve plug and associated guiding surfaces is generally of more concern than the noise emitted.

Another source of mechanical vibration noise is resonant vibration, which occurs when a valve component resonates at its natural frequency. Resonant vibration produces a single-pitched tone normally having a frequency between 3000 and 7000 hertz. This type of vibration produces high levels of mechanical stress that may produce fatigue failure of the vibrating part. Valve components susceptible to natural frequency vibration include contoured valve plugs with hollow skirts and flexible seals.

The noise caused by the vibration of valve components is usually of secondary concern, and, ironically, may even be beneficial because it gives warning when conditions exist that could produce valve failure. Noise resulting from mechanical vibration has for the most part been eliminated by improved valve design. Most modern control valves employ cage guiding and more precise bearings to eliminate vibration problems. Testing helps isolate and eliminate resonant frequency problems before installation.

The second type of noise is hydrodynamic noise. Hydrodynamic noise results from liquid flow and is caused by the implosion of vapor bubbles formed in the cavitation process. Vapor bubble formation occurs in valves controlling liquids when the service conditions are such that the local static pressure, at some point within the valve, is less than or equal to the liquid vapor pressure. Localized areas of low static pressures within the valve are a result of the pressure-to-velocity-head interchange that occurs at the valve vena contracta. When the vapor bubbles move downstream, they encounter pressures higher than the vapor pressure and collapse. The rapid implosion can result in severe damage to adjacent valve or pipeline surfaces, and generate high noise levels.

Hydrodynamic noise sounds similar to that of gravel flowing through a pipe. Intense cavitation can cause noise levels as high as 115 dBA, but such cavitation would not be tolerated because cavitation damage would drastically shorten the operating life of the installation. Therefore, control valve damage is normally of more concern than the noise produced in cavitating services.

Aerodynamic noise is generated by the turbulence associated with control of gas, steam, or vapors. While generally thought of as accompanying high capacity, high pressure systems, damaging noise levels can be produced in a two-inch line with as little as a 200 psi pressure drop. Major sources of aerodynamic noise are the stresses or shear forces present in turbulent flow.

Some of the sources of turbulence in gas transmission lines are obstructions in the flow path, rapid expansion or deceleration of high-velocity gas, and directional changes in the fluid stream. Specific areas that are inherently noisy include headers, pressure regulators, line size expansions, and pipe elbows.

Aerodynamic noise is generally considered the primary source of control valve noise. There are several reasons for this:

- This type of noise has its highest energy components at the same frequencies where the human ear is most sensitive - between 1000 and 8000 hertz.

- Large amounts of energy can be converted to aerodynamic noise without damaging the valve. In the past, the noise was considered a nuisance, but as long as the valve did its job, it was not of major concern. Today, with increasing focus on environmental issues, including noise, there are guidelines on the amount of noise a valve can emit in a given workplace. Research has also shown that sustained noise levels above 110 decibels can produce mechanical damage to control valves.

High noise levels are an issue primarily because of OSHA's standards for permissible noise limits and the potential for control valve damage above 110 dBA. Additionally, loud hydrodynamic noise is symptomatic of the more dangerous and destructive phenomenon known as cavitation.

Noise Prediction

Industry leaders use the International Electrotechnical Commission standard IEC 534-8-3. This method consists of a mix of thermodynamic and aerodynamic theory and empirical information. This method allows noise prediction for a valve to be based only upon the measurable geometry of the valve and the service conditions applied to the valve. There is no need for specific empirical data for each valve design and size. Because of this pure analytical approach to valve noise prediction, the IEC method allows an objective evaluation of alternatives.

The method defines five basic steps to noise prediction:

1. Calculate the total stream power in the process at the vena contracta.

The noise of interest is generated by the valve in and downstream of the vena contracta. If the total power dissipated by throttling at the vena contracta can be calculated, then the fraction that is noise power can be determined. Because power is the time rate of energy, a form of the familiar equation for calculating kinetic energy can be used. The kinetic energy equation is:

$$E_k = 1/2mv^2$$

where,
m = mass
v = velocity

If the mass flow rate is substituted for the mass term, then the equation calculates the power. The velocity is the vena contracta velocity and is calculated with the energy equation of the first law of thermodynamics.

2. Determine the fraction of total power that is acoustic power.

This method considers the process conditions applied across the valve to determine the particular noise generating mechanism in the valve. There are five defined regimes dependent upon the relationship of the vena contracta pressure and the downstream pressure. For each of these regimes an acoustic efficiency is defined and calculated. This acoustic efficiency establishes the fraction of the total stream power, as calculated in step one, which is noise power. In designing a quiet valve, lower acoustic efficiency is one of the goals.

3. Convert acoustic power to sound pressure.

The final goal of the IEC prediction method is to determine the sound pressure level at a reference point outside the valve where human hearing is a concern. Step two delivers acoustic power, which is not directly measurable. Acoustic or sound pressure is measurable and, therefore, has become the default expression for noise in most situations. Converting from acoustic power to the sound pressure uses basic acoustic theory.

4. Account for the transmission loss of the pipe wall and restate the sound pressure at the outside surface of the pipe.

Steps one and three are involved with the noise generation process inside the pipe. There are times when this is the area of interest, but the noise levels on the outside of that pipe are the prime requirement. This method must account for the change in the noise as the reference location moves from inside the pipe to outside the pipe.

The pipe wall has physical characteristics, due to its material, size, and, shape, that define how well the noise will transmit through the pipe. The fluid-borne noise inside the pipe interacts with the inside pipe wall causing the pipe wall to vibrate, then the vibration transmits through the pipe wall to the outside pipe wall, and there the outside pipe wall interacts with the atmosphere to generate sound waves. These three steps of noise transmission are dependent upon the noise frequency. The method represents the frequency of the valve noise by determining the peak frequency of the valve noise spectrum. It also determines the pipe transmission loss as a function of frequency. The method then compares the internal noise spectrum to determine how much the external sound pressure will be attenuated by the pipe wall.

5. Account for distance and calculate the sound pressure level at the observer's location.

Step four delivers the external sound pressure level at the outside surface of the pipe wall. Again, basic acoustic theory is applied to calculate the sound pressure level at the observer's location. Sound power is constant for any given situation, but the associated sound pressure level varies with the area of distributed power. As the observer moves farther away from the pipe wall, the total area of distributed sound power increases. This causes the sound pressure level to decrease.

Methods to Attenuate Noise

With increasing interest in the environmental impact of all aspects of industry, there are increasing demands for noise abatement procedures and equipment.

In a closed system, (not vented to the atmosphere) noise becomes airborne only by transmission through the valves and adjacent piping that contains the flowstream. The sound field in the flowstream forces these solid boundaries to vibrate, causing disturbances in the surrounding air to propagate as sound waves.

Figure 6-1*. Whisper Trim I cage used for reducing aerodynamic noise*

Noise control techniques fall into one of two basic categories:

- Source treatment
- Path treatment

While preventing noise at the source is the preferred approach to noise control, it is sometimes economically or physically impractical due to particular application requirements. Path treatment is then a reasonable approach. There are also instances when source treatment alone does not provide sufficient noise reduction; path treatment is then used as a supplement.

In any event, the decision to use source treatment, path treatment, or a combination of both should be made only after the application requirements and alternative approaches have been thoroughly analyzed.

Source Treatment

The Fisher Whisper Trim™ I cage, illustrated in figure 6-1 , is interchangeable with standard trim in many globe valves. It uses many narrow parallel slots designed to minimize turbulence and provide a favorable velocity distribution in the expansion area of the valve. It provides a multitude of low noise flowpaths, which combine to produce less overall noise than standard cages. A Whisper Trim I cage is most efficient when the ratio of pressure drop to inlet pressure is equal to or less than 0.65 (that is, $\Delta P/P_1$ is less than or equal to 0.65). In addition, this approach is most effective when the maximum downstream velocity of the fluid is equal to or less than half the sonic velocity of that fluid. This style of cage will provide up to 18 dBA attenuation versus a standard cage with little sacrifice in flow capacity.

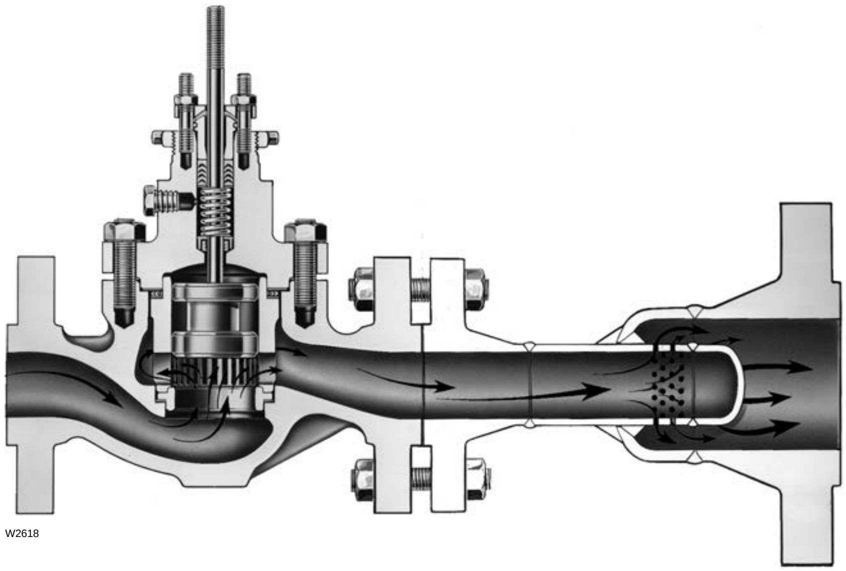

Figure 6-2*. Valve with Whisper Trim I and Inline Diffuser Combination*

When the pressure drop ratio exceeds 0.65, the Whisper Trim I cage loses its effectiveness. Diffusers, used in conjunction with the Whisper Trim I cage to divide the overall pressure drop into two stages, can extend the useful capability and also improve noise performance (figure 6-2). The diffuser provides a fixed restriction, which increases backpressure to the valve thereby reducing the pressure drop across the valve. This decreases the pressure drop ratio which in turn decreases the sound pressure level. The use of a diffuser allows the Whisper Trim I cage to remain within its most efficient P/P_1 range. Diffusers are only effective for the condition they are sized for. They are not effective in throttling applications. At this optimum condition they can provide up to an additional attenuation of 25 dBA.

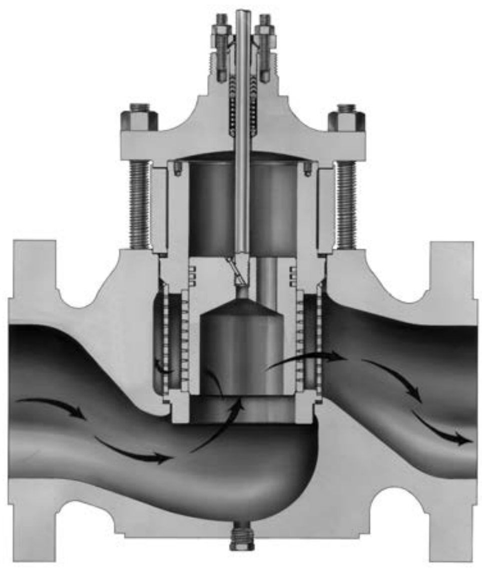

Figure 6-3*. Whisper Trim III*

When pressure drop ratios are high, a Whisper Trim III cage (figure 6-3) may be used. Fluid flows from the inside of the cage out through many orifices. The performance of these cages is closely tied to spacing of these orifices. As the pressure drop ratio increases, the centerline distance to hole diameter of these orifices also needs to increase to prevent jet recombination. Therefore, as the level of the Whisper Trim III cage increases, so does the centerline distance to hole diameter. For many applications involving high pressure drop ratios, a baffle is installed outside the cage. For very high pressure drop ratios a baffle is often used to act on the fluid jets exiting from the cage to further reduce turbulence. Cages similar to the Fisher Whisper Trim III cage can reduce control valve noise by as much as 30 dBA. These cages are most effective when the maximum downstream velocity of the fluid is equal to or less than 0.3 of the sonic velocity of that fluid.

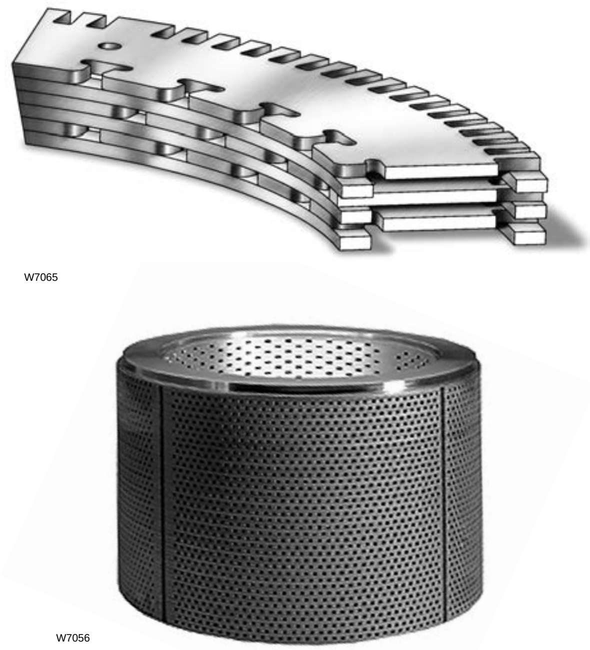

Figure 6-4. *WhisperFlo Technology*

Fisher WhisperFlo™ trim (figure 6-4) is well-suited for applications that have high noise levels and require large Cvs. It is effective in applications that have a pressure drop ratio up to 0.99. When a pressure drop ratio of .94 or higher is expected, and WhisperFlo is desired, the noise calculations will be performed by the engineering experts at Emerson Process Management. This design is a multi-path, two-stage design that has the capability of reducing noise up to 50 dBA. The key factor behind this attenuation is allowing the pressure to recover between stages. This allows for the pressure drop ratio of the second stage to be less than the pressure drop ratio of the first stage. In achieving this, along with special passage shapes, the frequency is shifted to a higher spectrum, velocities are managed, and the jets maintain independence.

All of the Whisper Trim cages and WhisperFlo trims are designed for sliding stem valves. In applications requiring rotary valves that have high noise, an attenuator, diffuser, or combination there of may be applied. Applications with ball valves can apply an attenuator to obtain up to 10 dBA reduction in noise. These attenuators are designed to reduce both aerodynamic and hydrodynamic noise. With butterfly valves you can only attenuate aerodynamic noise utilizing an inline diffuser. As mentioned above, these diffusers can provide up to a 25 dBA reduction in noise.

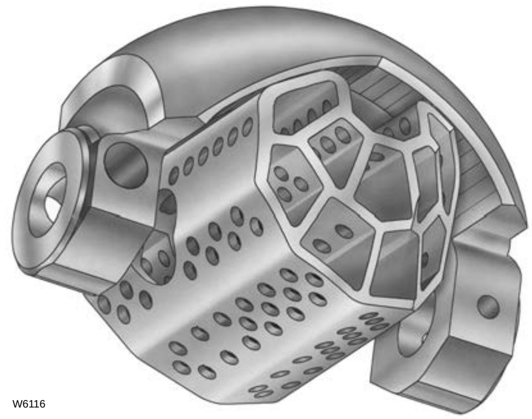

Figure 6-5. *Vee-Ball Noise Attenuator*

For control valve applications operating at high pressure ratios ($\Delta P/P_1$ is greater than 0.8), a series approach can be very effective in minimizing the noise. This approach splits the total pressure drop between the control valve and a fixed restriction (such as a diffuser) downstream of the valve. In order to optimize the effectiveness of the diffuser, it must be designed for each unique installation so that the noise levels generated by the valve and diffuser are equal.

Control systems venting to atmosphere are generally very noisy, as well. This is because of the high pressure ratios and high exit velocities involved. In these applications, a vent silencer may be used to divide the total pressure drop between the actual vent and an upstream control valve (figure 6-6). This approach quiets both the valve and the vent. A properly sized vent silencer and valve combination can reduce the overall system noise level by as much as 60 dBA.

Path Treatment

Path treatment can be applied where source treatment is more expensive, or in combination with source treatment where source treatment alone is inadequate. Path treatment consists of increasing the resistance of the transmission path to reduce the acoustic energy that is transmitted to the environment. Common path treatments include the use of:

- Heavy walled pipe

The noise attenuation possible with heavy-walled pipe varies with the size and schedule used. As an example, increasing a pipeline from schedule 40 to schedule 80 may reduce sound levels by approximately 4 dB.

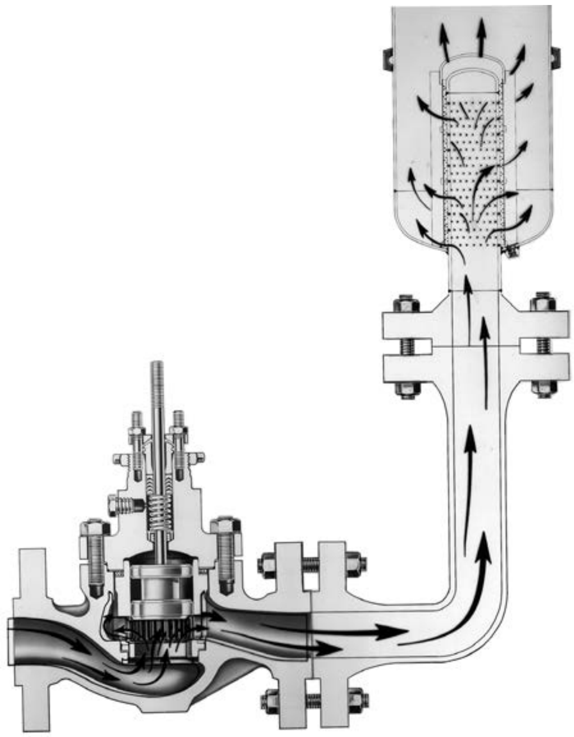

***Figure 6-6**. Valve and Vent Diffuser Combination*

- Acoustical or thermal insulation

The noise level near the valve can be lowered by applying insulation to absorb the noise. Insulation absorbs much of the noise that would normally reach the atmosphere, but does not absorb any of the noise going up or down inside the pipe walls.

Thermal insulation can give 3 to 5 dBA noise reduction per inch of insulation thickness to a maximum attenuation of 12 to 15 dBA. Acoustical insulation can give 8 to 10 dBA noise reduction per inch of blanket type insulation. The maximum attenuation that should be expected is 24 to 27 dBA.

Path treatments such as heavy-walled pipe or external insulation can be a very economical and effective technique for localized noise abatement. However, they are effective for localized noise reduction only. That is, they do not reduce the noise in the process stream, but only shroud it where the treatment is used. Noise propagates for long distances via the fluid stream and the effectiveness of the treatment ends where the treatment ends.

- Silencers

The silencer differs from other path treatments in that it does actually absorb some of the noise energy. Therefore, it reduces sound intensity both in the working environment and in the pipeline. In gas transmission systems, in-line silencers effectively dissipate the noise within the fluid stream and attenuate the noise level transmitted to the solid boundaries. Where high mass flow rates and/or high pressure ratios across the valve exist, an in-line silencer is often the most realistic and economical approach to noise control. Use of absorption-type in-line silencers can provide almost any degree of attenuation desired. However, economic considerations generally limit noise attenuation to approximately 35 dBA.

Hydrodynamic Noise

The primary source of hydrodynamic noise is cavitation. Recall that cavitation is the formation and subsequent collapse of vapor bubbles in a flowing liquid. This phenomenon sounds similar to that of gravel flowing down the pipe.

Source treatment for noise problems associated with control valves handling liquid is directed primarily at eliminating or minimizing cavitation. Cavitation and its associated noise and damage can often be avoided at the design stage of a project by giving proper consideration to service conditions. However, where service conditions are fixed, a valve may have to operate at pressure conditions normally resulting in cavitation. In such instances, noise control by source treatment can be accomplished by using one of several methods; multiple valves in series, a special control valve, or the use of special valve trim that uses the series restriction concept to eliminate cavitation.

Cavitrol Trim is a source treatment solution as it eliminates cavitation across the control valve. This is achieved by staging the pressure drop across the valve so the pressure of the fluid never drops below its vapor pressure (figure 6-7). Cavitrol Trim is only effective in clean processes. If a process contains particulate, it will require Dirty Service Trim (DST). DST also operates on the concept of staging the pressure drops (figure 6-8).

While path treatment of aerodynamic noise is often an economical and efficient alternative, path treatment of hydrodynamic noise is not generally recommended. This is because the physical damage to control valve parts and piping produced by cavitation is generally a much more serious issue than the noise generated.

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Figure 6-7. *Cavitrol III Trim*

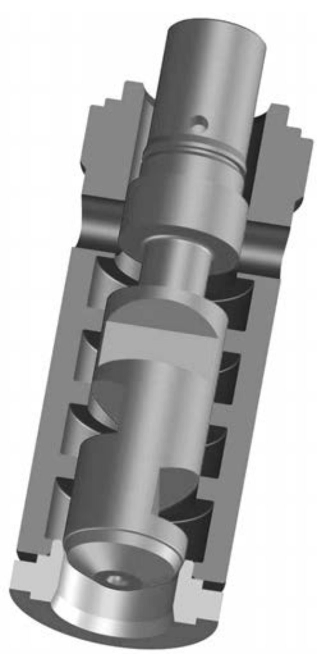

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Figure 6-8. *NotchFlo DST Trim for Fisher Globe Style Valves*

However, if cavitation damage can be eliminated using the special trims discussed, it becomes practical to use the path treatment method to further reduce the local noise caused by the cavitating liquid. This may be accomplished through the use of heavy-walled pipe and acoustical or thermal insulation.

Much technology now exists for predicting and controlling noise in the industrial environment. Prediction techniques accurately alert the designer to the need for noise control. When it is a problem, a variety of solutions are available ranging from simple path insulation to sophisticated control valves which eliminate noise at the source.

Two-Phase Noise

As the properties of the fluids vary, the noise generation, propagation, and pipe excitation processes area are all affected. Acoustical wave speed and the density of the fluid are key considerations. In an all gas or all liquid application, these are reasonably predictable at any point from the inlet of the downstream piping.

However, for a multiphase fluid, either one-component or two-component, there can be tremendous variations in these important parameters. In fact, at the vena contracta where the velocities are greatest, the phases may separate and form annular flow, with the gas and the liquid phases having different velocities. This possibility makes the noise generation process nearly impossible to model.

Between the vena contracta and the downstream piping, the phases may be re-oriented to a homogenous mixture. Propagation of a pressure wave in this region would be again nearly impossible to model, as even if it is perfectly homogenous, the void fraction would be constantly changing with pressure.

Wave speed and density are also important in determining the efficiency with which a sound field is coupled to the pipe wall to cause vibrations and subsequent external noise radiation.

Emerson engineers have conducted field studies on applications where flashing noise was present in an attempt to quantify the problem, if indeed there was one. After an extensive search there were not any applications which were considered noise problems, nor have any surfaced since.

Based upon this experience, two conclusions were made:

1. 1. A technically appropriate two-phase noise prediction method does not exist

2. Two-phase, or pure flashing, applications do not create noise problems.

Control Valve Noise Summary

The requirement for noise control is a function of legislation to protect our wellbeing and to prevent physical damage to control valves and piping.

Noise prediction is a well defined science. Actual results will be within 5 dBA of predicted levels.

Prediction is based upon contributions for:

- Pressure drop
- Flow rate
- P/P_1 and trim style
- Piping and insulation
- Downstream pressure

Noise reduction is accomplished in two general ways:

1. Source treatment, which acts upon the amount of noise generated.

2. Path treatment, which blocks transmission on noise to the environment.

There are two common source treatments:

1. Valve noise trim is based on principles of dividing the flow to create many small noise sources which combine to a lower level than a single large flow noise. Diffusers used with control valves share pressure drop creating two lower noise sources which again combine to an overall lower level.

2. Path treatment involves use of insulation or absorptive devices to lower the sound level which reaches observers.

Hydrodynamic noise from liquid flow streams can mainly be traced to cavitation. In this case, damage from the cavitation is of more concern than the noise. Appropriate treatment of the cavitation source should be initiated through staging the pressure drop.

Two-phase, or pure flashing, applications do not create noise problems, and there is no technically appropriate two-phase noise prediction method.

Chapter 7

Steam Conditioning

Introduction

Power producers have an ever-increasing need to improve efficiency, flexibility, and responsiveness in their production operations. Changes resulting from deregulation, privatization, environmental factors, and economics are combining to alter the face of power production worldwide. These factors are affecting the operation of existing power plants and the design of future plants resulting in a myriad of changes in the designs and operating modes of future and existing power plants.

Competing in today's power market requires heavy emphasis on the ability to throttle back operations during non-peak hours in order to minimize losses associated with power prices falling with demand. These changes are implemented in the form of increased cyclical operation, daily start and stop, and faster ramp rates to assure full load operation at daily peak hours.

Advanced combined cycle plants are now designed with requirements including operating temperatures up to 1500°F, noise limitation in urbanized areas, life extension programs, cogeneration, and the sale of export steam to independent customers. These requirements have to be understood, evaluated, and implemented individually with a minimum of cost and a maximum of operational flexibility to assure profitable operation.

Great strides have been made to improve heat rates and increase operational thermal efficiency by the precise and coordinated control of the temperature, pressure, and quality of the steam. Most of the steam produced in power and process plants, today, is not at the required conditions for all applications. Thus, some degree of conditioning is warranted in either control of pressure and/or temperature, to protect downstream equipment, or desuperheating to enhance heat transfer. Therefore, the sizing, selection, and application of the proper desuperheating or steam conditioning systems are critical to the optimum performance of the installation.

Thermodynamics of Steam

Highly superheated steam, (i.e. 900 - 1100°F) is usually generated to do mechanical work such as drive turbines. As the dry steam is expanded through each turbine stage, increasing amounts of thermal energy is transformed into kinetic energy and turns the turbine rotor at the specified speed. In the process, heat is transferred and work is accomplished. The spent steam exits the turbine at greatly reduced pressure and temperature in accordance with the first law of thermodynamics.

This extremely hot vapor may appear to be an excellent source for heat transfer, but in reality it is just the opposite. Utilization of superheated steam for heat transfer processes is very inefficient. It is only when superheated steam temperatures are lowered to values closer to saturation that its heat transfer properties are significantly improved. Analysis has shown that the resultant increase in efficiency will very quickly pay for the additional desuperheating equipment that is required.

In order to understand why desuperheating is so essential for optimization of heat transfer and efficiency, we must examine the thermodynamic relationship of temperature and the enthalpy of water. Figure 7-1 illustrates the changes of state that occur in water over a range of temperatures, at constant pressure, and relates them to the enthalpy or thermal energy of the fluid.

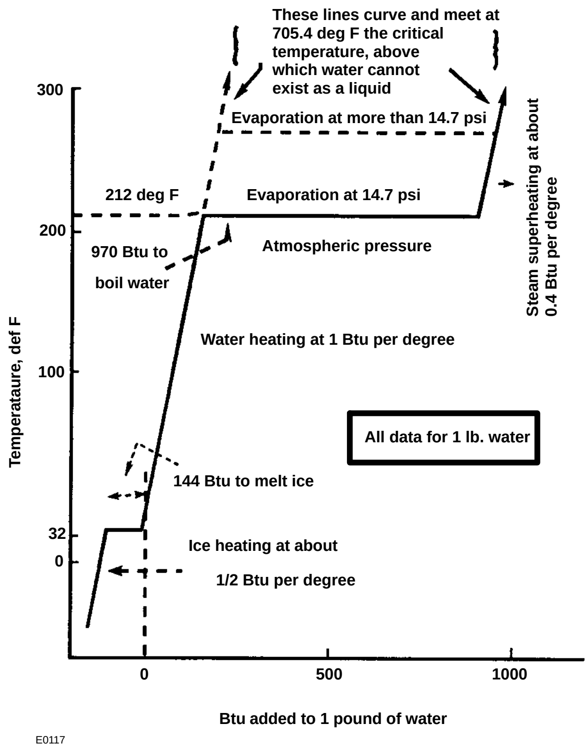

***Figure 7-1**. Temperature enthalpy diagram for water. Note that the greatest amount of thermal energy input is used to vaporize the water. Maximum efficiency in heat transfer requires operation at near saturation temperature to recover this energy.*

In the lower left portion of the graph, the water is frozen at atmospheric pressure and below 32°F. At this point, heat is being rejected from the water as it maintains its solid state. As heat is gradually added the ice begins to change. Addition of heat to the ice raises the temperature and slows the rate of heat rejection. It requires approximately 1/2 BTU of thermal energy to be added to a pound of ice to raise its temperature 1°F. Upon reaching 32°F, the addition of more heat does not immediately result in an increase in temperature. Additional heat at this point begins to melt the ice and results in a transformation of state from a solid to a liquid. A total of 144 BTUs is required to melt one pound of ice and change it to water at 32°F.

Once the phase change from a solid to a liquid is complete, the addition of more heat energy to the water will again raise its temperature. One BTU of heat is required to raise the temperature of one pound of water by 1°F. This relationship remains proportionate until the boiling point (212°F) is reached. At this point, the further addition of heat energy will not increase the temperature of the water. This is called the saturated liquid stage.

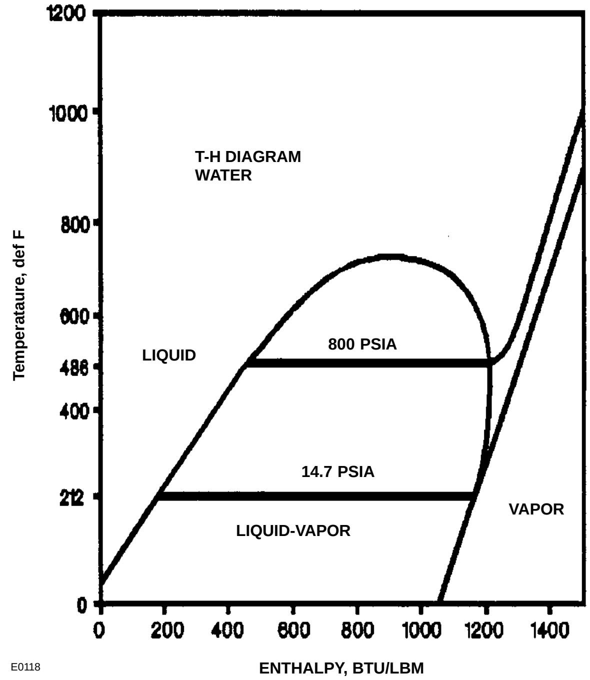

***Figure 7-2.** Temperature enthalpy diagram for water showing that saturation temperature varies with pressure. By choosing an appropriate pressure, both correct system temperature and thermal efficiency can be accommodated.*

The water begins once again to change state, in this case from water to steam. The complete evaporation of the water requires the addition of 970 BTUs per pound. This is referred to as the latent heat of vaporization, and is different at each individual pressure level. During the vaporization process the liquid and vapor states co-exist at constant temperature and pressure. Once all the water, or liquid phase, has been eliminated we now have one pound of steam at 212°F. This is called the saturated vapor stage. The addition of further thermal energy to the steam will now again increase the temperature. This process is known as superheating. To superheat one pound of steam 1°F requires the addition of approximately 0.4 BTUs of thermal energy.

The potential thermal energy release resulting from a steam temperature change differs significantly depending on temperature and superheat condition. It is much more efficient, on a mass basis, to cool by addition of ice rather than by the addition of cold fluids. Similarly, it is more efficient to heat with steam at temperatures near the saturation temperature rather than in the superheated region. In the saturated region much more heat is liberated per degree of temperature change than in the superheated range because production of condensate liberates the enthalpy of evaporation, the major component of the total thermal energy content. The temperature-enthalpy diagram in figure 7-2 is generalized to show the thermodynamic relationship at various pressures.

The graph in figure 7-2 illustrates three distinct phases (i.e., liquid, vapor, and liquid-vapor) and how enthalpy relates to temperature in each phase at constant pressure. The rounded section in the middle of the graph is called the "steam dome" and encompasses the two-phase, liquid-vapor region. The left boundary of the steam dome is called the saturated liquid line. The right boundary line is the saturated vapor line. The two boundaries meet at a point at the top of the dome called the critical point. Above this point, 3206 psi and 705°F, liquid water will flash directly to dry steam without undergoing a two-phase coexistence. When conditions exceed this critical point they are considered to be existing in the supercritical state.

In the lower left side of the graph, the saturated liquid line intersects the temperature axis at 32°F. At this point we have water and a defined enthalpy of 0 BTU/LB. As heat is added to the system, the temperature and enthalpy rise and we progress up the saturated liquid line. Water boils at 212°F at 14.7 psia. Thus, at 212°F and 180 BTU/LB, we note a deviation from the saturated liquid line. The water has begun to boil and enter a new phase; Liquid-Vapor.

As long as the liquid stays in contact with the vapor, the temperature will remain constant as more heat is added. At 1150 BTU/LB (at 14.7 psi) we break through to the saturated vapor line. Thus, after inputting 970 BTU/LB, all of the water has been vaporized and enters the pure vapor state. As more heat is added, the temperature rises very quickly as the steam becomes superheated.

Why Desuperheat?

Desuperheating, or attemperation as it is sometimes called, is most often used to:

- Improve the efficiency of thermal transfer in heat exchangers

- Reduce or control superheated steam temperatures that might otherwise be harmful to equipment, process or product

- Control temperature and flow with load variation

Dry superheated steam is ideally suited for mechanical work. It can be readily converted to kinetic energy to drive turbines, compressors and fans. However, as the steep temperature-enthalpy line slope would indicate, the amount of heat output per unit of temperature drop is very small. A heat exchanger using superheated steam would have to be extremely large, use great quantities of steam, or take tremendous temperature drops. A 10°F drop in temperature liberates only 4.7 BTU per pound.

If this same steam had been desuperheated to near saturation the thermal capabilities would be greatly enhanced. The same 10°F drop in temperature would result in the release of over 976 BTU of heat. This illustrates the obvious advantages of desuperheating when thermal processes are involved. Only by desuperheating the superheated steam is it possible to economically retrieve the energy associated with vaporization. By changing steam pressure, the saturation temperature can be moved to match the temperature needs of the process and still gain the thermal benefits of operating near saturation.

The previous discussion centered on why we superheat steam (to do mechanical work) and when it should be desuperheated back to saturation (to heat). There are many situations when saturated steam suddenly and unintentionally acquires more superheat than the downstream process was designed to accommodate. This "unintentional" superheat produces the same thermal inefficiencies mentioned previously. In this case, we are talking about the sudden expansion and temperature change associated with a pressure reducing valve. Take the following steam header conditions for example:

Conditions: P_1 = 165 psia
T_1 = 370°F
Enthalpy = 1198.9 BTU/LB

Saturation temperature at 165 psia is 366°F. Therefore, the steam has only 4°F of superheat and would be excellent for heat transfer. Assume that another thermal process requires some steam, but at 45 psia rather than 165 psia. The simple solution is to install a pressure reducing valve. Since throttling devices, such as valves and orifices, are isenthalpic (constant enthalpy processes) the total heat content of the steam will not change as flow passes through the restriction.

After the valve, the steam will have the following conditions:

Conditions: P_2 = 45 psia
Enthalpy = 1198.9 BTU/LB

Referencing a set of steam tables, we see that at the above conditions the steam temperature is 328°F giving the impression that it has cooled. However, from the steam tables we see that the saturation temperature for 45 psia steam has also dropped to 274°F. The net result is that our steam now has 54°F of superheat (328°F - 274°F). Use of this steam for heat transfer could be uneconomical and return on investment on a desuperheater would be most favorable.

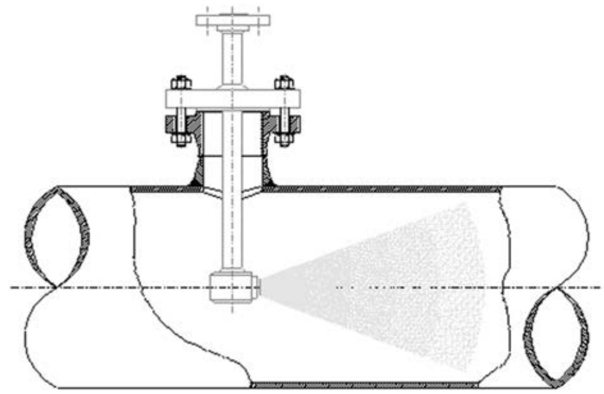

Figure 7-3. *Insertion style desuperheater injects a controlled amount of cooling water into superheated steam flow.*

Desuperheating

In this section we will briefly discuss the process of desuperheating. The need to desuperheat is usually performed simply to control the steam temperature, or heat content, of the flowing vapor media. Depending on the process downstream of the main steam source, a desuperheater will be utilized to transform the steam into a medium that is more efficient for heat transfer or just more conducive for interaction with its surrounding components. One means of accomplishing this is with a direct contact heat transfer mechanism. This can easily be achieved by the use of a single spray injection nozzle that, when properly placed, diffuses a calculated quantity of liquid into the turbulent flow stream. Vaporization of the liquid phase proceeds while mass, momentum, and energy transfer occurs, and the resultant vapor exits the process at the desired temperature or heat content level.

Desuperheaters

A desuperheater is a device that injects a controlled amount of cooling water into a superheated steam flow in an effort to reduce or control steam temperature (figure 7-3). Desuperheaters come in various physical configurations and spray types that optimize performance within specified control and installation parameters. Selection should also always include attention to those details that would provide the most economic solution without sacrificing required performance.

The success of a particular desuperheater station can rest on a number of physical, thermal, and geometric factors. Some of the factors are quite obvious and others are more obscure, but they all have a varying impact on the performance of the equipment and the system that it is installed in. Considerable research has been conducted into the characteristics of desuperheaters and the transformation of spraywater to vapor. The findings are of considerable interest to both design and process engineers. In the next several sections, we will discuss these findings and how they relate to the desuperheating system as a whole.

The most important factor is the selection of the correct desuperheater type for the respective application. Units come in all shapes and sizes and use various energy transfer and mechanical techniques to achieve the desired performance criteria and optimize the utilization of the system environment. These design criteria include:

- Mechanically Atomized − Fixed and Variable Geometry Spray Orifice
- Geometrically Enhanced
- Externally Energized

The mechanically atomized style of desuperheater is the most popular and simplistic style that provides nominal performance over a wide range of flow and conditions. These models are of the internally energized variety. The atomization and injection of the spray water is initiated by the pressure differential between the spraywater and the steam. The DMA, fixed geometry spray orifice, units are the simplest and by design have a constant area flow path. These units are highly

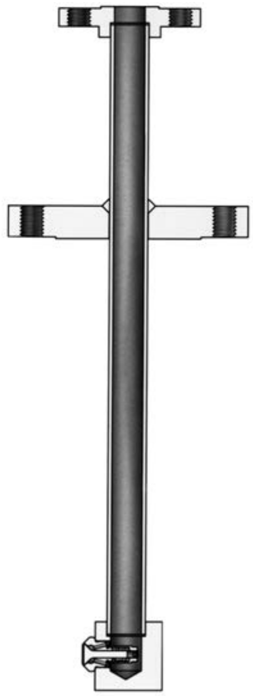

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Figure 7-4. *The DMA/AF desuperheater utilizes variable-geometry, back-pressure activated spray nozzles.*

dependent on the pressure differential and thus provide levels of performance that are commensurate with the magnitude of the difference. Obviously, the larger the water/steam differential the better the unit will perform (i.e., penetration velocity, flow variation and droplet size). Since the equipment turndown is usually limited to 4:1, it is best suited for near steady load applications.

An upgrade from the fixed geometry unit is the DMA/AF (figure 7-4) variable geometry nozzle desuperheater. Here the actual flow geometry of the unit is varied to maintain an optimum differential across the discharge orifice. As a result of this change, the level of flow variation is greatly enhanced and so is the performance. Equipment turndowns can exceed 40:1, thus making this style a good choice for medium to high load change applications.

Another form of mechanically atomized desuperheater is the DVI, Geometric Enhanced style, (figure 7-5). Here, the unit is supplied a high pressure recovery flow restriction that alters flow geometry and helps to keep the level of turbulence and kinetic energy at a high level during all phases of the units operation due to an increased velocity at the point of spray water injection. This increased level of surrounding energy helps to

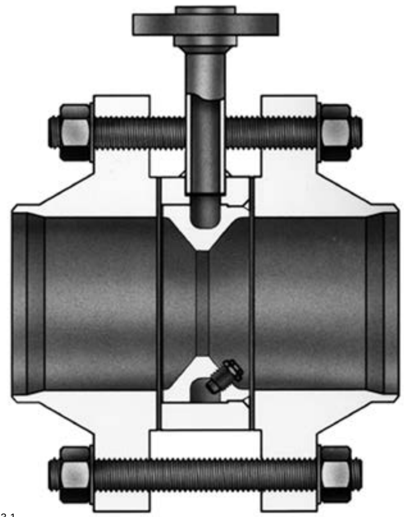

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Figure 7-5. *The DVI desuperheater injects spraywater in the outlet of the venturi section, assuring excellent mixing and rapid atomization.*

impart energy transfer to the droplets and assists in break-up, mixing, and vaporization. This style is best suited for medium turndown applications typically around 15:1.

The last group of desuperheater units utilizes an external energy source for the atomization of the spraywater. The most common medium is a high pressure steam source. In this case, the high levels of kinetic energy are provided by a critical pressure reduction in the desuperheater sprayhead. The critical drop is used to shear the water into a fine mist of small droplets, which is ideal for vaporization, as shown in figure 7-6. This type of system can provide a very high degree of flow variation without requiring a high pressure water supply. Applications requiring turndown ranges greater then 40:1 utilize this type of equipment for best performance. In addition to an external spraywater control valve, the system will also require an atomizing steam shut-off valve (figure 7-7).

Other factors that have a large amount of impact on the performance of a desuperheating system include:

- Installation Orientation
- Spray Water Temperature
- Spray Water Quantity
- Pipeline Size
- Equipment vs. System Turndown

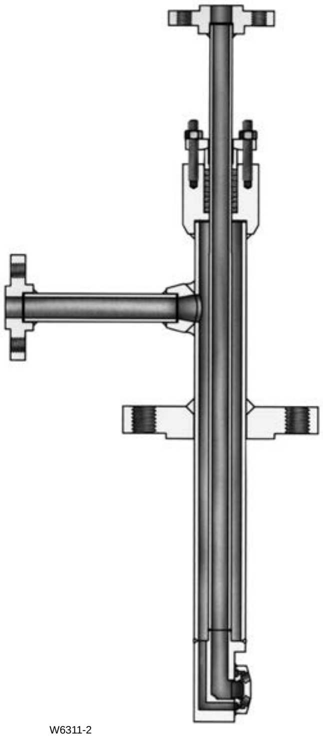

Figure 7-6. *The DSA desuperheater uses high-pressure steam for rapid and complete atomization of spraywater in low-velocity steam lines.*

Installation orientation is often overlooked, but a critical factor in the performance of the system. Correct placement of the desuperheater can have more impact on the operation than the style of the unit itself. For most units, the optimum orientation is in a vertical pipeline with the flow direction up. This flow direction is ideal, as the natural flow direction of the injected water tends to be in the counter direction due to effect of gravity. The role of gravity in this orientation will suspend the droplets in the flow longer while they are being evaporated, thus shortening the required downstream distance or efficient mixing.

Other orientation factors that are of concern include downstream pipefittings, elbows, and any other type of pipeline obstruction that can provide a point for water impingement or fallout.

Spraywater temperature can have an great impact on the desuperheater performance. While it goes against logical convention, hotter water is better for cooling. As the temperature increases and moves closer to saturation, its flow and thermal characteristics are improved and impact most significantly the following:

- Surface Tension
- Drop Size Distribution
- Latent Heat of Vaporization
- Vaporization Rate

Improvement in all these areas will act to improve the overall performance of the system, as the spraywater will evaporate and mix with the steam at a faster rate.

The quantity of water to be injected will, as with any mass flow calculation, have a directly proportionate affect on the time for vaporization.

The heat transfer process is time dependent; thus, the quantity of spray water will increase the time for complete vaporization and thermal stability.

Another concern for proper system performance is pipeline size. Pipe size should be determined in an effort to balance the velocity of the steam flow. Steam traveling at a fast rate will require longer distances to effectively cool, as heat transfer is a function of time. Steam traveling at low velocity will not have enough momentum to suspend water droplets long enough for evaporation. As a result, water will fall out of the steam flow to collect along the bottom of the pipe, and it will not cool the steam effectively. Ideal velocity is typically in the range of 250 ft/sec to 300 ft/sec.

As the pipeline size increases to limit steam velocity, more attention must be paid to the penetration velocity of the spray and the coverage in the flow stream. Experience shows that single point injection type desuperheaters will have insufficient nozzle energy to disperse throughout the entire cross-sectional flow area of the pipeline. As a result, the spray pattern collapses and thermal stratification occurs (i.e., sub-cooled center core within a superheated outer jacket.)

This condition normally is eliminated after the flow stream undergoes several direction changes, although this is not always possible within the limits of the control system or process. Proper placement of high-energy TBX-T (figure 7-8) multi-nozzle steam coolers in the larger pipelines will normally prevent thermal stratification.

The most over used and misunderstood word in the field of desuperheating is “turndown.” When applied to a final control element, such as a valve, it is a simple ratio of the maximum to minimum controllable flow rate. Turndown is sometimes used interchangeably with rangeability; however, the exact meaning differs considerably when it

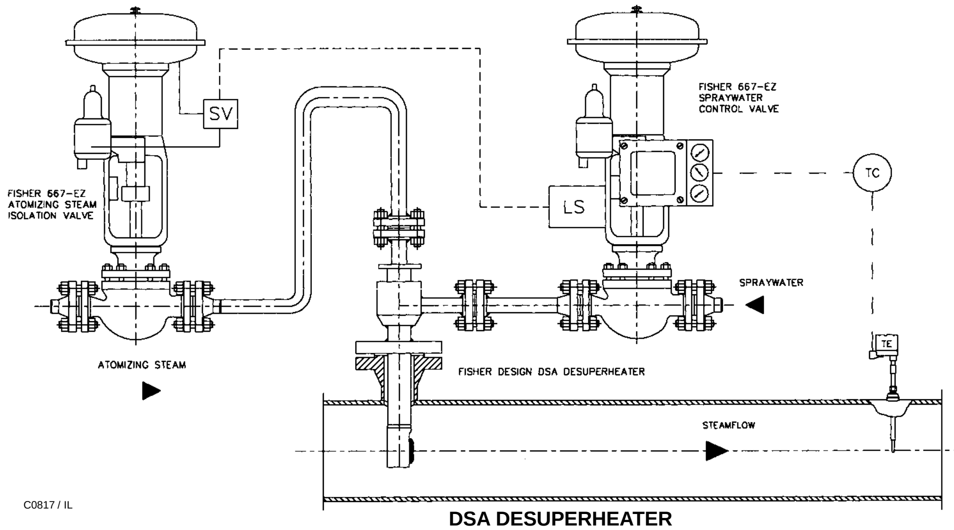

Figure 7-7. *The DSA desuperheater utilizes two external control valves: a spraywater unit and an atomizing steam valve.*

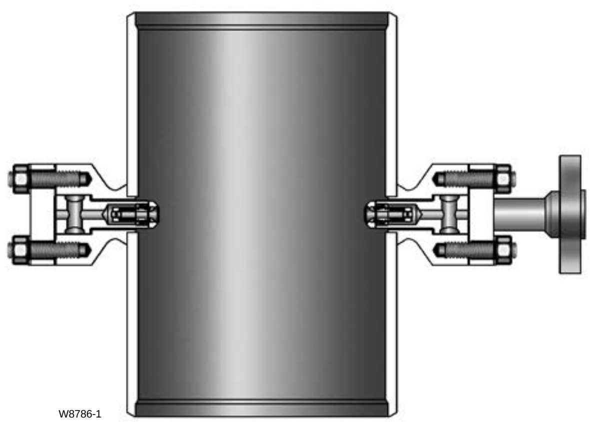

Figure 7-8. *TBX-T Cooler*

comes to actual performance comparisons. Since a desuperheater is not a final control element its performance is linked directly to its system environment; thus, the actual turndown is more a function of system parameters rather than based on the equipment's empirical flow variations. Once this is understood, it is obvious that even a good desuperheater cannot overcome the limitations of a poorly designed system. They must be evaluated on their own merits and weighed accordingly.

A final design parameter for all insertion type desuperheaters is its ability to withstand high levels of thermal cycling. Due to the nature of operation of today's plants, desuperheaters should be designed with the intent to operate under daily cycling environments. Exposure to frequent daily cycling can lead to thermal fatigue and desuperheater failure if the unit is not designed for the operation. Design upgrades for this application consist of thermal liners to reduce thermal loads and structural optimization to reduce induced vibration at stress sensitive welds.

To summarize the requirements to correctly size a desuperheater, the following system and operating information is required:

- Minimum and Maximum Steam Flow
- Steam Pressure and Temperatures
- Cooling Water Pressure and Temperature
- Required System Turndown Ratio
- Pipe Size and System Layout
- Planned Mode of Operating

Steam Conditioning Valves

Steam conditioning valves represent state-of-the-art control of steam pressure and temperature by integrally combining both functions within one control element unit. These valves address the need for better control of steam conditions brought on by increased energy costs and more rigorous plant operation. Steam conditioning valves also provide better temperature control, improved noise abatement, and require fewer piping and installation restrictions than the equivalent desuperheater and pressure reduction station.

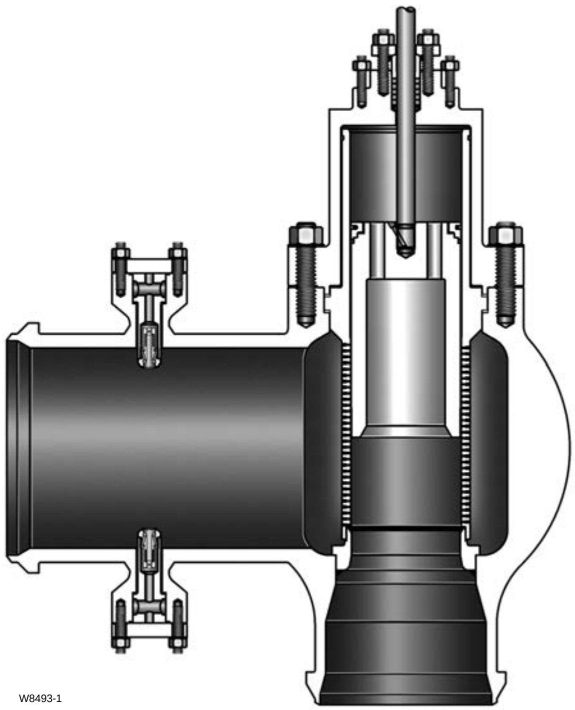
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Figure 7-9. *The TBX utilizes an external spraywater manifold with multiple nozzles for moderate to large volume applications.*

Steam conditioning valve designs can vary considerably, as do the applications they are required to handle. Each has particular characteristics or options that yield efficient operation over a wide range of conditions and customer specified requirements.

The TBX steam-conditioning valve (figure 7-9) combines pressure and temperature control in a single valve. Finite element analysis (FEA) and computational fluid dynamic (CFD) tools were used in its development to optimize the valve's operating performance and overall reliability. The rugged design of the TBX proves capable of handling full mainstream pressure drops, while its flow-up configuration, in conjunction with Whisper Trim technology, prevents the generation of excessive noise and vibration.

The simplified trim configuration used in the TBX accommodates rapid changes in temperature as experienced during a turbine trip. The cage is casehardened for maximum life and is allowed to expand during thermally induced excursions. The valve plug is continuously guided and utilizes cobalt-based overlays both as guide bands and to provide tight, metal-to-metal shutoff against the seat.

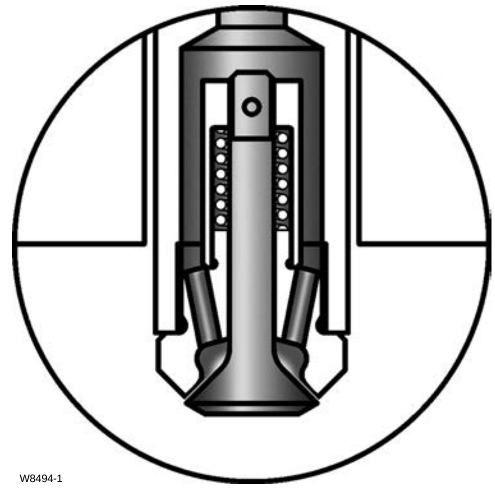
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Figure 7-10. *Detail of AF Spray Nozzle.*

The TBX incorporates a spraywater manifold downstream of its pressure reduction stage. The manifold features variable geometry, backpressure activated AF nozzles that maximize mixing and quick vaporization of the spraywater.

The AF nozzle (figure 7-10) was developed originally for condenser dump systems in which the downstream steam pressure can fall below the saturation level. In these instances, the spraywater may flash and significantly change the flow characteristic and capacity of the associated nozzle at a critical point in the operation.

Spring loading of the valve plug within the AF nozzle prevents any such changes by forcing the plug to close when flashing occurs. With flashing, the compressibility of the fluid changes, and the nozzle spring will force closure and re-pressurization of the fluid leg. Once this is done, the fluid will regain its liquid properties and reestablish flow to the condenser.

The TBX injects the spray water towards the center of the pipeline and away from the pipe wall. The number of injection points varies by application. With high differentials in steam pressure, the outlet size of the valve increases drastically to accommodate the larger specific volumes. Correspondingly, an increased number of nozzles are arranged around the circumference of the outlet making for a more even and complete distribution of the spray water (figure 7-11).

The simplified trim arrangement in the TBX permits extending its use to higher pressure classes (through ANSI Class 2500) and operating temperatures. Its balanced plug configuration

Figure 7-11. *The TBX showing external spraywater manifold.*

provides Class V shutoff and a linear flow characteristic.

The TBX typically uses high-performance, pneumatic piston actuators in combination with FIELDVUE Digital Valve Controllers to achieve full stroke in less than two seconds while maintaining highly accurate step response. The FIELDVUE instruments along with AMS ValveLink™ software provide a self-diagnostic capability that gives answers about valve performance. The current valve/actuator signature (seat load, friction, etc.) can be compared against previously stored signatures to identify performance changes before they cause process control problems.

When piping dictates, the TBX valve can be provided as separate components, allowing pressure control in the valve body and temperature reduction in a downstream steam cooler. The steam cooler is equipped with a water supply manifold (multiple manifolds are also possible). The manifold provides cooling water flow to a number of individual spray nozzles that are installed in the pipe wall of the cooler section. The result is a fine spray injected radially into the high turbulence of the axial steam flow.

Installation Guidelines

Installation of desuperheaters and steam conditioning valves is key to long term success and performance. It is best to install desuperheaters in a straight run of horizontal or vertical pipe. Installation in elbows is also possible, but it can affect system turndown and thermal stratification due to momentum caused changes in the velocity profile.

Momentum forces the majority of the steam flow to the outside surfaces of the bend. This results in a low velocity void on the inside of the elbow. If high turndowns are not required, this installation is satisfactory since the voids would rarely be below minimum velocity at maximum flow. As the flow is reduced, however, these areas may lose their ability to perform as required to desuperheat the steam.

Other installation parameters that are always of interest to the piping designer are how much straight run of pipe is required and where the temperature sensor should be located. Both are thermally derived questions and require thermally derived answers. It is desirable to have the thermal sensor as close as possible to the desuperheater in order to reduce the signal lag time. It is also desirable not to have any piping components (e.g., elbows or tees) that would detract from the thermal process.

The following equations provide guidelines for designing a proper system. These equations relate to time required for complete vaporization and mixing.

<u>Downstream Straight Pipe Requirements (SPR):</u>
SPR (ft) = 0.1 Sec. x Maximum Steam Velocity (ft/sec)

<u>Downstream Temperature Sensor Distance (TS):</u>
15% Spraywater or less:
TS (ft) = 0.2 Sec. x Maximum Steam Velocity (ft/sec)

Greater than 15% Spraywater:
TS (ft) = 0.3 Sec. x Maximum Steam Velocity (ft/sec)

Temperature control is not limited to receiving a signal from a downstream temperature sensor. Another valid alternative is feed-forward control.

Feedforward control is accomplished using an algorithm that is characterized specifically to the valve installed in the application. The algorithm is programmed into the distributed control system to provide an accurate calculation of the spray water that is required to reduce the steam enthalpy and temperature to the desired outlet set point. The algorithm requires input of upstream temperature and pressure as well as the position of the valve. Upstream and spraywater enthalpies are then determined using an inherent steam table within the DCS. The total spraywater required is calculated from a heat balance using the final enthalpy into the condenser. This method of temperature control is a practical solution for applications that do not have enough downstream pipe distance for accurate measurement by a temperature sensor.

Turbine Bypass Systems

The most severe and critical application of any steam conditioning installation is that of the turbine bypass.

The concept of the turbine bypass has been around for a long time; however, its application and importance has broadened significantly in recent years. Steam turbine bypass systems have become essential to today's power plant performance, availability, responsiveness, and major component protection.

The following will concentrate on the general application of bypass systems as used in fossil fueled utility power plants. The closed water/steam heat cycle of such typical units may be comprised, but not limited to, sub- or super-critical pressures, to single, double, or triple reheat sections and to condensation at or near ambient temperatures. The steam generating principles where such bypass systems are employed include natural or assisted circulation drum boilers, combined circulation boilers, and once-through boilers. The turbine may be of single or double shaft design and operated either at fixed inlet pressure or on sliding pressure.

Bypass System Benefits

Just how beneficial a bypass system proves to be depends upon many factors (e.g., plant size, mode of operation, age of existing components, size of the condenser, main fuel type, control philosophy, etc). However, the main benefits for the application of a comprehensive bypass system in the 25-100% size range are:

- **The matching of steam and heavy turbine metal component temperatures during the startup and shutdown phase.** This has proven to be of major economic significance in terms of fuel savings and the thermal protection of critical heavy wall boiler and turbine components. By limiting temperature differentials during turbine admission the effects of thermal fatigue are minimized and longevity of components maximized. This is especially important for life extension programs where the role and justification of the bypass system may be centered solely on this aspect.

- **The ability to avoid a boiler trip following a full load rejection.** A boiler (HRSG) / turbine unit with a bypass can withstand a complete system load rejection and remain available for rapid reloading after the disturbance has been removed. This important advantage for system flexibility and operating efficiency can make the difference between a more costly and time consuming warm start and a hot start.

- **Reduction in solid-particle erosion of turbine components.** The loss of material from the boiler tubing and internals is most prevalent during commissioning startup and after the unit has been shutdown for an expended period of time. Thermal transients assist in the dislodging of scale, oxides, and weldments within the boiler circuit to form an abrasive steam flow that, over time, could accelerate the wear of sensitive turbine blades and seriously affect operating efficiencies and maintenance costs. Damage can be reduced or eliminated by routing the steam through the bypass system.

- **Independent operation of the boiler and turbine set.** The ability to operate the boiler without the turbine, at any load up to the limit of the bypass capacity, can be surprisingly useful for operational or testing purposes. For example, all boiler controls and firing systems can be tested and fine-tuned independent of the turbine operation. This significantly reduces both cost and time relating to initial commissioning of the plant, retrofitting and checking equipment performance, and system troubleshooting.

General System Description

A complete and comprehensive turbine bypass system can be comprised of many inter-linked and coordinated components. These include the bypass valves, spray water control valves, control system, and the actuation and positioning system. For this discussion, we will center our attention on the bypass valves themselves.

The bypass system incorporates the dual operating function of steam conditioning valves (i.e., for the controlled reduction of both pressure and temperature). The bypass valve incorporates

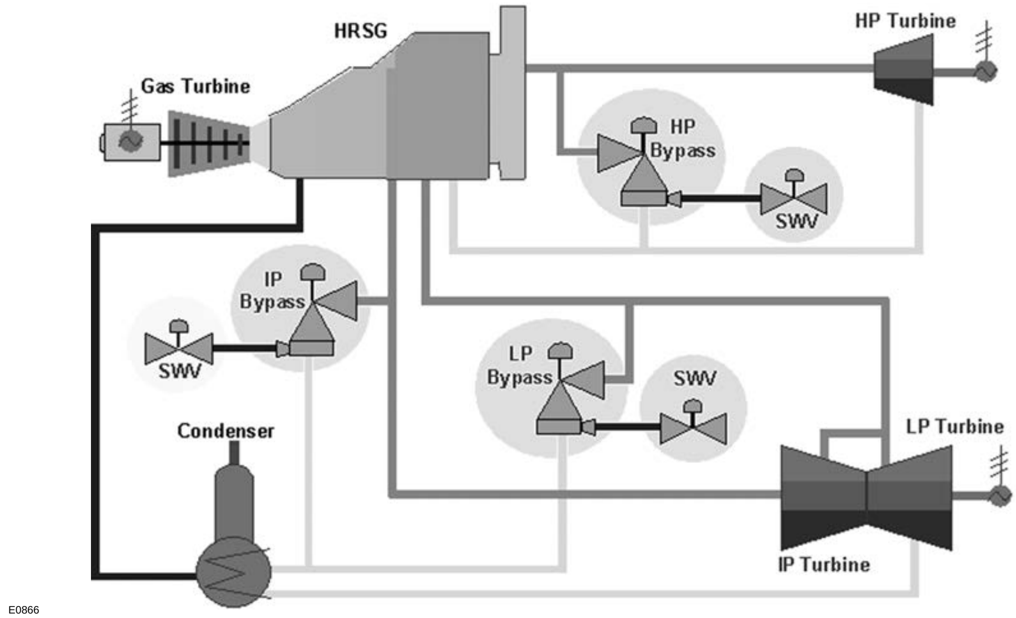


Figure 7-12. *Turbine Bypass System*

the latest technology in pressure-reducing/low noise trim to handle the flow and reduction of pressure energy to acceptable levels. However, since steam throttling in a control valve is an isenthalpic process, desuperheating is required to control the discharge temperature and enthalpy levels. As a result, the valves are equipped with a special spraywater injection system that produces a finely atomized and evenly distributed water interface for rapid vaporization and steam temperature control.

The bypass system can be supplied with one or two control inputs depending on the role it plays in the control scheme. If the valve is used solely for startup and shutdown, it will receive a single modulating control signal to position the trim as a function of the startup and shutdown curves for the respective unit. If the valve must also act to relieve pressure during a turbine trip or load rejection, an additional discrete input is included that will ramp open the valve quickly to a predetermined position, before reverting to a modulating configuration in accordance with the boiler control requirements. Fast positioning speed and resultant alternate flow path are critical to counteract the pressure build-up resulting from the isolation of the boiler piping circuit when the turbine valves close in this trip situation.

High Pressure Bypass

During startup, shutdown, or on turbine trip, the HP bypass system directs steam from the superheater outlet to the cold reheat line, thereby bypassing the HP turbine section (figure 7-9). The major advantages of such an action have been generally outlined above. However, more specific duties are:

1. Pressure and temperature controlled bypass of the HP turbine section.
2. Controlled main steam pressure build-up in the boiler.
3. Cooling of the reheat section of the boiler.
4. Prevention of the opening of spring-loaded HP safety valves during minor disturbances.
5. Avoidance of condensate loss and noise from blowing safety valves.
6. Protection of the boiler against exceeding design pressures.

The failure mode of the HP bypass system is very dependent on local design codes and the performance scenario for the system. If it is designed as a safety bypass system and replaces the standard safety relief valve function, the valves must always fail in the open position. However, if the standard safety relief valves are in place, the valve is normally required to fail closed, especially in over-temperature situations on drum boilers.

Control of the HP bypass is normally initiated via feedback input signals from the main steam pressure and the cold reheat temperature. The ratio of steam to spraywater is normally inversely proportional to the respective valve position, especially during startup and shutdown. This is because startup conditions normally require large valve Cvs, due to the large specific volumes associated with low pressures at high temperatures, even though flow is greatly reduced.

During trip conditions, the opposite is true, and large quantities of spraywater are required at lower valve openings. For this situation, special control algorithms usually are incorporated into the control system to provide independent feedforward control. This is especially important during a trip sequence where time of response is critical to maintain system integrity, performance, and component protection.

Spraywater for cooling is normally obtained from the boiler feed pump discharge and is regulated by an external spraywater control valve that is properly sized to handle the required flow and pressure drop.

Hot-Reheat and Low Pressure Bypass

During startup, shutdown, or on turbine trip, the HRH and LP bypass systems direct steam from the hot reheat line to the condenser, thus bypassing the IP and LP turbine sections (figure 7-12). The major advantages of such an action have been generally outlined above. However, more specific duties are:

1. Pressure and temperature controlled bypassing of the IP and LP turbines.
2. Controlling pressure build-up in the boiler reheat section.
3. Prevention of condensate losses during load trips and minor disturbances.
4. Protecting the condenser against excessive pressure, temperature, and enthalpy excursions during bypass operation.

In contrast to the HP bypass, the HRH and LP bypass valves only fail closed as a failure mode. While it is important to control the hot reheat pressure, it is even more critical to protect the condenser against damage from uncontrolled or improper admission of steam. The condenser manufacturer interfaces specific condenser control permissives with these bypass control systems. If any of these permissives is not met or is exceeded during bypass operation, the valve is quickly shut. These permissives include, but are not limited to:

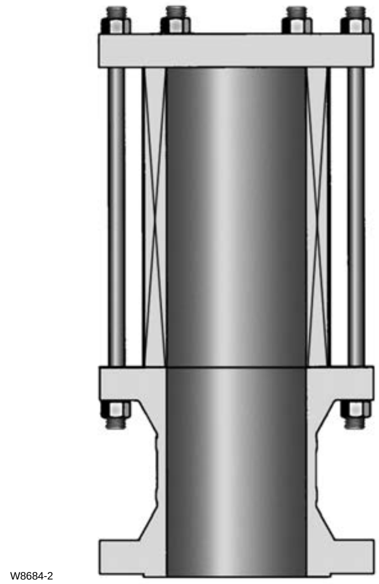


Figure 7-13. *TBX WhisperFlo Sparger.*

1. Condensate level high
2. Condenser temperature high
3. Condenser pressure high
4. Spraywater pressure low
5. Loss of coolant

Another added challenge of the HRH and LP bypass system is to properly control the amount of backpressure on the bypass valves. A condenser or condenser duct, which is downstream of these bypass valves, typically operates at a vacuum in the range of 1 - 3 psia. Given this scenario, it is crucial to create backpressure in order to maintain a desired velocity within reasonable pipe sizes.

A second challenge to this application is to create these desired conditions while minimizing the noise generated by this process. Dumping high velocity steam into a low pressure, thin wall condenser/turbine exhaust duct requires careful evaluation in order to assure steam jets do not converge. Hole spacing within the sparger and sparger placement within the duct are critical for maintaining low noise levels.

A typical bypass to condenser installation requires a steam conditioning valve to control pressure and temperature, a spraywater valve to regulate the water supply, and a downstream TBX sparger to create backpressure. Low noise WhisperFlo trim alternatives are also available for the TBX sparger (figure 7-13).

Control of the HRH and LP bypass valves normally is initiated via feedback input signals from the hot reheat steam pressure and the specified condenser inlet temperature/enthalpy. The steam entering the condenser must be controlled specifically to guard against excessive thermal expansion of the tubing and shell. As in the case of the HP bypass, the ratio of steam to spray water is normally inversely proportional, especially during startup and shutdown. In addition, the dual role of the HRH and LP bypass system in controlling the thermal admission parameters to the condenser normally results in the requirement for a prescribed amount of over-spray.

This situation is compounded by the close proximity of these valves to the condenser. This makes any kind of feedback temperature control almost impossible considering the quantity of spray water to be vaporized and the short distance available to measure the process. It is highly recommended that feedforward control algorithms be incorporated into the control system to provide independent feedforward control for the spraywater admission.

Spraywater for cooling is normally obtained from the condensate boost pump discharge and is regulated by a properly sized external spraywater control valve.

Bypass Size

A comprehensive bypass system includes HP bypass, HRH bypass and LP bypass valves. However, they may or may not be sized for the same capacity. There are many variables that can influence the required size of each bypass system.

Bypasses for once-through boiler plants are generally designed for 100% of full-load steam to suit startup and part-load operation. If conventional safety valves are omitted, 100% bypass capacity is essential.

Bypass capacity for drum boiler plants involve several different issues. Some argue that 100% capacity bypasses are worthwhile, but experience has proven that bypasses with capacities of between 25 - 70% normally are sufficient to handle most operating and trip conditions.

For temperature matching in a drum plant during hot startup only, it may be possible to use a bypass of only 30% when firing with oil and 40-50% for coal. Overall, these values are considered the lowest practical load for the boiler under automatic control.

On bypass applications requiring the control of a full turbine trip, the values increase to 40% on gas and oil-fired drum units and up to 70% for coal. In selecting the bypass capacity, it is important to consider all control systems and plant components and their ability to turn down instantaneously from full to auxiliary load.

Note also that if the high pressure bypass capacity exceeds approximately 50%, and the low pressure bypass passes all the steam to the condenser, then condenser duty during bypass operation is more severe than during normal, full-load turbine operation. This fact may limit bypass capacity, especially on systems being retrofit to existing plants.

Starts, Trips, Load Rejection, Two-Shift Operation

The worth of a turbine bypass and the flexibility, added efficiency, and responsiveness are never more apparent than during starts, trips, or load rejections. Modern bypass systems operate during:

- Cold starts
- Warm starts
- Hot starts
- Load rejection
- Quick turbine shutdown
- Two-shift operation

Bypass valves and systems that are designed correctly have noteworthy advantages for these individual modes. They are detailed as follows:

Cold Starts

A cold start typically occurs after the unit has been down for over a week. Preheating of the system is required as first stage and reheat temperatures are normally below 200°F. The bypass system permits involvement of the furnace, superheaters, and reheater very early in the steam/water cycle.

This is important in the production of steam purity before the turbine start. Steam flow through the superheater and reheater enhances the tube cooling effect, thereby allowing greater latitude in gas and steam temperatures. During the startup, thermal stresses are controlled while achieving the fastest possible loading rate. Depending on the size of the bypass system, the unit can typically be brought on line in 4.5 - 9 hours.

Warm Starts

A warm start is indicative of a weekend shutdown. In this case, the HP turbine casing is usually above 450°F. As with the cold start, the steam temperature can be controlled to permit the matching of steam and metal temperatures under all operating conditions. Expected startup time is between 2.5 - 5 hours.

Hot Starts

A hot start is usually associated with a minor disturbance that created a unit trip. The bypass allows the boiler to remain on line until the disturbance is cleared and the unit can be reloaded in the shortest possible time, which is usually between 1 - 2 hours.

Load Rejection/Quick Restart

During load rejection, the bypass system provides the necessary control and flow path for unit runback to minimum load and for the establishment of a definitive course of action (i.e., complete shutdown or quick restart). All systems are protected, and a minimum of condensate is lost.

Two-Shift Operation

Two-shift operation may become necessary if a utility grid has a number of large base-loaded units, which are not as maneuverable as the smaller fossil fueled units used for peaking purposes. This would require that the smaller units be shutdown every night and restarted every morning, which is a very material-life consuming means of operating. Once again, the bypass system provides a means for the efficient and timely matching of steam and metal temperatures. This allows the efficient startup of the units every morning without thermally stressing the components, yet it increases unit efficiency and availability.

Chapter 7 — Steam Conditioning Summary

The implementation of a properly designed turbine bypass system can be beneficial and instrumental in the pursuit of increased efficiency, flexibility, and responsiveness in the utility power plant. Component life can be extended as the ability to regulate temperatures between the steam and turbine metal is enhanced. Commissioning time and cost can be reduced through independent boiler and turbine operation. The magnitude of return on investment hinges on the specific application mode, style or service of plant, and equipment supplied. While not discussed here, this logic applies as well to combined cycle plants, cogeneration facilities, and industrial power facilities.

Short Notes:

- A desuperheater is a device that sprays a precisely controlled amount of water into a steam line to modify steam temperature.

- System parameters and required turndown are the most influential parameters in desuperheater selection.

- Desuperheating is done primarily to improve efficiency of thermal transfer devices and to provide temperature protection for process, product and equipment.

- Another reason to desuperheat is to control the “unintentional superheat” created by pressure reduction valves.

- Proper installation is key to best performance. Guidelines for piping geometry and placement of downstream temperature sensors are available.

- Steam conditioning is the process of combining pressure reduction and desuperheating into a single control element.

- Turbine bypass systems are beneficial and instrumental for achieving high efficiency, flexibility, and responsiveness in today’s power plants.

Chapter 8

Process Overview

The modern pulp and paper mill is a complex manufacturing process involving many varied types of operation. Many factors influence the type of process used by a specific mill. Some of these factors include: type of wood available (hardwood or softwood), type of paper or paperboard produced, age of mill, and availability of an abundant supply of water. This sourcebook will focus primarily upon the Kraft or sulfate pulping process as illustrated in figure 1.

Wood Preparation

Wood preparation is a series of steps that converts logs to a suitable form for use in the pulp mill. This area of the mill is commonly referred to as the woodyard.

Logs from the forest are usually received from a truck, rail car, or barge. Large overhead cranes are used to unload and sort the logs into piles for long or short logs. Logs may pass through a slasher, which cuts the logs into segments, if a certain length is required.

The next step involves debarking, which removes both dirt and bark from the logs. The most common method employed is mechanical debarking via a barking drum. Logs are fed into the rotating cylinder and the rotating/tumbling action rubs the bark from the logs. The bark falls out of the cylinder via slots and debarked logs exit the opposite end of the cylinder. Bark is used as fuel for the power boiler or log boiler.

Following debarking, the logs are fed to the chipper. The chipper uses high speed rotating blades to reduce the logs to chips of a suitable size for pulping. Chips are then screened for acceptable sizes by passing them over a set of vibratory screens. The rejects are returned for further chipping and acceptable chips are stored in large outdoor piles or silos for pulp mill use.

Pulping

Pulping is the process of separating the wood chips into fibers for paper manufacture. This is accomplished primarily by mechanical, chemical, or combined mechanical/chemical processes. Some mills that produce various grades of paper have both mechanical and chemical pulping processes.

Mechanical pulping, or the groundwood process, involves pressing logs against a rotating grindstone and washing away the torn fibers with water. This process is a large consumer of electric power due mainly to the grindstone motor. This type of pulp is used primarily for the production of newsprint grade paper.

More modern methods of mechanical pulping involve shredding and grinding of wood chips between the rotating disk of a refiner. The product is referred to as refiner mechanical pulp (RMP). Variations of this process involve pretreating of wood chips with steam and/or chemicals. This is commonly referred to as thermo-mechanical pulp (TMP) or chemithermomechanical pulp (CTMP).

The majority of pulping processes in North America are chemical processes. The most common are the sulfate and sulfite processes. Of these two, the sulfate or Kraft process is the dominant process. The Kraft cooking process is part of a larger process called the Kraft recovery cycle. A typical Kraft recovery cycle is illustrated in figure 2.

The Kraft process involves cooking the wood chips under pressure in an alkaline solution of sodium hydroxide (NaOH) and sodium sulfide (Na_2S). This solution, known as white liquor, breaks down the glue-like lignin which binds the cellulose wood fibers together. Cellulose fibers are used to form a paper sheet on the paper machine.

The primary piece of equipment in the pulp mill is the cooking vessel or digester. The digester is a vessel in which wood chips and white liquor are steam heated to a predetermined pressure and temperature. The objective is to remove as much lignin as possible without decreasing fiber (cellulose) strength.

Both batch and continuous processes are used to cook wood chips. The batch process involves filling a vessel with wood chips and white liquor. The contents are then heated to a predetermined cooking temperature and pressure via direct or indirect steam heating. After a prescribed cooking time, the contents are blown to a holding tank and the process repeated.

As its name implies, the continuous digester has a fairly constant input of chips and outflow of pulp fibers. The chips are usually preheated in a steaming vessel before they are conveyed to the digester. As the chips move down through the digester (vertical type), they are successively heated, cooked, and washed prior to cooling and discharge to the blow tank. Indirect steam heating of the cooking liquor is used to control the temperature in each section of the digester. Most of the newer pulp mills have favored the continuous digester cooking process over the batch process.

Following cooking, the pulp from the blow tank must be washed to remove residual cooking chemicals. This is sometimes referred to as brown stock washing. The resulting process stream from washing the stock is referred to as weak black liquor.

For many years, the standard method of washing has been a series of rotary vacuum washers. The pulp and wash filtrate (black liquor) flow in a countercurrent sequence with clean water used only for the final washing stage. This allows an increase in wash solids as it flows toward the first stage washer and a decrease in pulp solids as it moves to the last stage washer.

As mills face growing economic and environmental pressures, new methods of washing have been developed. Some of these systems include rotary pressure filter systems, continuous digester washing, and pressure diffusion washers. Each of these systems are designed to achieve clean pulp and reclaim cooking chemicals with less wash water.

A final step in the pulping process involves passing the pulp through knotter and screen equipment. These steps may occur before, after, or split around brown stock washing. The knotters remove uncooked wood chips, knots, and fiber bundles called shives. Screening is removal of other tramp rejects such as rocks, steel, plastic or conveyor parts.

Recovery of Kraft Pulping Liquors

Due to the high cost of pulping chemicals (sodium and sulfur), effective recovery following cooking has an important economic impact on mill operating cost. The primary purpose of the Kraft recovery cycle (see figure 2) is to reclaim these chemicals and regenerate them to cooking liquor form. A secondary objective is efficient heat recovery and steam generation from the combustion of wood organics in black liquor fuel. This complex process will be covered in three steps: evaporation, burning, and causticizing or regeneration.

Evaporation

Weak black liquor from the brown stock washers contains spent cooking chemicals, wood organics such as lignin, and water. At this stage, the solids content is typically 12 - 18%. Before burning, water must be evaporated to raise the solids content to 65 - 70%. The bulk of this task is commonly accomplished by multiple-effect evaporators.

A set of evaporators commonly consists of six vessels and interconnecting pumps and piping. Steam is used as a heating medium to evaporate water from the liquor. Steam typically flows countercurrent to the liquor for maximum economy. Since the vessels operate at different pressures, the vapors from one vessel serve as the steam supply for the next vessel. Liquor typically leaves the evaporators at 50% solids with 5 - 6 lbs. of water evaporated per pound of steam used.

Burning

Black liquor from the evaporators at 50 - 55% solids cannot be burned in the recovery boiler. Further evaporation to 65 - 70% solids must be attained prior to combustion. This is accomplished by evaporator-like vessels called concentrators or by direct contact evaporators (cascade or cyclone type) which use boiler flue gas for evaporation. If direct contact evaporators are used (older designs), air is mixed with the black liquor in the black liquor oxidation system prior to direct heating. This helps prevent the release of odorous gases due to direct heat contact. Most new boilers use concentrators for final evaporation since indirect steam heating emits fewer odors. This is commonly referred to as low odor design.

The recovery boiler is one of the largest and most expensive pieces of hardware in the mill. It is the heart of the chemical recovery process. The heavy black liquor is sprayed into the furnace for combustion of organic solids. Heat liberated from burning serves to produce steam in the water circuit and reduce sulfur compounds to sulfide. The molten sodium compounds accumulate to form a smelt bed on the furnace floor. The molten smelt, consisting primarily of sodium carbonate (Na_2CO_3) and sodium sulfide (Na_2S), flows by gravity to the dissolving tank. The dissolving tank is filled with a water solution (weak wash) to cool the smelt. This solution is called green liquor and is transferred to the causticizing area.

Causticizing

Green liquor is sent to the causticizing area for transformation to white liquor for cooking. The process begins with clarification of the green liquor to remove impurities called dregs. Clarified green liquor is then mixed with lime in the slaker to form white liquor. The lime (CaO) activates the conversion of Na_2CO_3 in the green liquor to form sodium hydroxide (NaOH) for white liquor. To allow time for a complete reaction, the white liquor passes to a series of agitated tanks called causticizers.

A second chemical reaction resulting from the addition of CaO is the precipitation of lime mud ($CaCO_3$). The lime mud is removed from the white liquor by filtration or gravity settling and the clarified white liquor is stored for digester chip cooking.

Lime mud filtered from the white liquor is washed to remove residual cooking chemicals. The wash water, or weak wash, is sent to the recovery boiler dissolving tank. The washed lime mud is sent to the lime kiln where heat is added for conversion to lime. This calcined lime, along with purchased make-up lime, is used to supply the slaker.

Although many variations exist, this completes a typical Kraft recovery cycle as illustrated in figure 2. The next step is the preparation of the pulp for paper making.

Bleaching

The primary objective of bleaching is to achieve a whiter or brighter pulp. If a mill produces brown paper such as linerboard, a bleaching sequence is not required. However, if white paper such as writing or magazine paper is produced, bleaching is required. Bleaching removes the lignin which remains following digester cooking. Lignin is the source of color and odor for pulp.

The bleach plant has recently evolved to the most controversial area of pulp and paper production due to the formation of dioxin from chlorine bleaching. Environmentalists claim dioxin in pulp mill effluent is contaminating rivers while other studies indicate levels of dioxin in effluent are too low to pose any danger. Nevertheless, many technology changes have occurred in the past decade that have significantly reduced dioxin emissions.

Bleaching practices prior to 1980 used large amounts of chlorine to achieve the desired level of brightness. Although other stages using sodium hydroxide, chlorine dioxide, and hypochlorite were used, chlorine was the prime bleaching agent. Following each stage, washing was required to remove residuals. Large quantities of water were used following the chlorination stage where the majority of toxic byproducts are formed. Various methods of post bleaching treatment of effluent were used with mixed success.

Beginning in the mid-1980’s, mills began making significant changes due to increasing environmental awareness. One change is the increased use of oxygen (O_2) delignification prior to bleaching with chlorine and chlorine dioxide. This provides lignin removal with the benefit of chlorine-free effluent. This also allows for less chemical use in subsequent bleaching stages.

A second change is extensive reuse of washer filtrate to reduce fresh water usage. This reduces the amount of effluent to be treated prior to discharge from the mill. Some modern plants use totally enclosed pressure diffusion washers following O_2 delignification to further reduce toxic effluent.

Another change involves increased substitution of chlorine dioxide for chlorine gas. Chlorine dioxide does not release the chlorine ions responsible for forming dioxin. Although chlorine dioxide is more expensive to produce, it requires 2.5 - 3 times less to bleach the same amount of pulp. Some processes which use O_2 delignification prior to bleaching have achieved 100%.

Though evolution has caused dioxin emissions to decrease overtime, changes such as this will continue to take place in the future. Federal and state regulator agencies continue to disagree on allowable emission limits. Future technology will continue to move toward zero discharge limits for dioxins and other by-products of the bleaching process.

Stock Preparation

Pulp, as produced in the pulp mill, is not suitable for manufacture of most grades of paper. Properties must be added to the pulp which will aid in uniform sheet distribution and bonding of fibers. Two major steps used to impart desired properties are stock proportioning and mechanical treatment by beating and refining pulp fibers.

Stock proportioning involves the addition of other types of pulp and chemical additives to achieve a desired grade of paper. Different pulps, along with water, are added to achieve proper consistency. Consistency is defined as the percentage by weight of dry pulp fiber in a combination of pulp and water. Typical consistencies in the paper machine range from 1/2 - 3%. “Broke” pulp may also be added to the mixture. “Broke” pulp consists of paper breaks and trim ends from the paper machine which have been beaten in a broke repulper.

Various chemical additives are required to aid in proper sheet formation and drainage of water. Some additives and their effects are:

- Starch — improves paper strength and surface “feel” at the dry-end of the paper machine

- Alum — pH control and chemical retention onto pulp fibers

- Fillers — common fillers are clay, calcium carbonate, or titanium dioxide. These particles serve to fill gaps between fibers to produce a smoother, brighter sheet.

These are a few of the many additives that may be used. The chemical additives and various pulp are mixed in a blending chest and the mixture is commonly referred to as furnish.

Another step in pulp treatment involves mechanical action. The two most common treatments are referred to as beating and refining. This action tends to separate and shear pulp fibers which increases paper strength and allows fibers to more easily absorb water and additives. Two basic types of refiners are conical and disk refiners. Both types consist of rotating elements and a stationary housing to provide shearing action. Refining is often done in two stages. One stage involves treatment of virgin pulp fiber only and a second stage for treatment of virgin fiber, broke, and chemical additives.

Finally, the mixture of pulp and chemicals from the blending chest is pumped through refiners to the machine chest. The machine chest is also supplied by the save-all. The save-all screens fibers from white water drained from the paper sheet into the wire pit.

Paper Machine

Following stock preparation, the furnish is sent to the machine room for final sheet forming. Even though different types of paper machines exist for manufacture of various grades of paper, most all perform the same basic functions which can be divided into two broad categories. The “wet end” is where the pulp and water solution is spread onto a moving wire and dewatered to form sheet. The sheet then moves to the “dry end” for further evaporation of water and smoothing of the sheet. The type of machine used most today is the Fourdrinier paper machine.

The portion of the wet end that supplies stock to the machine is referred to as the approach system. Primary components in this system are the wire pit, machine chest, fan pump, basis weight valve, screens, and cleaners. The system involves the fan pump accepting a mixture of white water from the wire pit and stock from the machine chest. The basis weight valve controls the flow of stock from the machine chest to the fan pump. The mixture of stock and white water is pumped through screens and cleaners to the head box. Screen and cleaners remove undesirable particles such as dirt, grit and clumps of fibers, or chemical additives. The next step involving the head box and forming wire actually begins the formation of a paper sheet. The head box accepts stock and white water from the fan pump and is required to deliver a uniform flow onto the moving machine wire. Most modern head boxes are pressurized. Proper control for achieving an even and uniform outflow is critical for proper sheet formation. The continuous fine screen wire provides for the formation of a mat of fibers and drainage of water. Modern wires run at speeds of 3000 - 5000 feet per minute. Due to the high wire speeds, drainage is aided by a vacuum system found under the wire screen.

After initial sheet formation and dewatering, the sheet moves to the dry end of the machine. From the machine wire, the sheet is transferred to the press section. The press section rolls provide a mechanical means for water removal and pressure which consolidates and smooths the sheet. The sheet is conveyed through the various presses on a felt or synthetic fabric. The fabric provides for transfer of pressing forces onto the paper and volume space for removal of water and air. A paper sheet leaving the presses is typically at 30 - 35% consistency (70% water).

The paper sheet is now transferred to the dryer section where heat is applied to evaporate the moisture content to 5 - 10%. The system consists of a series of large diameter cylinders that are internally steam heated. The paper sheet is conveyed by a synthetic fiber over the cylinders where moisture is evaporated and carried away by a ventilation system. Condensate formed in the dryer cylinders is removed by siphons and returned to the powerhouse. Even drying across the entire sheet is a major challenge in this section.

Following drying, the paper is sent to the calendar where large roll presses consolidate the paper to its final thickness and smoothness. The calendar stack consists of hard cylinders capable of providing high compression forces. Paper from the calendar is fed onto spools and rolled into large reels. These reels are then processed to meet customer size specifications by the winder and roll finishing areas prior to shipment.

Utilities

So far, attention has focused on processing of the primary raw ingredient, wood. However, other raw materials such as water and electricity, as illustrated in figure 3, play important roles in the production of paper.

A paper mill requires large volumes of water for use throughout the process. Although a few processes can use raw water directly from the source, most users require a higher quality of water. Most water requires treatment in a sedimentation basin followed by filtration to remove suspended solids and other impurities. The degree of treatment required depends on the source of the water such as a river, lake, or well.

Additional treatment for removing dissolved minerals is required for water used in boilers. Failure to remove these deposits results in build-up of sludge and scale which eventually leads to operational problems in the boilers. The most common method employed to remove the dissolved minerals is with ion-exchange resins called demineralizers. Demineralized water production has a high capital and operating cost.

Water required for boilers demands special treatment. In addition to demineralizers, further treatment involving mechanical deaeration and chemical additives is required to remove oxygen. This ultra-pure water is used to produce steam in both the power and recovery boilers. Steam produced is used for both process heating and generating electricity with steam turbine generators. Dual use of fuel energy is called cogeneration. Since the cost of making demineralized water is high, it is important that clean steam condensate be returned to the boiler for reuse. A typical return rate is about 50%.

The other basic raw material, electrical power, is typically provided by a combination of own-make and a tie to the local utility. Own-make electricity is produced via high pressure superheated steam from the power and recovery boilers fed to steam turbines. The turbines extract energy from the steam which, in turn, drives an electrical generator. The power boiler produces steam from burning wood waste such as bark and is supplemented with coal or oil. In most cases, approximately 185 pound steam is sent to the digester and turbine while 80 pound steam is used in the steam room. Additionally, the recovery boiler burns black liquor as fuel.

Since a mill typically does not produce enough power to meet all of its electrical requirements, a tie is usually established with the local utility. This also allows the mill to remain in operation if their electrical production is curtailed or down completely. Most mills try to use as little purchased electricity as possible.

Waste Treatment

An important consideration for modern pulp and paper mills involves the effective treatment of water and air waste streams. Increased environmental awareness has led to stringent emission limits. This aspect of pulp and paper mills could be one of the most controversial and capital intensive areas in the future.

The primary concern for water is treatment of effluent which is returned to the source (river or lake). Water used in areas such as the pulp mill and bleach plant picks up contaminants which would make it harmful for fish and people. The waste effluent is typically treated in sedimentation clarifiers and/or aeration lagoons to remove contaminants. Although some methods are highly effective, future trends will be toward closed systems with no effluent waste stream.

Air pollution from pulp and paper mills involves both particulate and odor emissions. The major sources of particulate emissions involve power and recovery boilers. Fine particulate from various sodium compounds are emitted from recovery boilers and coarse particulate from burning wood waste in the power boiler. Treatment for particulate typically involves collection devices such as scrubbers or electrostatic precipitators.

Although odor emissions in general are not dangerous to the public, resentment due to the smell requires pollution control application. The various sulfur gases causing the odor are referred to a TRS (Total Reduced Sulfur). Since odor pollution is difficult to treat, in-process methods resulting in less generation of odorous gases is preferred. However, absorption of gases with wet scrubbers is often used to achieve final abatement.

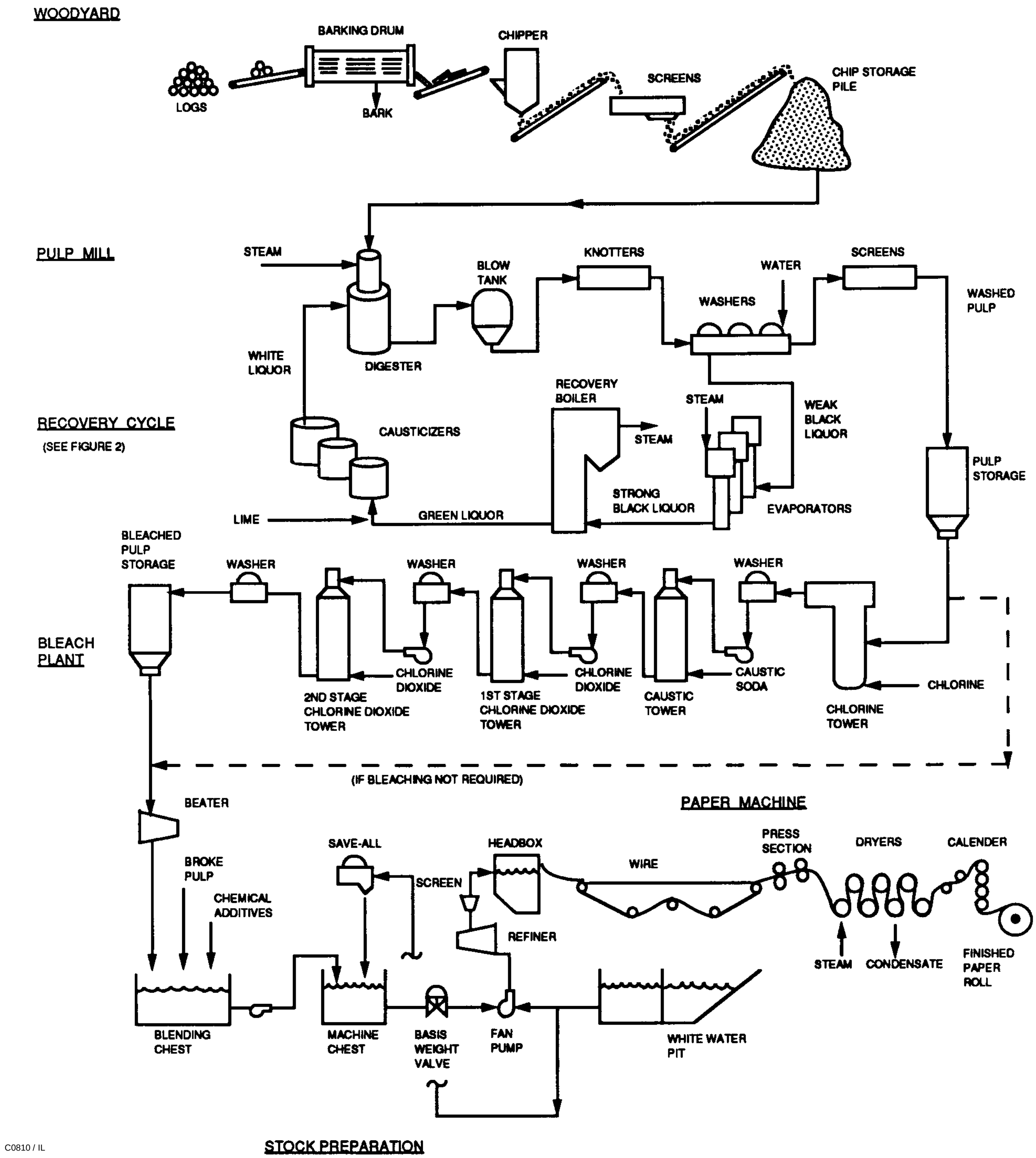


Figure 8-1. *Kraft Pulp and Paper Mill Process Overview*

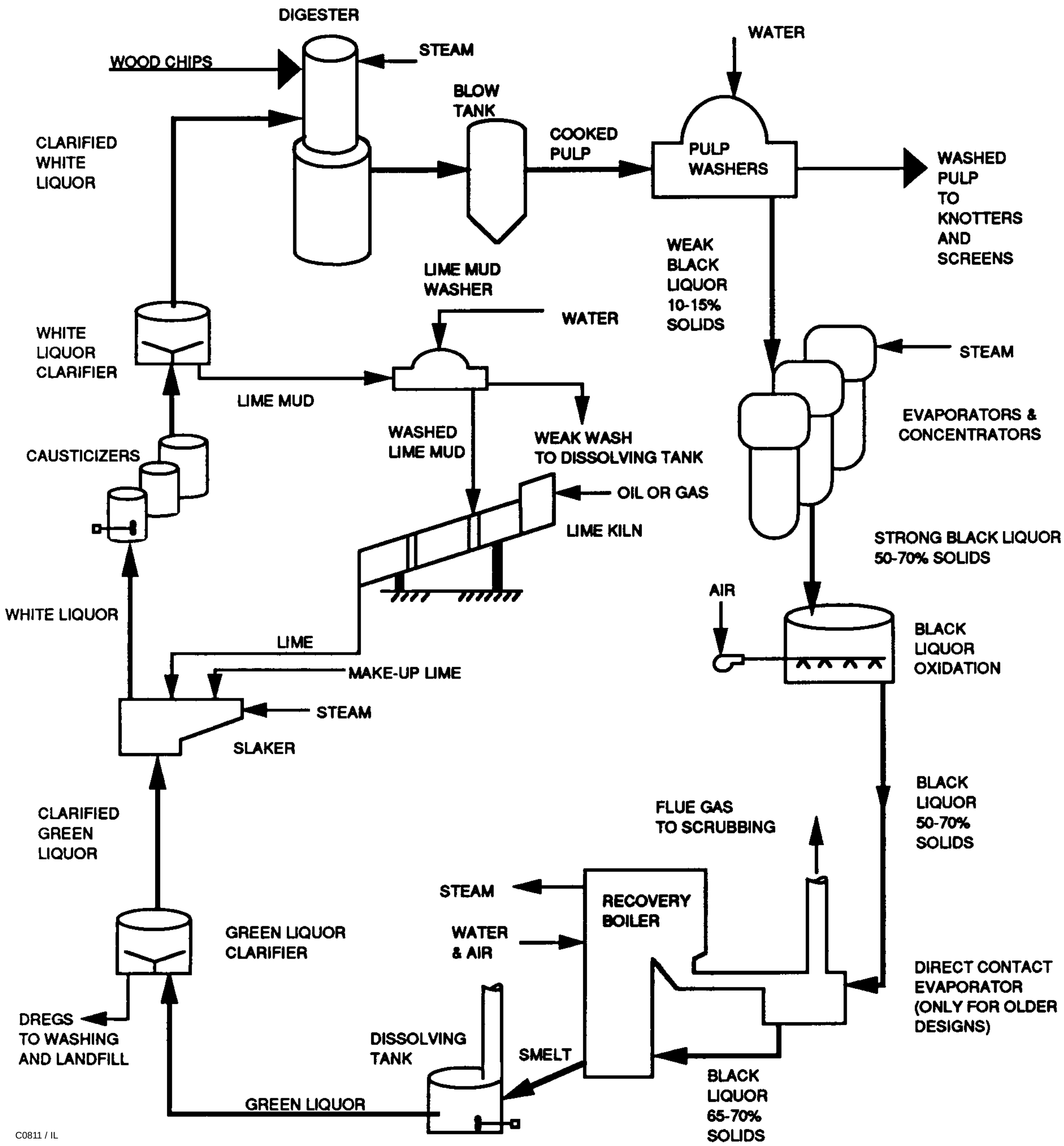


Figure 8-2. *Kraft Recovery Cycle*

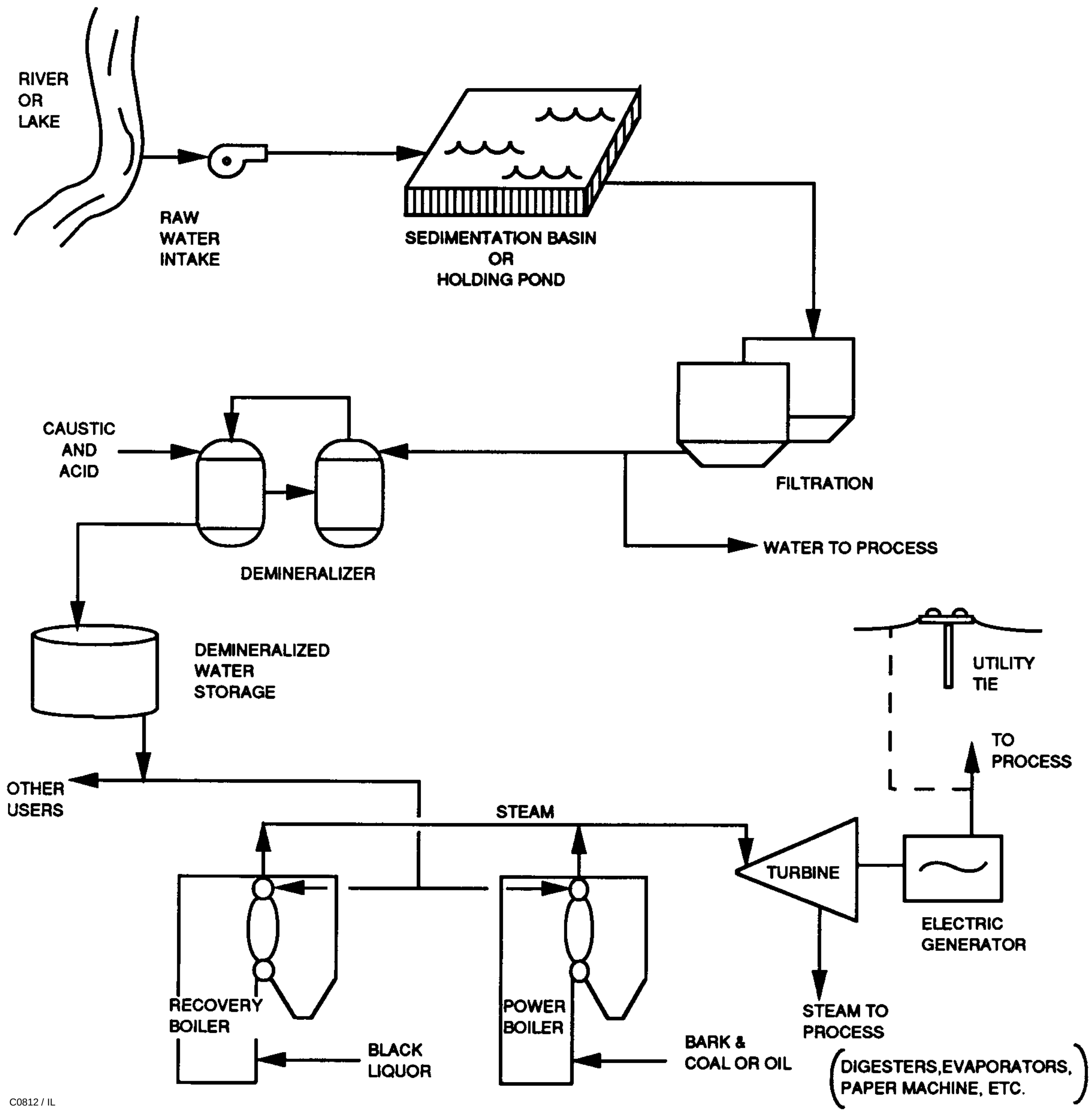


Figure 8-3. *Utilities*

Chapter 9

Pulping

Pulping is the process of converting wood material to separate pulp fibers for paper making. Processes range from purely mechanical, in which the wood is ground into fibers by refiners or grindstones, to chemical processes, in which the fibers are separated by chemically degrading and dissolving the lignin that binds fibers together. In many cases, mills will produce various grades of paper having both mechanical and chemical pulping processes.

Mechanical Pulping

Stone Groundwood

Process:

The most basic type of mechanical pulping is known as stone groundwood (SGW), and has been virtually unchanged since its development in the 1840s. This process involves rotating manufactured grindstones to be pressed against small wood logs that are oriented parallel to the axis of the stone where a typical modern SGW plant will consist of only four to six grinders to supply a large paper machine.

The quality of the produced pulp (strength and drainage properties) depends primarily on the surface characteristics of the stone. Water is added to wash away the torn fibers. Virtually all stones are artificially manufactured using a hard grit material, typically embedded with silicon carbide or aluminum oxide.

This process is a large consumer of electric power due to the rotating grindstone, and the pulp produced is typically used for the production of newsprint grade paper.

Refiner Mechanical Pulp

Process:

Commercial production of refiner mechanical pulp (RMP) began in 1960. It is produced in most modern mills using chips rather than logs and rigged metal discs used for shredding and grinding of the wood chips. The chips are ground between the rotating discs in a refiner, producing RMP.

This process is typically done in two separate stages operating in series, and produces a longer-fibered pulp than SGW. As a result, the pulp is stronger, freer, bulkier, and usually somewhat darker in color.

Thermomechanical Pulping

Process:

The first major modification to RMP was the addition of steam before the refiner. This is known as thermomechanical pulping (TMP). The steaming serves to soften the chips, resulting in the pulp having longer fibers and fewer shives than RMP. These longer fibers produce a stronger pulp than either SGW or RMP, making for a stronger final sheet of paper. This process is still employed on a large scale to produce high-tier pulps for newsprint and board.

Referring to figure 1, chips are fed by a feeding plug and screw feeder to a presteamer, which is heated by PCV-1 to typically 15 to 30 psig and 265 to 285°F. After a retention time of a couple of minutes, the pressurized chips are fed to the

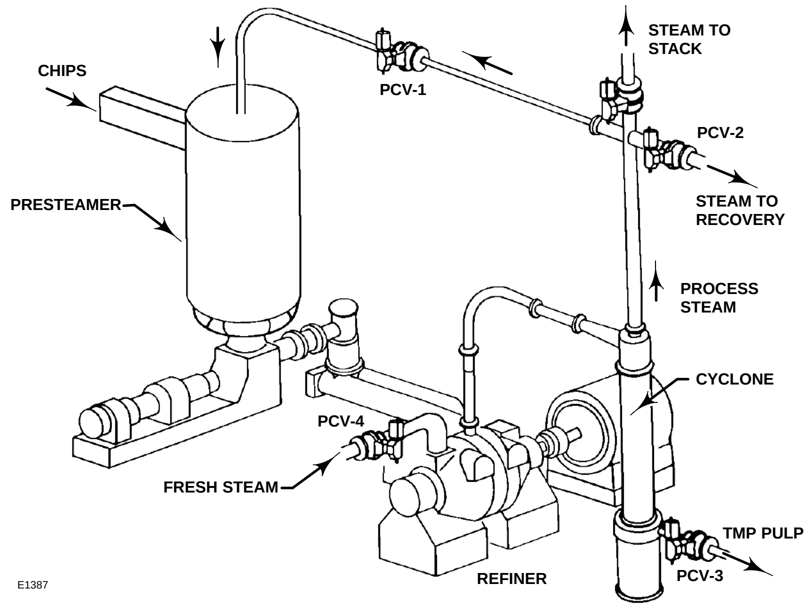


Figure 9-1. *Thermomechanical Pulping Process*

refiner. The refiner may then be fed with fresh steam via PCV-4, during startup, to increase the pressure to 60-75 psig or 300°F.

The refiner discharges the pulp and steam to the cyclone, which separates the steam from the pulp. The PCV-1 and PCV-2 valves control the pressure in the refiner. During production, this steam is sent to heat recovery, while during startup it goes to the steam stack for disposal. The TMP pulp (approximately 35% solids) is discharged through valve PCV-3 from the first stage refiner to the second stage, and from there, to further treatment in the screening and cleaning stages.

Valve Selection:

The control of clean steam from PCV-4 can be easily accomplished by the Fisher Vee-Ball segmented ball valve. Where fibers can build up and result in potential plugging problems, namely PCV-1 and PCV-2, the Vee-Ball has proven successful with its V-notch ball, as this shears through any pulp fibers. However, any use of the Vee-Ball attenuator must be evaluated with care. The Fisher Control-Disk can also be used in this service.

The TMP discharge, or blow valve, PCV-3 contains pulp at 35% consistency, and steam/condensate. Because of the high pressure drop of the system, this valve must withstand erosion. One solution is the Vee-Ball with stellited internals and trim, including the ball seal. The water control valve should be a Vee-Ball to ensure optimal control.

Valve Selection

Tag	Application	Recommended	Alternate
PCV-1, PCV-1	Steam (process)	Vee-Ball segmented ball	Control-Disk
PCV-3	Refiner Blow	Vee-Ball segmented ball w/ stellited trim	
PCV-4	Steam (fresh)	Vee-Ball segmented ball	Control-Disk
- - -	Water (control)	Vee-Ball segmented ball	Control-Disk

Chemithermomechanical Pulp

Process:

Wood chips can be pretreated with sodium carbonate, sodium hydroxide, sodium sulfide, or other chemicals prior to refining with equipment similar to a mechanical mill. The conditions of the chemical treatment are much less vigorous than in a chemical pulping process since the goal is to make the fibers easier to refine rather than removing the lignin as in a fully chemical process (described later in this section). Pulp made using these hybrid processes are known as chemithermomechanical pulp (CTMP).

Chemical Pulping

Chemical pulp is produced by combining wood chips and chemicals in large pressure vessels known as digesters (see chapter 3) where heat and the chemicals break down the lignin, which binds the cellulose fibers together, without seriously degrading the cellulose fibers. Chemical pulp is used for materials that need to be stronger or combined with mechanical pulps to give a product with different characteristics.

Sulfite

Process:

The sulfite process produces wood pulp, which is almost pure cellulose fibers, by using various salts of sulfurous acid to extract the lignin from wood chips in digesters. This process is used to make fine paper, tissue, glassine, and to add strength to newsprint. The yield of pulp is higher than Kraft pulping as the process does not degrade lignin to the same extent as the Kraft process, and sulfite is easier to bleach.

Sulfite pulping is carried out between a pH of 1.5 and 5, depending upon the counterion to sulfite and the ratio of base to sulfurous acid. The pulp is in contact with the pulping chemicals for four to fourteen hours, and at temperatures ranging from 265°F to 320°F, again depending upon the chemicals used.

The pulping liquor for most sulfite mills is made by burning sulfur with the correct amount of oxygen to give sulfur dioxide (SO_2), which is then absorbed into water to give sulfurous acid (H_2SO_3).

$S + O_2 \rightarrow SO_2$
$SO_2 + H_2O \Leftrightarrow H_2SO_3$

Care must be given to avoid the formation of sulfur trioxide (SO_3) as this produces sulfuric acid (H_2SO_4) when it is dissolved in water. This promotes the hydrolysis of cellulose without contributing to delignification (removal of lignin), and ultimately damages the cellulose fibers. This is one of the largest drawbacks of the sulfite process, and leads the pulp fibers not being as strong as Kraft pulp fibers.

The cooking liquor is prepared by adding the counter ions, such as hydroxide or carbonate salts. The relative amounts of each species present in the liquid depends largely on the amounts of sulfurous acid used.

For monovalent hydroxides (Na^+, K^+, and NH_4^+), MOH:

$H_2SO_3 + MOH \rightarrow MHSO_3 + H_2O$
$MHSO_3 + MOH \rightarrow M_2SO_3 + H_2O$

For divalent carbonates (Ca^{2+}, Mg^{2+}), MCO_3:

$MCO_3 + 2H_2SO_3 \rightarrow M(HSO_3)_2 + CO_2 + H_2O$
$M(HSO_3)_2 + MCO_3 \rightarrow 2\ MSO_3 + CO_2 + H_2O$

The spent cooking liquor from the process is known as brown or red liquor. Pulp washers, using countercurrent flow, remove the spent cooking chemicals and degraded lignin and hemicellulose. The extracted brown liquor is then concentrated in multiple effect evaporators. The concentrated brown liquor can be burned in the recovery boiler to generate steam and recover the inorganic chemicals for reuse in the pulping process, or it can be neutralized to recover the useful byproducts of pulping.

The most common recovery process used is magnesium-based sulfite pulping, called the “Magnefite” process. The concentrated brown liquor is burned in the recovery boiler, producing magnesium oxide (MgO) and sulfur dioxide, both of which are recovered from the flue gases created by the burning of the brown liquor. Magnesium oxide is recovered in a wet scrubber to give a slurry of magnesium hydroxide ($Mg(OH)_2$).

$MgO + H_2O \rightarrow Mg(OH)_2$

This magnesium hydroxide slurry is then used in another scrubber to absorb sulfur dioxide from the flue gases, producing a magnesium bisulfite ($Mg(HSO)_3$) solution that is clarified, filtered, and used again as the pulping liquor.

$Mg(OH)_2 + 2\ SO_2 \rightarrow Mg(HSO_3)_2$

Sulfate (Kraft)

Process:

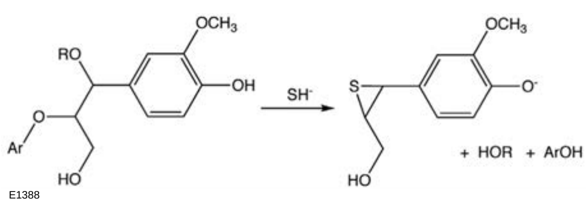
The sulfate or Kraft process is the dominant chemical process used by pulp mills today. The Kraft process involves cooking the wood chips under pressure in an alkaline solution of sodium hydroxide (NaOH) and sodium sulfide (Na_2S). This solution breaks down the glue-like lignin which binds the cellulose wood fibers together. This process produces stronger pulp than the other processes, but is darker in color than the other pulp processes. However, the benefit to this process is the wide range of fiber sources that can be used, and the regeneration of cooking liquors.

Woodchips are fed into digesters where they are impregnated with the cooking liquors of warm black liquor and white liquor (see chapter 3). The warm black liquor is spent cooking liquor coming from the blowtank. White liquor is a mixture of sodium hydroxide and sodium sulfide, produced in the Kraft recovery process. Delignification requires several hours of cooking at 265°F to 355°F. Under these conditions, the lignin and some hemicellulose degrade to give fragments solubility in a strongly basic liquid.

White Liquor:

$NaOH \Leftrightarrow Na^+ + OH^-$
$Na_2S + H_2O \Leftrightarrow 2Na^+ + OH^- + HS^-$

The lignin is removed by the following reaction, where the HS^- ion the component that ultimately removes the lignin.



The finished cooked wood chips are blown from the digester, and the action of the cooked wood chips hitting the walls of the blowtank produce individual pulp fibers. The solid pulp (about 50% by weight based on dry wood chips) is then collected and washed. The washing stages separate the cooking liquors from the cellulose fibers, where the pulp is brown after cooking and is known as brown stock.

The combined liquids, known as black liquor due to its color, contains lignin fragments, carbohydrates from the breakdown of hemicellulose, sodium carbonate, sodium sulfate, and other inorganic salts.

Recovery Process:

The excess black liquor is concentrated in a multiple effect evaporator (see chapter 4) into heavy black liquor, and burned in the recovery boiler (see chapter 5) to recover the inorganic chemicals for reuse in the pulping process. More concentrated black liquor increases the energy and chemical efficiency of the recovery cycle. The combustion is carried out such that sodium sulfate (Na_2SO_4) is reduced to sodium sulfide by the organic carbon in the mixture:

1. $Na_2SO_4 + 2\,C \rightarrow Na_2S + 2\,CO_2$

The molten salts (smelt) from the recovery boiler are dissolved in process water known as weak wash (see chapter 6). The solution of Na_2CO_3 and sodium sulfide results in green liquor. This liquid is mixed with calcium hydroxide ($Ca(OH)_2$) to regenerate the white liquor in the pulping process.

2. $Na_2S + Na_2CO_3 + Ca(OH)_2 \Leftrightarrow Na_2S + 2\,NaOH + CaCO_3$

Calcium carbonate ($CaCO_3$) precipitates from the white liquor and is recovered and heated in a lime kiln where it is converted to calcium oxide (lime).

3. $CaCO_3 \Leftrightarrow CaO + CO_2$

Lime is reacted with water to regenerate the calcium hydroxide used in reaction 2.

4. $CaO + H_2O \rightarrow Ca(OH)_2$

The combination of reaction 1 through 4 forms a closed cycle with respect to sodium, sulfur, and calcium. The recausticizing process where sodium carbonate is reacted to regenerate sodium hydroxide is the main reaction in the process where approximately 98% of the original chemicals are regenerated.

Chapter 10A

Digesters

Batch Digesters – Kraft Pulping

Kraft batch digesters have been produced in several different configurations, including rotating, horizontal, and spherical vessels. By far the most prevalent configuration is the upright, cylindrical batch digester.

Typically a batch digester is two to three and a half stories tall and has 2500 to 7000 cubic feet of capacity. The quantity of pulp produced per batch ranges from five to 25 tons.

Wood chips, chemicals, and steam are combined, coked under pressure to a schedule, and then dumped to a blow tank on a batch basis. Mills with batch digesters have been between four and 36 units. Some mills have both batch and continuous digesters.

There are two methods of heating batch digesters:

- **Directly steam batch digesters (figure 10A-1):** These units are the least complicated and are usually of older design. Steam at 50 to 150 psi is injected at the base of the digester into direct contact with the wood chips and cooking liquor.

- **Indirect steam batch digesters (figure 10A-2):** Cooking liquor is extracted from the digester through a screen to prevent removal of wood chips or pulp. The liquor is passed through an indirect heat exchanger and then recirculated to the top and bottom of the digester. Chip packing, air evacuation systems, and presteaming are incorporated with indirect heating to produce a more modern batch digester design. A relatively new derivation of the modern, indirectly steamed batch digester is the “low energy process.” The low energy process batch digester is covered later in the chapter.

A drawback to the directly steamed digester is the dilution effect from condensed steam. Indirectly steamed digesters; however, require more maintenance due to the screens, pumps, and external heat exchangers. Regardless of the digester steaming method, the process objective is the same: to elevate the temperature and pressure of the chip-liquor mass such that the alkaline component in the cooking liquor can dissolve the desired amount of lignin and extractives from the cellulose fiber.

Batch Digester Process Parameters

The Kraft pulping process is also known as the sulfate or alkaline process. The actual cooking liquor is a mixture of white liquor from the chemical recovery boiler and recausticizing operations, and black liquor (spent white cooking liquor), which has been separated from previous batches by brown stock washers. The main constituents in the white liquor that contribute to dissolving away the lignin binder material are NaOH and Na_2S. The Kraft cooking liquor is alkaline, or basic, with a starting pH above 13 units. The temperature of the cooking liquor, when added to the digester, is typically 160 to 190°F. The temperature of the wood chips is typically 60 - 80°F, but may be much colder in northern climates. The following paragraphs describe the various process parameters associated with the Kraft batch pulping process.

Chemical Concentration of Cooking Liquors

A key process parameter in the production of Kraft pulps is the chemical strength of the white cooking liquor being added to the wood chips in a digester. To achieve a target pulp yield at a target K (or Kappa) number, a specific quantity of white and black cooking liquors must be added per unit of

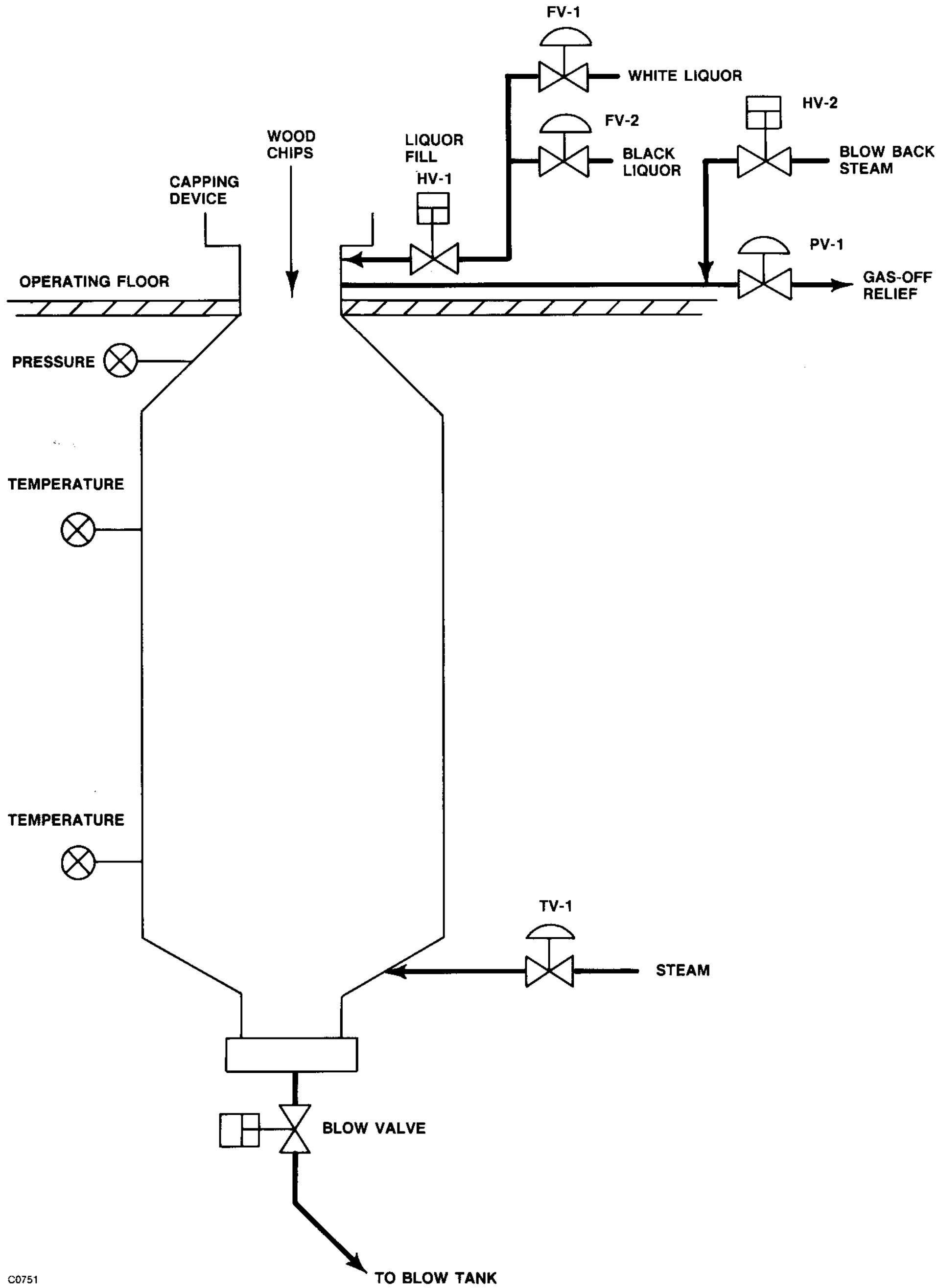


Figure 10A-1. *Directly Steamed Batch Digester*

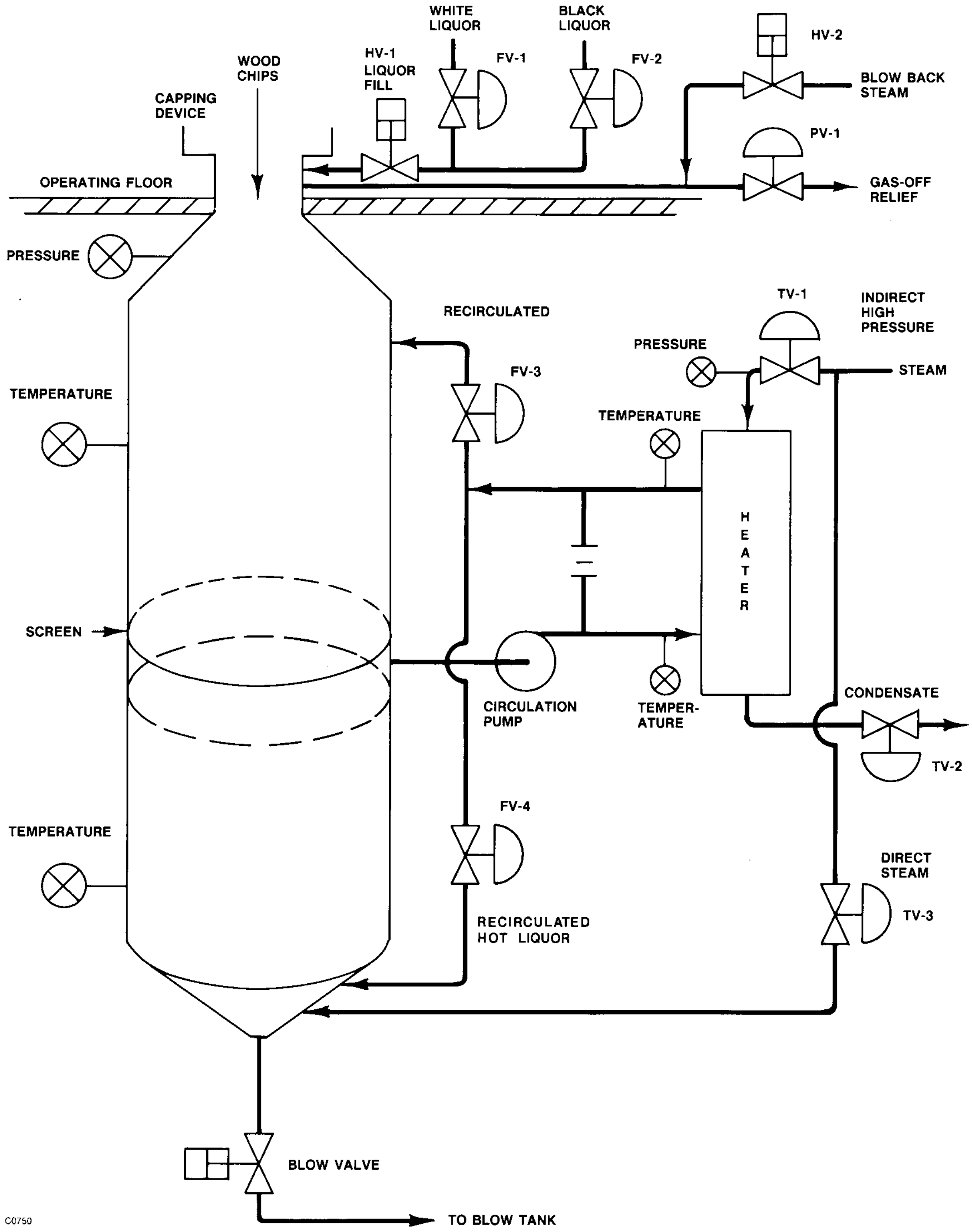


Figure 10A-2. *Indirectly Steamed Batch Digester* dry wood. However, these total liquor-to-wood and liquor-strength-to-wood ratios are difficult to enforce because on-line measurement of chip moisture and weight have proven unreliable, and the chemical strength of the white liquor solution is not a stable or directly measurable variable. Sensor developments in both areas are rapidly advancing.

Cooking Time

A digester begins to cook slowly as soon as the white liquor and black liquor solutions are applied to the wood chips (even at atmospheric pressure, i.e., before capping). Typically, a digester cooking cycle is as follows: the digester is capped, steaming is begun, and the temperature and pressure ramp up to a predetermined pressure (or temperature). Further steaming is then regulated to maintain the desired target pressure (or temperature). When the target “H” factor has been reached, the digester’s contents are blown to the blow tank.

The total length of the cooking cycle per batch digester will depend on the desired pulp grade and the mill’s criteria of operations. Consequently, a batch cooking cycle can range from two hours “cap-to-cap” for a hard cook (high yield), to five hours for a soft cook (low yield).

Cooking Temperature

The batch digester temperature is also a significant factor in achieving cooking uniformity (delignification) throughout the mass of chips. Higher temperatures accelerate the rate of chemical reaction between the wood chips and the cooking liquors. The quantity of rejects (i.e., knots or partially cooked chips) in a batch is related to uneven temperature distribution in the digester. For example, if poor convection mixing causes temperature differences between the bottom and top, it is not uncommon for pulp at the bottom of a digester to be several Kappa units different from pulp at the top of a digester.

Typically, a charged batch digester at atmospheric pressure is at around 165°F to 195°F. Upon capping and steaming, the maximum desired cooking temperatures will range from 330°F to 350°F at pressures of 100 to 120 psi. Normally, there is at least a top and a bottom temperature sensor on each digester. A middle temperature probe is encouraged for improved indication of temperature distribution. The bottom temperature usually exceeds the top temperature due to hydrostatic liquor head on directly steamed units, because the sensor is closer to the entry point of steam.

Cooking Pressure

Digester pressure rises as the steam flow to the digester raises the temperature of the chip and liquor mass. Batch temperature is considered to be the key variable, but batch pressure is an easier and faster variable to measure than a “representative” chip and liquor mass temperature. The pressure/temperature relationship is based on saturated steam tables. The implied digester temperature should include a slight increment for the boiling point rise of the cooking liquor. The elevated boiling point over water is due to organic and inorganic solids in the liquor. Digester pressure ranges from atmospheric at liquor charging to a maximum of 100 to 120 psi for the extended cooking period.

Digester pressure causes the cooking liquor to more readily impregnate the wood chips so that the delignification reactions proceed from the inside of the chip to the outside of the chip, as well as vice-versa. Pressure in a batch digester ranges from atmospheric at liquor changing to a maximum of 100-120 psi for the extended cooking period.

Pressure Profile

The batch digester cooking cycle is usually represented in text books by a graph of the internal digester pressure vs. time, such as that shown in figure 10A-3. In real life, the cooking cycle pressure profile is never this rigid. The time interval at each different phase of the cook can vary significantly from one grade of pulp to another and from mill to mill. Figure 10A-4 shows a more realistic representation of the pressure profile over the entire cooking cycle. Figure 10A-5 shows the steam demand profile required to complete this representative cooking cycle. The vertical axis defining the amount of steam demanded is not labeled because different pulp grades or different sized digesters will require different quantities of steam. However, a typical 3-hour cooking cycle at 100 psig consumes from 4000 to 6500 pounds of steam per ton of pulp produced. Therefore, a 7-ton digester could consume about 40,000 pounds of steam per cooking cycle.

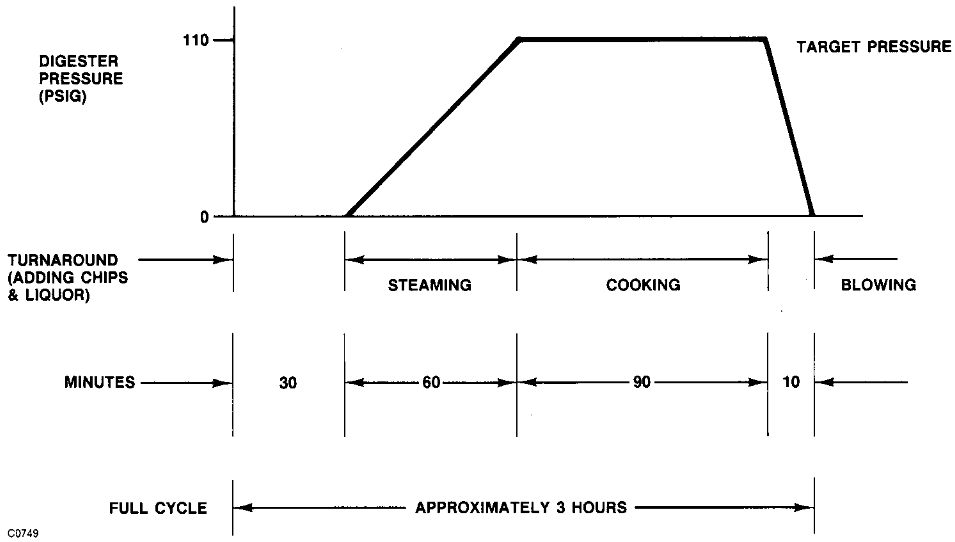


__Figure 10A-3.__ Theoretical Batch Cooking Cycle

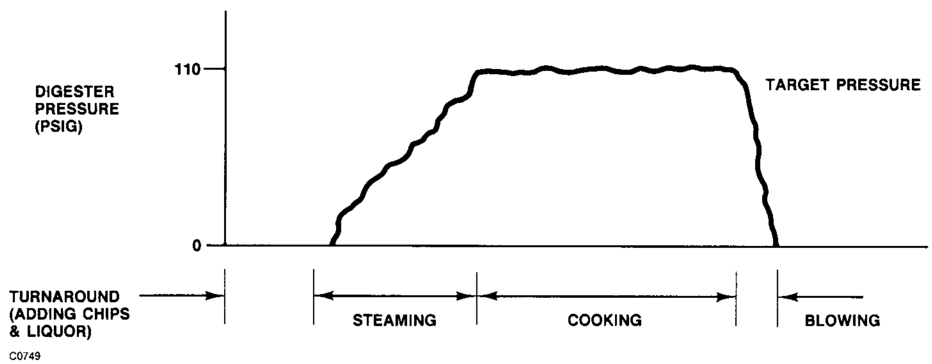


__Figure 10A-4.__ Actual Batch Cooking Cycle

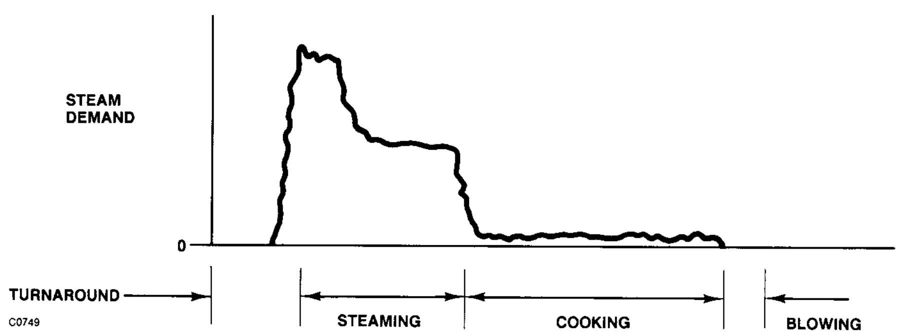


__Figure 10A-5.__ Steam Demand Profile

False Pressure

A batch digester is basically a large pressure cooker. As steam is applied to the mass of chips and liquor, a quantity of resinous vapors are distilled off. These vapors, along with air initially entrained with the chips and a small quantity of non-condensed steam, migrate to the top of the digester. These vapors and gases are systematically drawn off through the digester relief (gas off) piping. The vapors are a major source of the distinctive Kraft mill odor.

If the non-condensable portions of these gases are not relieved from the digester they would eventually accumulate sufficiently in the top of the digester to indicate a falsely high pressure relative to the steam saturation temperature. Under such conditions, the correct control action would be to reduce the steam flow to the digester. The cook would then take place at a steam saturation temperature corresponding to say, 102 psig instead of the 100 psig target. The resulting batch would be very undercooked and possibly ruined. Therefore, the non-condensable portion of the relieved gases must be removed from the digester in order to maintain the correct temperature-pressure relationship.

Overpressure

Overpressure of a digester means that the actual digester pressure is above the desired target. Overpressure may result from trying to maintain the proper temperature while false pressure exists (overshooting), or via exothermic reactions once the target pressure has been reached. For insurance and safety purposes, each digester will have an upper pressure limit rating. Overpressure exposes production personnel to a hazardous environment and is a contributor to off-quality pulp.

Relief or Gas Off

The previous discussions of digester overpressure and digester false pressure outlined the necessity for relieving excess gases from a digester. Figure 10A-1 shows a typical relief piping arrangement. When the gas off valve is open, the blow back valve must be closed. This interlock must exist for both safety and economic reasons.

In general, a relief line is connected to the neck of the digester through a relief screen. The screen prevents large quantities of cellulose fibers or chips from entering the relief line piping system. Liquor, being a fluid, can readily pass through the screen, but it is undesirable to allow any chemical loss to occur. All relief gases and liquids pass from their respective digesters into a common header. This header directs all such materials to a central separating device which separates non-condensable gases from condensable gases and liquor, pulp, etc. The non-condensable gases are quite odorous. These gases are usually scrubbed and/or burned in a lime kiln. The condensable gases, however, can contain, in addition to steam, a significant quantify of a valuable byproduct, i.e., crude turpentine. Three to four gallons of crude turpentine can be distilled off and recovered per ton of resinous southern pine pulp produced.

Blow Back

Blow back is basically a short reversal of steam flow through the gas off line to the top of the digester for the purpose of cleaning the relief screen and/or collapsing the steam bubble, which may form within the chip mass in the lower area of the digester. The sequence is typically: (1) shut off the high pressure steam valve to the base of the digester, (2) shut off the gas-off valve to the common header, and (3) open the blow back valve (see figures 10A-1 and 10A-2). This sequence allows high pressure steam to be briefly injected through the relief lines and into the top of the digester. The surge of high pressure steam blows the screen clean while the increased pressure from the top forces the chip mass down, collapsing the bubble. A blow back typically lasts only 10-30 seconds, and then the valves revert to the original status.

Blow Tank

When a digester cooking cycle is completed, the blow valve is opened to connect the digester with a common blow tank. The blow tank is a low pressure receiving vessel, which is usually capable of holding several blows. Several batch digesters producing the same grade of pulp will discharge into the same blow tank. The high pressure in the digester will blow the entire mass of chips and black liquor into the blow tank.

Typically, a blow tank is equipped with both vacuum and pressure relief valving systems because 100 to 120 psi is released when the blow valve is opened. A significant quantity of vapor will be flashed off the pulp and liquor as it enters the blow tank. A blow tank is not designed to withstand digester-like pressures and so the relief valve will pop if the outlet for gas-off is plugged with pulp. Similarly, flashed vapor to a condensing device can create sufficient vacuum to collapse a blow tank. The vacuum relief valve provides a margin of safety against such an occurrence. From the blow tank the brown stock is pumped to washing and screening stages.

Control Valve Selection

Digester Capping Valve

The chips are conveyed to the chip chute which is mounted directly to the capping valve (see figures 10A-1 and 10A-2). One of the most important valves, this valve is used to automate the chip filling operation. This is an erosive service as the chips impinge on the sides of the body and ball, so hardened materials and trim must be used. In addition, tight shutoff is necessary to ensure the appropriate pressure can be reached within the digester for chip cooking.

General Service Valves

Refer to figure 10A-1.

PROCESS			FISHER CONTROL VALVE PRODUCT DESIGN					
Valve Tag #	DIRECT STEAMED BATCH DIGESTER		V150	V300	V500	CV500	ED/ET	Typical Valve Size
	Application Description	Control Function						
HV-1	Liquor fill	O/O				P		10”
FV-1	White liquor to digester	T	S	S		P		8”
FV-2	Black liquor to digester	T	S	S		P		8”
HV-2	Blow back steam valve	O/O			P			2”
PV-1	Gas off	T			P			3”
TV-1	Cooking valve	T			S	P		8”

Refer to figure 10A-2.

PROCESS			FISHER CONTROL VALVE PRODUCT DESIGN					
Valve Tag #	INDIRECTLY STEAMED BATCH DIGESTER		V150	V300	V500	CV500	ED/ET	Typical Valve Size
	Application Description	Control Function						
HV-1	Liquor fill	O/O		S		P		10”
FV-1	White liquor to digester	T		S		P		8”
FV-2	Black liquor to digester	T		S		P		8”
HV-2	Blow back valve	O/O			P			2”
PV-1	Gas off	T			P			3”
TV-1	Indirect steam valve	T			S	P		3”
FV-3	Digester top recirculation	T				P		8”
FV-4	Digester bottom recirculation	T				P		8”
TV-2	Condensate return	T			P		S	3”
TV-3	Direct steam valve	T			S	P		6”

CODE:
P = Primary selection, S = Secondary selection, T = Throttling, O/O = On/Off

Batch Digester – Low Energy Process

Much has been written about the relatively new low energy cooking process. Studies indicate improved pulping properties and operating efficiencies over conventional batch digesters. Some of the reported benefits of the low energy process are:

- Significant steam savings
- Reduced evaporator load
- Lower black liquor viscosities
- Lower alkali consumption
- Fewer brown stock washing stages
- Stronger pulp
- Lower environmental impact

The Process

The main difference between the low energy cooking process and a conventional batch digester is the tank farm associated with the heat recovery system. Accumulator tanks are added with each "stage" of process. A typical three-stage design is shown in the process schematic (see figure 10A-6). Actual mill installations have duplicate sets of pumps, valves and piping to handle odd and even digesters. Also there are typically sets of "A", "B", and "C" accumulator tanks. This arrangement allows for operations flexibility.

The function of the tank farm and management of the transfer of liquors is key to understanding the low energy process and cooking cycle. First, empty digesters are filled with wood chips. If desired, packing of the chip bed can be accomplished with steam or liquor. Steam provides higher compaction. Compaction of the bend increases capacity of the cook.

Cool black liquor from the atmospheric "A" tank is added to provide a liquor pad in the bottom of the digester. Warm black liquor from the pressurized "B" tank is then pumped into the digester displacing entrained air. The discharge valves are then closed. The warm liquor pump brings the digester up to pressure by pre-impregnating the chips and hydraulically filling the vessel.

The chips are further heated by pumping both hot black and hot white liquor into the digester. The white liquor is preheated through an indirect heat exchanger between the "C" and "B" tanks using hot black liquor as the heat source. The hot white liquor is then stored in a pressurized accumulator tank for delivery to the digesters. Warm black liquor is displaced to the "A" tank where soap is skimmed and excess liquor is sent to the weak liquor filters.

After completion of the hot liquor fill operation, the pulp mass is generally close to the required cook temperature and pressure. If necessary, further heating is done by an external liquor heater.

As the pulp is cooked, resinous vapors are given off. These vapors, along with any remaining entrained air, migrate to the top of the digester. These gases are systematically drawn off through the digester relief valve. If these gases were not drawn off a false pressure relative to the steam saturated temperature would be indicated. Under such conditions the control action might be to reduce steam to the digester and thus undercook the pulp. From time to time between relief cycles, steam is blown back through the relief line to clean debris off the relief screens.

Once the proper degree of cooking (H-factor) has been reached, cooking is stopped by pumping washer filtrate into the bottom of the digester. Most of the cooking liquor remains hot and is displaced to the "C" tank, ready to use for the next cook. The cooler liquor goes to "B" and "A" tanks. As a result, the pulp in the digester is washed and cooled below flash point at atmospheric conditions. This in-digester washing reduces load on both the brown stock washers and evaporators. The pulp is then transferred to the blow tank by cold-blowing the digester with compressed air. A high pressure air receiver is used for this air supply. Since the pulp is blown cool a number of benefits arise including improved pulp quality and lower emissions of total reduced sulfur.

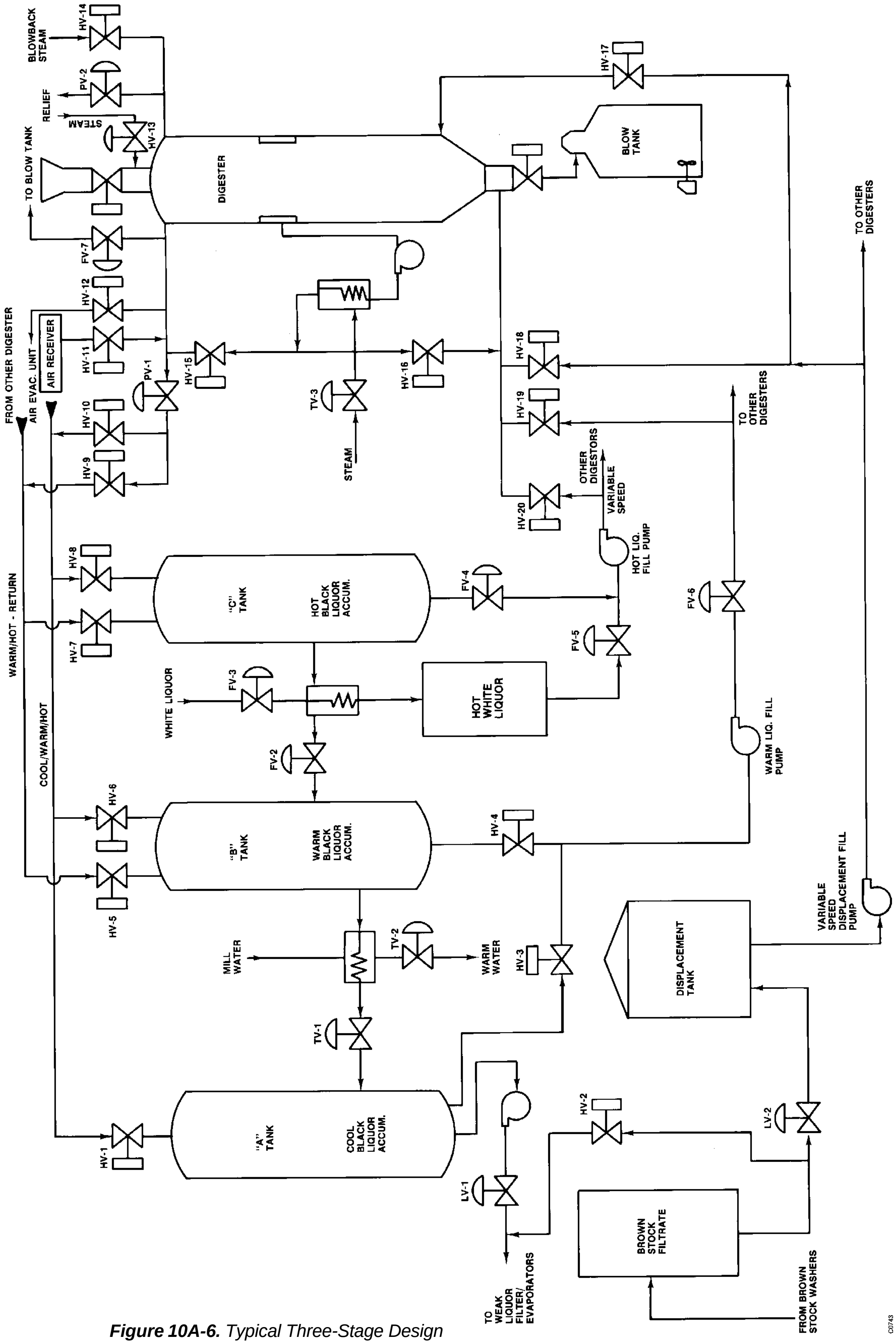


Figure 10A-6. *Typical Three-Stage Design*

Control Valve Selection

General Service Valves

Refer to figure 10A-6.

PROCESS			FISHER CONTROL VALVE PRODUCT DESIGN							
Valve Tag #	WARM BLACK LIQUOR ACCUMULATOR		V150	V200	V300	V500	CV500	A81	Control-Disk	Typical Valve Size
	Application Description	Control Function								
HV−4	Warm liquor to warm fill pump	O/O						P	S	14”
TV−2	Mill water temperature control valve through cooler	T	P						S	6”
HV−5	Digester liquor return header	O/O						P	S	12”
HV−6	Digester liquor return header	O/O						P	S	12”
FV−2	Warm liquor flow through liquor cooler	T			P				S	4”
FV−6	Warm fill control valve	T			P				S	10”

Refer to figure 10A-6.

PROCESS			FISHER CONTROL VALVE PRODUCT DESIGN								
Valve Tag #	WARM BLACK LIQUOR ACCUMULATOR AND DISPLACEMENT TANK		V150	V200	V300	V500	CV500	A81	Control-Disk	ED/ET	Typical Valve Size
	Application Description	Control Function									
HV−1	Digester liquor return header	O/O						P	S		12”
HV−2	Displacement tank bypass	O/O						P	S		12”
LV−1	Cool liquor level control valve to liquor filter	T	P						S		10”
TV−1	Warm liquor to cool-temp control	T							S	P	2”
HV−3	Cool liquor pad to warm fill pump	O/O						P	S		12”
LV−2D	Brown stock filtrate level control	T	P						S		12”

Refer to figure 10A-6.

PROCESS			FISHER CONTROL VALVE PRODUCT DESIGN								
Valve Tag #	HOT BLACK LIQUOR ACCUMULATOR AND WHITE LIQUOR ACCUMULATOR		V150	V200	V300	V500	CV500	A81	Control-Disk	ED/ET	Typical Valve Size
	Application Description	Control Function									
HV−7	Digester liquor return header	O/O						P	S		10“
HV−8	Displacement liquor return header	O/O						P	S		10”
FV−3	Cool white liquor to heat exchanger	T			P				S		6”
FV−4	Hot liquor to hot fill pump	T			P				S		8”
FV−5	Hot white liquor to hot fill pump	T			P				S		10”

Refer to figure 10A-6.

PROCESS			FISHER CONTROL VALVE PRODUCT DESIGN								
	DIGESTER										
Valve Tag #	**Application Description**	**Control Function**	**V150**	**V200**	**V300**	**V500**	**CV500**	**A81**	**Control-Disk**	**ED/ET**	**Typical Valve Size**
HV−9	Digester hot header return	O/O						P	S		10”
HV−10	Digester warm header return	O/O						P	S		10”
PV−1	Digester main pressure control valve						P				12”
HV−11	Air to receiver to digester	O/O						P	S		6”
HV−12	Digester air evacuation	O/O						P	S		12”
FV−7	Relief to blow tank						P				9”
HV−13	Digester steam packer valve						P				8”
PV−2	Digester relief to hot accumulator						P				3”
HV−14	Digester relief screen blow back						P				3”
HV−15	Digester top recirculation	O/O						P			12”
TV−3	Digester sparger steam valve									P	3”
HV−16	Digester bottom recirculation	O/O						P			12”
HV−17	Digester cone flush dilution	O/O					P				9”
HV−18	Digester displacement fill	O/O						P			10”
HV−19	Digester warm fill inlet	O/O					P				12”
HV−20	Digester hot fill inlet	O/O						P			10”

CODE:
P=Primary Selection, S=Secondary selection, T=Throttling, O/O−=On/Off

Kamyr® Continuous Digesters

Kamyr® continuous digesters vary depending upon the type of raw material, end product, the cost of chemicals, steam or power, as well as geographical location of the mill. There are five basic configurations:

- Single vessel hydraulic digester (the original design).

- Two vessel hydraulic digester (with separate high pressure impregnation vessel).

- Single vessel steam/liquor phase digester (with high pressure feeding system). Developed primarily for sulfite cooking, it has also been used for Kraft, pre-hydrolysis Kraft, and neutral sulfite semi-chemical pulp.

- Two vessel steam/liquor phase digester (with separate high pressure impregnation vessel)

- Steam/Liquor Phase Digester (with asthma feeder) used for pulping sawdust, shavings or non-wood fibers such as straw, bamboo, jute, etc.

The single vessel hydraulic digester was the original Kamyr digester. It is so named because the digester consists of a single vessel, which is operated completely full of liquor (no vapor being present). Digester heating is accomplished by heating the cooking liquor indirectly in heat exchangers using 150 to 175 psi steam and circulating this heated cooking liquor through the downward flowing chips in the digester vessel.

Over the years, this hydraulic digester system has constantly improved. The modern single vessel hydraulic digester has an improved steaming and feeding system, which improves its tolerance of dry and degraded chips. The combination improved cooking circulations and steps in the vessel diameter have made it possible to produce a more uniform pulp, with a poor quality of chip furnish.

The main features of a hydraulic digester are:

- Metering and steaming of the wood chips.

- Feeding chips to the digester via the high pressure feeder and top circulation loop.

- High pressure impregnation of the chips with cooking liquor.

- Heating to cooking temperature through liquor circulation, using indirect heating.

- Hi-heat-in-digester washing followed by a diffusion washer.

The hydraulic type digester with its long impregnation and cooking times produces a very uniform, high quality, strong pulp and is suitable for the production of either liner grade or bleachable grade pulps.

The two vessel hydraulic digester was originally designed to provide optimum pulp quality in very large digester systems (above 1200 TPD), but has been used for smaller tonnages.

For large tonnages, the digester vessel becomes large in diameter. This, in turn, makes it more difficult to ensure uniform circulation in the normal cooking liquor heating system.

In order to ensure uniform heating of the larger chip mass, an impregnation vessel is added to heat the chips to cooking temperature before they enter the second vessel (digester). This allows for all of the chips to be heated to exactly the same cooking temperature, helping to optimize pulp uniformity.

This digester is essentially unaffected by varying chip furnish, as there is a homogeneous chip mass throughout the chip column which explains a growing use of the two vessel digester system.

Process

Regardless of the type, a Kamyr continuous digester combines the digesting and washing process into one vessel so that only one washing stage is required following the blow tank. Chips from the wood yard are fed to a surge bin (chip bin) in the digester building. They are then metered continuously through a chip meter to a low pressure feeder. The chips then fall into the steaming vessel, and are conveyed to the chip chute and the high pressure feeder. Chips are then sluiced to the top of the digester and the top separator at a predetermined temperature and pressure. Cooking liquor is also fed continuously into the top of the digester in the desired ratio to the wood chips. The chips move slowly by gravity to the bottom where they are discharged as pulp. Along the way, they are heated to simulate the heating of a batch digester and its contents. The temperature is varied in the mid-section, or cooking zone, to suit different production rates. The bottom digester section is used as a washer and, at this point, any similarity between batch and continuous cooking ends.

With a vacuum drum washer, liquor is drained from the pulp and replaced by water. In the Kamyr digester wash system, the liquor is displaced by introducing very weak black liquor from the vacuum washer, diffuser or even warm water at the bottom of the digester, making it flow counter-currently to the pulp mass which is moving to the bottom. This is known as “hi-heat” diffusion washing. The up-flowing weak black liquor wash displaces the stronger residual black liquor, which is drawn off through a screen in the wall of the digester located about half-way up from the bottom, but below the cooking zone. This allows the pulp to be effectively washed before it is blown to the blow tank.

Although all components of the Kamyr digester are closely interrelated, the following is a logical step by step explanation of controlled loops, which will provide an understanding of the various stages of the Kamyr system.

Pressurizing

Weak black liquor (filtrate) or warm water, approximately 170°F, is pumped to the digester through the cold blow pump. There, it is used to maintain digester pressure. The digester pressure control system has three major components:

- An automatic pressure control valve on an input liquor line.
- An automatic pressure relief control valve on the digester relief line.
- A pressure pump kick-out switch on the digester.

The digester pressure can be controlled by moving the set point on the input control valve to 165 psig (normal digester pressure). A rise in the set point would then cause the valve to open to admit more liquor to the digester and, therefore, increase the pressure. The reverse occurs when the pressure set point is lowered. This is a rapid response controller.

The secondary pressure control element consists of the automatic relief valve, which bleeds liquor from the lower cooking zone header to the No. 2 flash tank. The relief valve is set slightly higher (15 psig) than the input valve and bleeds off liquor when the pressure exceeds this set point. The relief valve should always be in a closed position under normal conditions. It is only used as a pressure relief valve.

The third control device is primarily an emergency safety device, which is activated when the first two control devices fail. A pressure switch is mounted on the digester shell and stops the cold blow pump when the pressure rises too high. Digester pressure is normally set at 165 psig, the pressure relief valve is set on 180 psig, and the pressure switch at 225 psig. As the pressure continues to rise, the make-up liquor pump will kick-out.

Chip Feeding

Processed chips from the wood room are transmitted to the chip bin, which also serves as a short term chip storage bin. This storage can facilitate continued digester operation during small upsets between the wood room and the digester building. Chips flow by gravity from the bin through a tapered hopper into the chip meter. The chip meter is a rotating star feeder with seven pockets yielding a certain volume of chips per revolution. Digester production is regulated by a variable

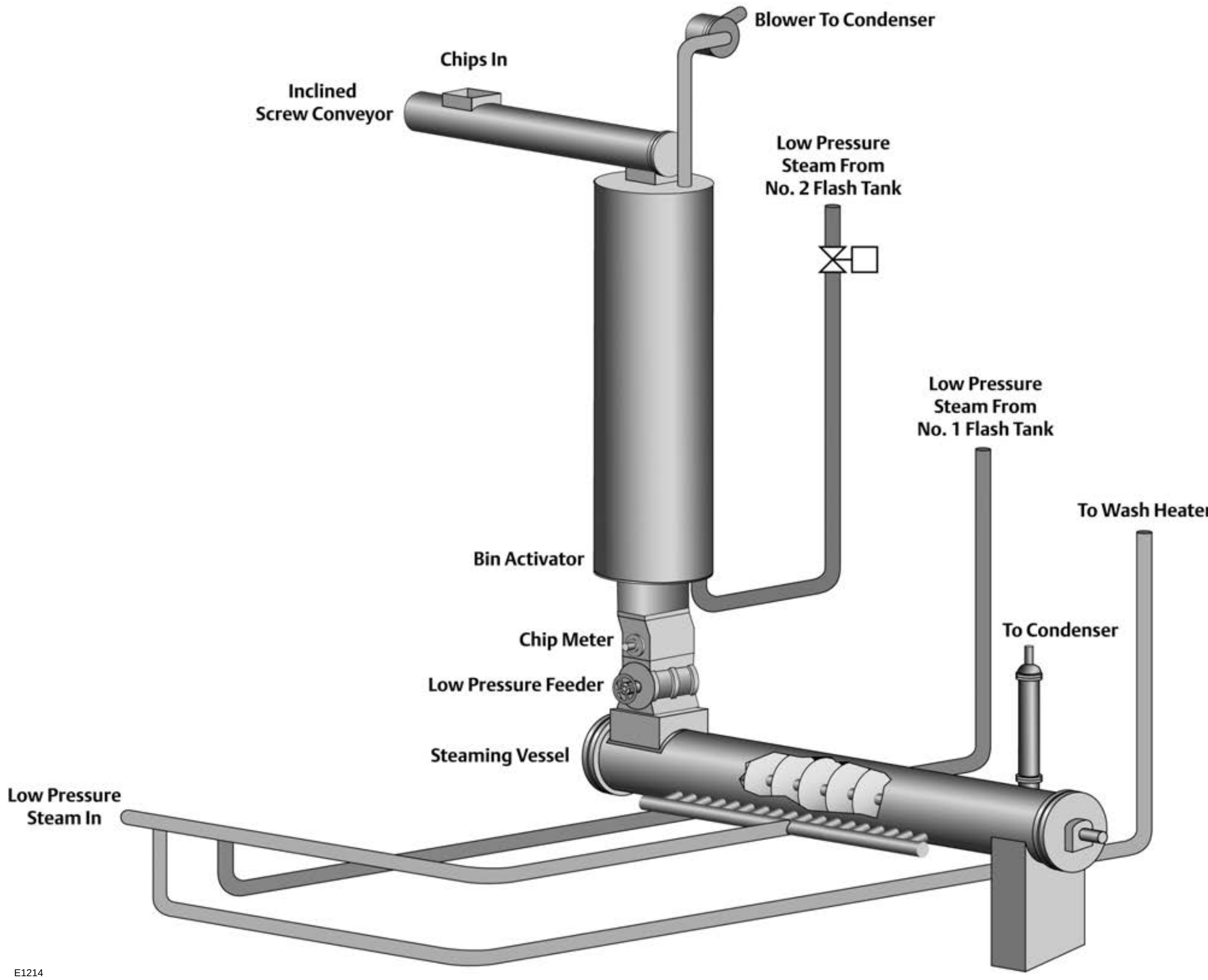


Figure 10B-1. *Chip Feeding*

speed drive on the chip meter drive. It is important to keep the chip meter full in order to maintain a steady feed rate. A vibrator is provided on the chip hopper for intermittent use, as required, to ensure a steady feed of chips to the chip meter.

Chips leaving the chip meter drop into a second feeder, called a low pressure feeder. It is simply a continuously rotating, tapered star feeder, which forms a seal between atmospheric pressure and 15-18 psig of the next stage. Its primary function is to prevent steam leakage and to deliver chips to the steaming vessel. Steam is injected into the ends of the rotor housing in order to blow sawdust and chip fines out. The pressure remains in the empty pocket after the chips have dropped out and is relieved through a pipe connected to the top of the chip hopper. To ensure a steady feed, the low pressure feeder is designed so that one pocket is being filled with chips, one pocket is discharging chips, and one pocket is relieving steam to the chip hopper.

Valve: TV-2A Chip bin temperature

This valve provides an alternate source of low pressure steam to the steaming vessel where the wood chips are pre-steamed at atmospheric pressure.

- Typical process conditions:
  - — Fluid: Steam
  - — T = 325 – 400°F
  - — P = 60 – 80 psig

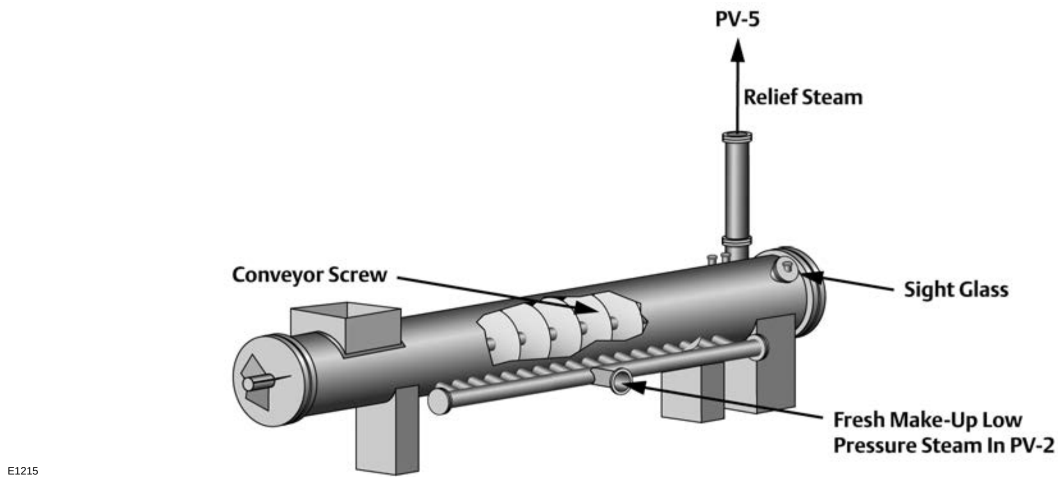


Figure 10B-2. *Steaming Vessel*

— dP = 50 – 60 psid
— Q = 2900 – 5000 lbs/hr

- Typical valve selection:

  — This is specified by Kamyr as a NPS 8 to NPS 10 Fisher Vee-Ball™ V150 valve, and could need an attenuator. Carbon steel body material has been used successfully, although stainless steel would provide an added level of durability. HD metal seats are specified with PTFE packing, PEEK bearings, and Nitronic 50 shafts.

Valve: TV-4 Fresh steam to chip bin

This valve provides hot water to the chip bin.

- Typical process conditions:

  — Fluid: Hot water
  — T = 312°F
  — P = 230 psig
  — dP = 135 – 145 psi

- Typical valve selection:

  — This valve is specified by Kamyr as a NPS 1/2 globe valve with a 300 lb. rating. A reduced port may be needed depending upon flow requirements. A carbon steel body is suggested with 316 SS equal percentage trim.

Pre-steaming and Conditioning

The steaming vessel is a normally horizontally mounted cylinder with an internal screw conveyor for carrying chips along from the low pressure feeder through steam to the next stage. Its main functions are to remove gases and air from the chips, raise the temperature to approximately 250°F, and bring the chips to a more uniform moisture content. A secondary aim is to maintain a pressure balance in the feeding system. This means that the steam pressure (15-18 psig) in the steaming vessel must always be higher than the vapor pressure of the liquor in the top circulation line so that the latter does not start to boil when it leaks back into the chip chute low pressure area. Removal of air and gases enables the cooking liquor to penetrate the chips more easily.

The steam is supplied from two sources: flash steam from the No. 1 flash tank and from a fresh make-up low pressure steam header.

In order to obtain an effective pre-steaming, the steam is introduced at the bottom of the steaming vessel (bottom steaming). There are no controls on the steam from the flash tank as it is dependent upon extraction flow from the digester. The venting of exhaust and non-condensable gases controls the amount of fresh steam usage. The exhaust line is equipped with a screen that prevents sawdust and fine particles from being carried into the heat recovery area.

After passing through the steaming vessel, the chips fall from the end of the screw conveyor, down a chute known as the chip chute, into a pool of liquor. At this point, the chips start to absorb liquor. An inspection port is provided on the steaming vessel for the monitoring of the flow of chips into the chute.

The chip chute is a vertical pressure vessel with an internal slotted screen plate. It sits directly on top of the high pressure feeder. The liquor in the chip chute is maintained at a constant level by the use of a level control valve on the overflow line, which carries excess liquor to a surge tank known as a level tank. The source of chip chute liquor is mainly leakage from around the high pressure feeder and some steaming vessel condensate. In order to take sudden flow surges, such as when the high pressure feeder starts rotating or when chips fall into the chute, the overflow control valve response is extremely rapid. The screen plates prevent chips from being carried with the overflow to the level tank, and keep the chips in the chip chute to feed the pockets of the high pressure feeder.

A pressure switch is connected to the make-up liquor pump from the same pressure-sensing unit that stops the cold blow pump. This safety device is necessary to avoid over-pressurizing the digester and it is set at approximately 240 psig.

The digester operates at 165 psig, measured at the bottom heating zone. The transfer of chips and liquor from a 15-18 psig steaming vessel pressure to the digester operating pressure needs to be accomplished via a pressure lock system. This is accomplished by the high pressure feeder, which is similar to the low pressure feeder. The high pressure feeder has a tapered rotor with four helical type pockets which go from one side of the rotor to the other and are set at an angle of 45° to each other. The feeding of chips is continuous. Two liquor pumps are used to aid in filling and discharging the high pressure feeder. They are as follows:

1. ***Chip chute pump —*** *Chips falling into the chip chute pool of liquor tend to float or be drawn to the side screen plates by the liquor overflowing to the level tank. In order to counteract this effect, the chip chute circulating pump is set to pull or suck the chips downward into the rotating high pressure feeder with a force greater than the sideways pull of the overflowing liquor. The discharge of the pump re-circulates the liquor to a point located above the pool of liquor in the chip chute. When severe conditions of sawdust and fines are prevalent, an in-line grainer may be installed between the pump discharge and the entry above the pool of liquor. Its function is to take liquor around the screen section, thus cutting down on the sideways pull of overflowing liquor. The pressure drop across the screens will reduce, allowing the natural wiping action of moving chips to keep the screens from plugging. As the pump will deliver 2,000 - 2,500 GPM, closing the valve between the in-line drainer and the level tank will allow the in-line drainer to clear itself by liquor flow to the chip chute.*

2. ***Top circulation pump —*** *The pump circulates liquor to the top of the digester and back out. Its action is to flush the chips out of the feeder pocket once it has rotated to the discharge point and to carry the chips into the digester. The liquor is then separated from the chips via the top separator screen and returned to the suction of the pump to form a continuous loop.*

When a pocket is in a vertical position, the chips are fed with the help of the chip chute pump. When the pocket has rotated 90° to a horizontal position, the chips are flushed out into the high pressure system with the liquor from the top circulation pump. The whole system is arranged so that there is always one pocket being filled while another is being emptied.

As mentioned previously, there is liquor leakage around the rotor due to the pressure differential between the operating digester pressures and the pressure in the chip chute and steaming vessel. This liquor leakage is an important feature of the high pressure feeder operation, as it provides constant lubrication between the feeder plug and housing, and washes sand and grit from this area. As the liquor is at a high temperature, it will boil in the chip chute unless held under higher pressure than the vapor pressure of the liquor. This is particularly true following a shutdown when heat rises to the top of the digester from the cooking zones due to convection currents. The hot liquor boils rapidly, or flashes, at the high pressure feeder and chip chute if the high pressure feeder is started. Therefore, the high pressure feeder must never be started unless the top section of the digester is first cooled below 240° F by addition of cold filtrate through the make-up liquor pump. The plug clearance is adjusted from time to time as it wears. Excessive wear of gap between the plug and housing allows too much liquor to pass to the chip chute and overloads the make-up liquor pump due to excess flow of liquor from the level tank to the make-up liquor pump. This can cause liquor to back up through the level tank into the chip chute and even back up as far as the chip bin. The high pressure feeder serves to complete the transfer of the chips from 15 psig to digester pressure without subjecting the chips to any harsh mechanical action, which would damage the fiber and degrade the resulting pulp quality.

The top circulation line, a part of which is a hole through the high pressure feeder, is a part of the digester vessel itself during normal operation. This means that it is under the influence of the digester

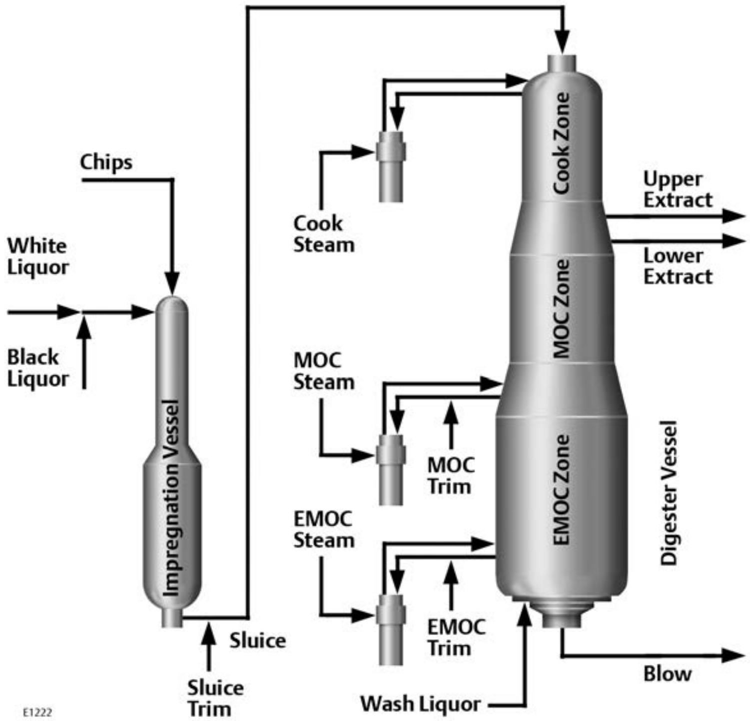


Figure 10B-3. *Cooking Flow Diagram*

pressure control valve. Two large piston-operated valves are designed to isolate the top circulation line from the digester. These valves cannot be opened unless there is equal pressure on each side of the valve. This prevents damage to piping and valves by a sudden surge of liquor from the digester flowing into the lines. A pressure switch is mounted on the return leg and is set to hold the valves closed until the pressure in the line is almost equal to that in the digester. Only then can these valves be opened by hand switches on the instrument panel. Chips only enter the digester through the top separator. This unit consists of a cylindrical screen with continuous vertical slots that separate the liquor from the chips so the liquor may be re-circulated through the high pressure feeder back to the top separator again. A slow-moving vertical screw conveyor inside the screen pushes the chips downward into the digester, keeping the screen clear. The chips fall onto the top of the column of chips. This is continuous throughout the entire digester. In other words, there is a solid body of chips from the top to the bottom of the digester undergoing various stages of treatment.

The sluicing liquor is extracted through the top separator screen and is returned to the suction of the top circulation pump to be recycled with chips to the top of the digester. Built into the top separator is a level-indicating device, which allows the operator to have an indication of the level of chips inside the digester. This level device is a small paddle which turns with the top separator down in the chip mass. The resistance of the chips against the paddle is measured by a torque indicator on the top of the top separator. This measurement is transmitted to the control panel, which has a low level light (green), a normal (yellow) and a high (red). The digester is normally run at a yellow-red level indication. If the level gets high enough so that the chips ride against the screw conveyor, an increase in amperage of the motor will be seen on the control panel. When the load becomes severe, the top separator alarm will go off, warning the operator to take corrective measures. The drive shaft of the top separator is sealed by packing. Digester pressure compresses the packing, forming a seal. When the pressure is radically changed, the packing may not properly seal for some time.

Valve: FV-3A High pressure feeder purge

Note: In older systems, this is HV-3A or HV-35.

- Typical process conditions:
  - Fluid = White liquor

— T = 190°F
— P = 240 psig – 280 psig
— dP = 75 psi – 110 psi
— Q= 50-125 gpm

- Typical valve selection:

— NPS 2 to NPS 3 valves with alloy 6 scraper seats are utilized due to concerns over white liquor scaling. A SST V300 valve with an alloy 6 HD seal and alloy 6 bearings should be used in this application.

Valve: TV-2 Flash steam to chip bin temperature control

This valve controls the flow of low pressure steam from the No. 2 flash tank to the steaming vessel where the wood chips are pre-steamed at atmospheric pressure.

- Typical process conditions:

— Fluid: Saturated steam
— T = 220°F
— P = 2.5 – 30 psid
— dP = 1.0 psi
— Q= 29000 – 50000 lbs/hr

- Typical valve selection:

— This is specified as a Fisher HPBV by Kamyr. Valve size is in the range of NPS 10 to NPS 18. Metal bearings and a metal seat are recommended by Kamyr. However, PEEK bearings and Teflon seats in a stainless steel body and with a 17-4 splined shaft are also appropriate.

Valve: PV-5A Steam vessel pressure relief

This valve is used for steam pressure relief in the chip steaming vessel at the beginning of the pulping process.

- Typical process conditions:

— Fluid: Steam
— T = 256 – 280°F
— P = 18 – 30 psig
— dP = 16 psi

- Typical valve selection:

— Kamyr specifies this valve as a NPS 8 one way, tight, spring assisted full bore ball valve due to relief valve sizing downstream. The V300 valve in stainless steel with alloy 6 trim would be a good alternative in this application if the specification allows.

Valve: PV-5 Steaming vessel pressure relief

This valve vents air and non-condensable gases from the steaming vessel.

- Typical process conditions:

— Fluid: Steam and non-condensable gases
— T = 312°F
— P = 60 psig
— dP = 17 - 40 psid
— Q = 4300 lbs/hr

- Typical valve selection:

— In cases where entrained particles are found in the flow, the recommended valve is a CV500 with hardened trim due to the potential erosion. If no particles are found in the flow, a standard Vee-Ball may be used. This is typically specified as a NPS 8 valve.

Valve: HV-5 Steaming vessel relief steam flow

This valve sends “clean” steam from the steaming vessel pressure relief to the steam condensers.

- Typical process conditions:

— Fluid: Steam
— T = 255°F
— P = 18 – 33 psig
— dP = 16 psi
— Q = 1200 lbs/hr

- Typical valve selection:

— This is a throttling application and Kamyr has specified a V150 valve with attenuator for this application. Stainless steel body material together with a Nitronic 50 shaft, HD metal seal, and PEEK bearings are recommended. The valve is typically in the NPS 6 size range.

Valve: PV-2 Steaming vessel pressure control

This valve controls the steam pressure from the No. 1 flash tank and fresh make-up low pressure steam.

- Typical process conditions:

— Fluid: Low pressure saturated steam
— T = 320°F
— P = 80 psig

— dP = 42 psi

- Typical valve selection:

  — In cases where entrained particles are found in the flow, the recommended valve is a CV500 with hardened trim due to the potential erosion. If no particles are found in the flow, a standard Vee-Ball may be used. This is typically specified as a NPS 8 valve.

Valve: LV-6 Chip chute level control

This valve controls the liquor level in the chip chute. The recommended value for this application is a Vee-Ball, possibly with an attenuator. Carbon steel body can be used, although stainless steel would provide an added level of durability.

- Typical process conditions:

  — Fluid: Black liquor
  — T = 235°F
  — P = 25 – 60 psig
  — dP = 3 psi – 7 psi
  — Q = 600 – 1700 gpm

- Typical valve selection:

  — The Fisher CV500 will handle this application with alloy 6 seal and in the reverse flow orientation. This is a scaling application which calls for the eccentric plug action of the CV500. If the valve fails to respond to changing levels in the chip chute, there is a danger of liquor and chip spillage.

Valve: FV-3B White liquor pump to bottom circulation

These valves are used to control the amount of white liquor which is added to the wood chips. They maintain the proper wood/liquor ratio. As production increases, these valves open more to maintain the proper ratio.

- Typical process conditions:

  — Fluid: White liquor
  — T = 190°F
  — P = 260 psig – 290 psig
  — dP = 60 psi – 90 psi

- Typical valve selection:

  — These are NPS 2 to NPS 3 valves with alloy 6 scraper seats due to concerns over white liquor scaling. A SST V300 valve with an alloy 6 HD seal and alloy 6 bearings should be used in this application.

Valve: FV-3C White liquor to wash circulation pump

- Typical process conditions:

  — Fluid: White liquor
  — T = 190°F
  — P = 270 psig – 290 psig
  — dP = 75 psi – 90 psi

- Typical valve selection:

  — NPS 2 to NPS 3 valves with alloy 6 scraper seats due to concerns over white liquor scaling are used. A SST V300 with an alloy 6 HD seal and alloy 6 bearings should be used in this application.

Valve: FV-3D White liquor to MC circulation

These valves are used to control the amount of white liquor which is added to the wood chips. They maintain the proper wood/liquor ratio. As production increases, these valves open more to maintain the proper ratio.

- Typical process conditions:

  — Fluid: White liquor
  — T = 190°F
  — P = 270 psig – 290 psig
  — dP = 70 psi – 90 psi
  — Q = 180 gpm

- Typical valve selection:

  — NPS 2 to NPS 3 valves with alloy 6 scraper seats due to concerns over white liquor scaling. A SST V300 valve with an alloy 6 HD seal and alloy 6 bearings should be used in this application.

Valve: FV-3E White liquor to wash circulation

- Typical valve selection:

  — NPS 2 to NPS 3 valves with alloy 6 scraper seats due to concerns over white liquor scaling are utilized. A SST V300 with an alloy 6 HD seal and alloy 6 bearings should be used in this application.

Valve: FV-3F White liquor make-up to impregnation vessel

These valves are used to control the amount of white liquor, which is added to the wood chips. They maintain the proper wood/liquor ratio. As production increases, these valves open more to maintain the proper ratio.

- Typical process conditions:

  — Fluid: White liquor
  — T = 190°F
  — P = 260 psig – 280 psig
  — dP = 35 psi – 60 psi
  — Q = 200 – 900 gpm

- Typical valve selection:

  — NPS 2 to NPS 4 valves with alloy 6 scraper seats due to concerns over white liquor scaling. A SST V300 valve with an alloy 6 HD seal and alloy 6 bearings should be used in this application.

Valve: LV-7 Digester level control valve

This valve controls liquor flow to the top of the impregnation vessel. This is a critical and difficult application on the Kamyr digester. This valve needs to be operable with up to 300 psi of differential pressure on some digesters. This requires a valve capable of tight shut-off and high pressure throttling. Cavitation is a common problem with this valve.

- Typical process conditions:

  — Fluid: Black liquor
  — T = 235°F
  — P = 300 psig
  — dP = 45 psi – 90 psi
  — Q = 1000-3000 gpm

- Typical valve selection:

  — The V500 valve or CV500 in stainless steel has proven to be a successful valve in this application. The design of the Fisher valves provides higher flow velocities which tends to reduce the problems with scaling that are seen at this location. Both the V500 valve and the CV500 should be supplied with alloy 6 seats and installed in reverse flow orientation.
  — NPS 6 valve. This may be the most critical valve in the system other than blow line control. Capacity issues are a concern.

Valve: FV-61A Impregnation vessel upper slouse flow

This valve is found only on dual vessel digesters where it is used to add liquor to the upper dilution zone to assist in the discharge of chips and liquor from the impregnation vessel.

- Typical process conditions:

  — Fluid: Black liquor
  — T = 325°F
  — P = 250 psig – 290 psig
  — dP = 15 psi – 82 psi

- Typical valve selection:

  — NPS 6 to NPS 8 valve with an alloy 6 scraping seat due to concerns over the precipitation of calcium carbonate causing plating or scaling buildup. A SST V300 valve with an alloy 6 HD seal and alloy 6 bearings should be used in this application.

Valve: FV-61 Impregnation vessel lower slouse flow

This valve is found only on dual vessel digesters where it is used to add liquor to the dilution zone to assist in the discharge of chips and liquor from the impregnation vessel.

- Typical process conditions:

  — Fluid: Black liquor
  — T = 345°F
  — P = 235 psig – 260 psig
  — dP = 25 psi – 52 psi

- Typical valve selection:

  — NPS 4 to NPS 6 valve with an alloy 6 scraping seat due to concerns over the precipitation of calcium carbonate causing plating or scaling buildup. A SST V300 valve with an alloy 6 HD seal and alloy 6 bearings should be used in this application.

Valve: PV-30 Impregnation vessel pressure relief

This valve is used to relieve excess pressure in the impregnation vessel by releasing excess liquor to the No. 2 flash tank.

- Typical process conditions:

  — Fluid: Black liquor
  — T = 235°F
  — P = 180 psig
  — dP = 155 psi
  — Q = 2800gpm

- Typical valve selection:

  — A CV500 (NPS 3) in stainless steel with alloy 6 trim is a good valve for this application.

Valve: FV-60 Black liquor to impregnation vessel (bottom circulation flow)

This valve is found only on dual vessel digesters and is used to add black liquor to the outlet of the impregnation vessel to raise the temperature of chips and liquor going to the digester.

- Typical process conditions:
  - — Fluid: Black liquor
  - — T = 345°F
  - — P = 250 psig – 275 psig
  - — dP = 38 psi – 75 psi
- Typical valve selection:
  - — NPS 6 to NPS 8 valve with an alloy 6 scraping seat due to concerns over the precipitation of calcium carbonate causing plating or scaling buildup. A SST V300 valve with an alloy 6 HD seal and alloy 6 bearings should be used in this application.

Valve: TV-60A-C Bottom circulation temperature

These valves control steam to the bottom circulation heaters which, in turn, control the temperature of liquor leaving the heaters for the bottom zone of the impregnation vessel.

- Typical process conditions:
  - — Fluid: Steam
  - — T = 400 – 525°F
  - — P = 165 psig
  - — dP = 60 psi
  - — Q = 10000 – 40000 lbs/hr
- Typical valve selection:
  - — These are throttling valves, typically NPS 6, for which Kamyr has specified V300 valves with stainless steel bodies and stainless steel trim. Nitronic 50 shafts, PEEK bearings, and HD metal seals are also called for.

Valve: PV-10 Digester pressure relief

This valve is used in emergency situations to relieve elevated digester pressure by releasing black liquor from the top screens to the No. 2 flash tank. This valve requires tight shutoff and fail-closed spring return actuation.

- Typical process conditions:
  - — Fluid: Black liquor
  - — T = 350°F
  - — P = 180 psig
  - — dP = 180 psi maximum
  - — Q = 2600 gpm
- Typical valve selection:
  - — Kamyr has specified full bore ball valves for this application. However, a CV500 (NPS 3 to NPS 6) in stainless steel with alloy 6 trim is an excellent valve for this application.

Valve: PV-11 Digester pressure control

This is a critical valve in the digester process. This valve is used to maintain pressure in the digester and to distribute fresh cool water to the pulp. This prevents the overheating of the pulp, which would result in the degradation of the pulp fibers. This valve is typically interlocked with PV-10 to prevent over-pressurization of the process.

- Typical process conditions:
  - — Fluid: Washer filtrate
  - — T = 180°F
  - — P = 250 psig
  - — dP = 55 psi
- Typical valve selection:
  - — Kamyr has specified a Vee-Ball V300 valve, NPS 4 to NPS 6 size, for this application. The valve should have a stainless steel body and ball, Nitronic 50 shaft, PEEK bearings, and an HD metal seal. A piston actuator is typically used.

Valve: HV-54 Top circulation pressure control

This valve is used primarily during start-up to supply cooking liquor to pressurize the top circulation lines prior to pumping.

- Typical process conditions:
  - — T = 170°F
  - — P = 320 psig
  - — dP = 45 psid
  - — Q = 400 gpm
- Typical valve selection:
  - — The V300 valve is an appropriate alternate valve for this tag. This valve is typically in the NPS 3 size range.

Valve: HV-52 Top circulation isolation valve

This valve serves to isolate the high pressure feeder line from the impregnation vessel. It is typically installed on the main chip/liquor feed-line.

- Typical process conditions:
  - — T = 240°F
  - — P = 250 psig

— Q = 9000 gpm

- Typical valve selection:

  — This valve is specified as a full bore ball valve by Kamyr, and is referred to as the RO1 valve. It is normally open, and only closed when the digester must be isolated from the HP feeder. NPS 12 to NPS 16 in size with additional 1/8 inch thickness on RF male flange.
  — This unique size makes this valve a non-ANSI flange thickness. Fisher does not have an offering available for this valve.

Valve: HV-51 Top circulation isolation valve

This is an isolation valve for liquor being sent back to the high pressure feeder from the impregnation vessel.

- Typical valve selection:

  — This valve is specified to be a full bore ball valve by Kamyr, and is referred to as the RO2. It too has the special “male flange” requirement as referenced in HV-52.

Valve: PDV-18 Digester outlet device differential pressure

This valve adds liquor to the bottom of the digester to assist in chip discharge and to help regulate consistency.

- Typical process conditions:

  — Fluid: Washer filtrate
  — T = 170°F
  — P = 238 psig
  — dP = 45 psi
  — Q = 100 – 1000 gpm

- Typical valve selection

  — This is typically a NPS 4 valve for which Kamyr has specified a V300 valve with stainless steel body and ball. The valve should be offered with a Nitronic 50 shaft, PEEK bearings, and an HD metal seal. A piston actuator is normally specified.

Impregnation

The chips at the top of the column now enter the liquor impregnation zone. In this zone, chips are subjected to a complete soaking or penetration of the cooking liquor at a temperature of approximately 250°F. The impregnation stage lasts about 45 to 60 minutes at design tonnage. It is important that thorough penetration takes place before the heating stage. If penetration is incomplete, chips with uncooked centers will result.

The white liquor, or cooking liquor, is added to the digester together with black liquor, which is recovered from the chip chute overflow. It is also possible to put weak black liquor into the makeup liquor pump suction, but this is normally not required.

The chip chute overflow goes to the surge tank (level tank). There, it is controlled at a constant level, and then goes to the make-up liquor pump where it is combined with the white liquor. The make-up liquor pump transports the mixture to the top of the digester and injects it at a point just below the top separator. All of this liquor returns to the high pressure feeder by the top circulation return line, and is mixed with fresh chips to be returned to the inside of the top separator and then to flow down the digester. The amount of white liquor added is based upon the production rate and is in direct proportion to the chip feed rate.

Valve: TV-3A White liquor to make-up liquor line temperature

- Typical process conditions:

  — Fluid: White liquor
  — T = 120° F
  — P = 55 psig
  — dP = 10 psi

- Typical valve selection:

  — This valve has been specified by Kamyr to be a NPS 3 V150 valve with stainless steel body and 317 stainless chrome plated ball, Nitronic 50 shaft, HD metal seal, PEEK bearings, and a fail-close actuator.

Valve: FV-4 Black liquor flow

This valve only sees infrequent use in the process. Its function is to add cool washer filtrate liquor to the black liquor line coming from the level tank in the event the black liquor and the temperature at the top of the digester exceed specified temperature limits.

- Typical process conditions:

  — Fluid: Washer filtrate
  — T = 180°F
  — P = 30 – 60 psig
  — dP = 10 – 60 psid

— Q = 500 gpm

- Typical valve selection:

  — Kamyr has specified a V150 Vee-Ball valve, NPS 2 – NPS 3 size, with stainless steel body and ball, Nitronic 50 shaft, PEEK bearings, and an HD metal seal. Typically, a fail closed actuator is used.

Valve: LV-17 No. 2 Flash tank level

Black liquor level in the No. 2 flash tank is controlled by LV-17, located between the No. 2 flash tank outlet and the evaporators.

- Typical process conditions:

  — Fluid: Black liquor
  — T = 220°F
  — P = 60 psig
  — dP = 10 – 20 psid
  — Q = 1000 – 2000 gpm

- Typical valve selection:

  — NPS 8 to NPS 10 butterfly valve that Kamyr has specified as a stainless steel HPBV with stainless steel disc, alloy 6 bearings, 17-4 shaft, and a NOVEX metal seal.

Valve: LV-16 No. 1 Flash tank level

Black liquor level in the No. 1 flash tank is controlled by LV-16 located at the outlet of the tank. This valve flows into the No. 2 flash tank.

- Typical process conditions:

  — Fluid: Foamy black liquor
  — T = 260°F
  — P = 20 – 50 psig
  — dP = 2 – 12 psid
  — Q = 500 – 1500 gpm

- Typical valve selection:

  — This valve is specified by Kamyr as a HPBV with a stainless steel body and disc and a NOVEX metal seal. alloy 6 bushings and a 17-4 shaft are recommended. This valve is in the NPS 8 to NPS 14 size range.

Valve: LV-81 Clean condensate flash tank level

- Typical process conditions:

  — Fluid: Clean condensate
  — T = 312°F
  — P = 90 psig
  — dP = 90 psi maximum

- Typical valve selection:

  — This valve has been specified by Kamyr to be a NPS 2 to NPS 3 V150 valve with stainless steel body and trim, Nitronic 50 shaft, HD metal seal, PEEK bearings, and a fail-close actuator.

Valve: LV-91 Contaminated condensate flash tank level

- Typical process conditions:

  — Fluid: Condensate
  — T = 212°F
  — P = 11 psig
  — dP = 10 psi

- Typical valve selection:

  — This valve has been specified by Kamyr to be a NPS 2 to NPS 3 V150 valve with stainless steel body and trim, Nitronic 50 shaft, HD metal seal, PEEK bearings, and a fail-close actuator.

Valve: KV-24 Sand separator valve

This is also called the “pocket valve”. This is a full bore ball valve with one of the normally open ends of the ball sealed. It is used to collect sand at the bottom of the sand separator. Occasionally, the valve rotates 180° to dump the collected sand.

- Typical valve selection:

  — Full bore valves that can rotate 145 degrees are chosen. It is typically NPS 6 to NPS 8, and cycles every five to ten minutes. El-O-Matic™ actuators with 180 degree rotation with an adjustment are used commonly. Due to high cycle life, this valve assembly needs to be inspected on a regular basis.

Heating Stage

From the impregnation zone, the chip column continues to move down until the upper cooking zone is reached. Chips and liquor are pre-heated to within 20°F of the actual cooking temperature while the lower cooking zone controls the final cooking temperature. This is accomplished by withdrawing liquor from the digester through a screen plate, circulating it through an indirect heater and returning the heated liquor down through a central distribution chamber. Then, it is discharged at a point opposite and slightly above the screen plates. This allows the chips to receive uniform heating as the liquor enters at the center and flows to the outer shell equally in all directions.

Chips continue down the digester for a short distance into the lower cooking zone, where a second heating process occurs. In this case, the chips are heated to the desired cooking temperature. To accomplish this, liquor is again extracted radially through screen plates to a second heater. It is returned through a pipe, which is located inside the central distribution chamber, and is discharged at a point just above the lower cooking screen plates. A spare heater is provided and may be valved as either the upper or lower heater so that the heat exchangers, which periodically become fouled by liquor scale, can be acid-cleaned while the digester is still in operation. Normally, the impregnation zone is subject to considerable scaling and the upper heater will require more cleaning than the lower. The time a heater may be run before it requires cleaning must be determined by operating experience on your liquor, wood, and cooking conditions. Once determined, heaters may be cleaned before they become fouled so severely that the tubes plug.

The function of all circulations is two-fold: first, to carry heat and chemicals into the digester; second, to homogenize the conditions in the digester cross-section. If the circulation is to work properly, the screen plates must be kept clean. This will not be possible if the chip column stands still and a large quantity of liquor is drawn through them. Therefore, the screen sections are built in two sections, one above the other. These two sets operate alternately, one set sucking while the other rests and is cleaned by the wiping action of the downward moving chip column. The change is accomplished by digester switching valves mounted in the circulation suction lines. The chip column is not too dense at this point, and alternate automatic switching time is fairly short (typically 90 seconds).

Temperature recorders on the upper and lower cooking zone heaters show a cycle of 5° to 10°F. The temperature cycle is due to the temperature differential across the heating zone screens and follows the timing of the switching valves. The recorded temperatures are averages for the entire screen section, and provided the liquor circulation is adequate, the end temperature is in control. The inlet and outlet of each heater should be within 10°F of each other.

The temperature recorders serve as an indication of the chip column movement. Interruptions of movement are reflected by temperature changes. Failure of the chip column to move is reflected by the coming together of the inlet and outlet heater temperatures, whereas a sudden drop of the chip column is shown by a sharp drop in the heater inlet temperature.

Valve: KV-8A and B Trim liquor switching valves

These valves extract liquor through screens located in the upper part of the digester. The extracted liquor is then sent to the bottom circulation heaters. The KV tagged valves are required to fully stroke approximately every 90 seconds. This causes a flow reversal through the extraction screens preventing the screens from plugging with chips and fiber.

- Typical process conditions:
  - Fluid: Black liquor
  - T = 325°F
  - P = 130 psig
  - dP = 130 psi
  - Q = 1500 gpm
- Typical valve selection:
  - NPS 6 to NPS 8 size range. The DSV valve is suitable for this application. This is a modified 8510 body with a strengthened shaft and no seal. Used in conjunction with the 1061 actuator with a quad seal option, this assembly is capable of a relatively long life in this service.

Valve: KV-60A and B Bottom circulation return switching valves

These valves extract liquor from the digester (in the upper region of the digester vessel) and send liquor to the bottom circulation heaters. These valves are only found on dual vessel digesters. The KV tagged valves are required to fully stroke approximately every 90 seconds. This causes a flow reversal through the extraction screens preventing the screens from plugging with chips and fiber.

- Typical process conditions:
  - Fluid: Black liquor
  - T = 325°F
  - P = 120 psig
  - dP = 120 psi
- Typical valve selection:
  - NPS 12 to NPS 14 size range. The DSV valve is suitable for this application. This is a modified 8510 body with a strengthened

shaft and no seal. Used in conjunction with the 1061 actuator with a quad seal option, this assembly is capable of a relatively long life in this service.

Valve: KV-60C and D Bottom circulation screen backflush valves

These valves work in conjunction with tags KV-60 A and B to ensure that the bottom circulation screens remain free of chips. These valves are only found on dual vessel digesters. The KV tagged valves are required to fully stroke approximately every 90 seconds. This causes a flow reversal through the extraction screens, preventing the screens from plugging with chips and fiber.

- Typical process conditions:
  - — Fluid: Black liquor
  - — T = 325°F
  - — P = 120 psig
  - — dP = 120 psi
- Typical valve selection:
  - — NPS 6 to NPS 8 size range. The DSV valve is suitable for this application. This is a modified 8510 body with a strengthened shaft and no seal. Used in conjunction with the 1061 actuator with a quad seal option, this assembly is capable of a relatively long life in this service.

Valve: PV-16 PV-17 No. 1 Flash tank relief steam pressure valves

These valves are used to slightly pressurize the flash tanks in order to reduce foaming of the black liquor in the tanks.

- Typical process conditions:
  - — Fluid: Steam
  - — T = 220°F
  - — P = 60 psig
  - — dP = 5 psi
  - — Q = 15000 – 75000 gpm for PV-16
  - — Q = 20000 – 100000 gpm for PV-17
- Typical valve selection:
  - — Both of these valves have been specified by Kamyr as HPBV valves with PV-16 being an NPS 8 or NPS 10 valve and PV-17 being an NPS 16 to NPS 18 valve. Both valves should be supplied with a stainless steel body and disc, 17-4 shaft, PEEK bearings, and a NOVEX metal seal.

Cooking Zone

Below the heating zones, the chips enter the cooking zone at the full cooking temperature. Here, the actual cooking takes place. The active chemicals in the cooking liquor are sodium hydroxide, NaOH, and sodium sulfide, Na_2S. These chemicals react with the lignin in the wood chips, converting it into chemical compounds which dissolve in the alkaline cooking liquor. The lignin, as it exists in wood, is somewhat like a cementing material and holds the individual fibers together; however, when it is made soluble during cooking, the fibers are set free and can be separated into the fibrous mass called wood pulp.

The chemicals in the cooking liquor also react with the pulp fibers themselves. This is not desirable because the fibers are required in their original condition. Therefore, cooking conditions are used which result in the highest removal of lignin with the least attack on the cellulose fibers.

The chips continue to fall and will increase slightly in temperature until cooking is complete and it has reached the next stage (hi-heat washing). The cooking reaction is stopped by cooling the chip mass down to about 280° - 300°F. This is done by extracting the residual cooking liquor through screens on the side of the digester, and replacing it with cool liquor, which rises from the wash zone. The amount of cool liquor used is determined by the quantity of wash liquor required to wash the pulp to a suitable low soda content. In order to control the uniformity of temperature, a portion of the extracted cooking and washing liquor is returned to the digester via the quench circulation pump through a pipe inside the central distribution chamber. This re-circulation lowers the temperature of the entire chip mass and permits washing to be carried out without further delignification or over-cooking.

Valve: KV-19 A-D A-F Modified cooking extraction switching valves

These valves extract liquor in the modified cooking zone of the digester located near the middle of the digester vessel. The extracted liquor is then sent to the modified cooking heater. The KV tagged valves are required to fully stroke approximately every 90 seconds. This causes a flow reversal through the extraction screens preventing the screens from plugging with chips and fiber.

- Typical process conditions:
  - — Fluid: Black liquor
  - — T = 325°F

— P = 170 psig 10
— dP = 170 psi

- Typical valve selection:

  — These are typically in the NPS 8 size range for KV-19 A, B, C, D and in the NPS 3 size for KV-19 E and F. The DSV valve is suitable for this application. This is a modified 8510 body with a strengthened shaft and no seal. Used in conjunction with the 1061 actuator with a quad seal option, this assembly is very capable of a relatively long life in this service.

Extraction and Hi-Heat Washing

Chips, having now passed through the cooking zone, reach the extraction screens. The column is considerably denser following cooking and has a better wiping action so that a cycling system is not required at this zone. The section from the extraction screens down to the bottom of the digester is the wash zone. Black liquor is extracted from two rows of screen plates. The upper screen extracts primarily the hotter spent liquor from the downward flow of chips and the lower screen extracts cooler liquor flowing upward, or countercurrent, from the washing zone.

The portion of extracted cooking liquor that is not returned to the digester through the quench circulation pump goes to the No. 1 flash tank, which serves as the first stage of the digester heat recovery system. The liquor leaves the digester at about 180 psig and discharges to the flash tank at 15-18 psig. The sudden pressure drop causes the liquor to boil rapidly, or flash, and form steam, which goes to the steaming vessel. The amount of steam produced is directly proportional to the hot liquor flow through the extraction line and reduces the flow of the fresh make-up steam required at the steaming vessel. The remaining liquor then bleeds off to the No. 2 flash tank and is pumped to the unoxidized weak black liquor storage tank. As the No. 2 flash tank is under atmospheric pressure, again flashing occurs and the flash steam goes to a condenser.

Counter-current hi-heat washing is accomplished by extracting a greater volume of liquor through the extraction screens than the liquor volume coming down with the chips, causing an upflow of wash filtrate. The wash filtrate is pumped in at the bottom of the digester where it fills the voids created by the increased extraction. It also flows out through the blow line with the pulp acting as dilution liquor.

Wash filtrate is weak black liquor produced by extraction and shower displacement of residual liquor from the pulp. This filtrate is returned to the digester, mixes with the stronger cooking liquors, and cools the pulp before it is discharged (cold blow). The ratio of the number of pounds of excess filtrate (upflow) added per minute to the number of pounds of O.D. pulp produced per minute is called “dilution factor”. For example, a dilution factor of two would require a net upflow in the wash zone of two pounds per minute of filtrate to each pound of A.D. pulp. The amount of filtrate is determined by the remaining soda content in the pulp and should be held to a minimum value. More filtrate produces less soda loss, but at some point, filtrate addition, which later has to be evaporated by steam heat, is greater than the cost of soda. It can, therefore, be seen that a balance must be made at the most efficient point.

Washing efficiency increases with increased temperature. Therefore, it is necessary to heat the wash liquor. Thus, another extraction screen is located near the bottom of the digester which draws liquor out. This liquor is circulated via the wash pump through a steam heater and returned through yet another chamber located inside the central distribution chamber. This heated liquor discharges at the lower wash screen and diffuses upward through the downflowing chips. It effectively washes the mass as it replaces stronger liquor, which has been extracted above.

The reason for injecting the cold liquor into the bottom and then extracting it to be heated for washing is explained in the next section. The pulp column has now reached the final or blowing stage.

Valve: HV-16 Digester washer extraction flow

This valve controls the flow of black liquor to the flash tank.

- Typical process conditions:

  — Fluid: Black liquor
  — T = 325°F
  — P = 130 psig
  — dP = 45 psi – 60 psi
  — Q = 500 – 2500 gpm

- Typical valve selection:

  — This application is typically specified as a full-bore ball valve. A CV500 in stainless steel will be a suitable valve for this application due to its ability to handle scaling process conditions.

Valve: KV-16A-D Digester extraction switching valves

These valves provide screened liquor extraction from the upper wash zone of the digester. This is located near the middle of the digester vessel. The extracted liquor is then sent to flash tank No. 1. The KV tagged valves are required to fully stroke approximately every 90 seconds. This causes a flow reversal through the extraction screens preventing the screens from plugging with chips and fiber.

- Typical process conditions:

  — Fluid: Black liquor
  — T = 325°F
  — P = 10 psig
  — dP = 150 psi
  — Q = 1500 gpm

- Typical valve selection:

  — NPS 6 to NPS 8 size range. The DSV valve is suitable for this application. This is a modified 8510 body with a strengthened shaft and no seal. Used in conjunction with the 1061 actuator with a quad seal option, this assembly is capable of a relatively long life in this service.

Valve: TV-9H Modified cooking circulation temperature valve

This valve controls steam to the Modified cooking heater which, in turn, controls the temperature of liquor going to the upper wash zone.

- Typical process conditions:

  — Fluid: Steam
  — T = 379°F
  — P = 165 psig
  — dP = 80 psi

- Typical valve selection:

  — This is a throttling valve, typically NPS 4 to NPS 6, for which Kamyr has specified V300 valves with stainless steel bodies and stainless steel trim. Nitronic 50 shafts, PEEK bearings, and HD metal seals are also called for.

Valve: HV-20 Washer heater circulation flow

This valve controls the flow of wash liquor from the bottom of the digester to the wash circulation heater of the main digester.

- Typical process conditions:

  — Fluid: Black liquor
  — T = 255°F
  — P = 250 psig
  — dP = 20 psi – 60 psi

- Typical valve selection:

  — This is typically not a scaling application. A V300 valve or a CV500 will be suitable.

Valve: FV-14 Inner counterwash flow

This valve controls the flow of washer filtrate to the pulp washing section of the digester vessel and is typically a NPS 4 valve.

- Typical process conditions:

  — Fluid: Washer filtrate
  — T = 170°F
  — P = 235 – 350 psig
  — dP = 5 – 130 psid
  — Q = 100 – 1000 gpm

- Typical valve selection:

  — Kamyr has specified a V300 valve with stainless steel body and ball. The valve should be offered with a Nitronic 50 shaft, PEEK bearings, and an HD metal seal. A piston actuator is normally specified.

Valve: TV-20 Wash circulation temperature control

This valve controls the flow of low pressure steam to the wash circulation heater for the digester.

- Typical process conditions:

  — Fluid: Steam
  — T = 379°F
  — P = 165 psig
  — dP = 55 psi

- Typical valve selection:

  — This is a throttling valve, typically NPS 6 to NPS 8, for which Kamyr has specified V300 valves with stainless steel bodies and stainless steel trim. Nitronic 50 shafts, PEEK bearings, and HD metal seals are also called for.

Valve: KV-20A-D Wash extraction switching valves

These valves extract wash water from screens located near the bottom of the digester vessel. The extracted wash water is then sent to the wash heater.

- Typical process conditions:
  - — Fluid: Black liquor
  - — T = 260°F
  - — P = 185 – 195 psig
  - — dP = 185 – 195 psi
  - — Q = 1500 gpm
- Typical valve selection:
  - — These are typically in the NPS 3 to NPS 8 range. The DSV valve is suitable for this application. This is a modified 8510 body with a strengthened shaft and no seal. Used in conjunction with the 1061 actuator with a quad seal option, this assembly is capable of a relatively long life in this service.

Blowing

At high temperatures, particularly over 220°F, the mechanical action of the chips resulting from the violent expansion during the blow is harmful to the fibers. As mentioned before, washing efficiency increases with increased temperature; however, damage to fibers will be reduced by blowing at a lower temperature. In order to overcome any loss in pulp strength, the pulp mass is cooled to about 190°F by the weak black liquor filtrate. This liquor is pumped via the cold blow pump into the digester at two locations: a portion through a screen plate around the digester shell near the bottom and another portion through four nozzles located under the paddles of the outlet device. The liquor entering through the screens regulates the digester pressure, whereas the flow under the outlet device is fixed by the operator and provides the required dilution before the pulp is actually blown from the digester.

Summarizing, we find that the chips undergo three basic temperature changes that take place from the extraction zone to the blowing of pulp from the digester:

First, the chips are cooled or quenched 40 to 50°F at the extraction zone. This drop occurs where the up-flowing wash liquor meets the down-flowing residual cooking liquor and both are drawn off. Most of the residual liquor goes to the No. 1 flash tank for heat and chemical recovery. The remainder is re-circulated via the quench circulation pump before being recovered at the flash liquor tank. Re-circulation provides a more uniform temperature control and is important to avoid over-cooking the pulp.

The chips are then cooled (30°F) gradually throughout the wash zone until a second sharp drop occurs in the blowing dilution zone. Here the chips are cooled rapidly again by about 60°F before blowing to avoid mechanical damage to the exploding chip fibers. The blow line temperature must be maintained at 210°F or less. The gradual temperature drop over the wash zone is simply a result of gradual heat exchange between the up-flowing wash liquor and the down-flowing chips.

The reverse procedure occurs with the cold filtrate liquor (160°F). After entering the digester, it is heated to about 190°F by heat transfer from the chips and is then extracted to be heated by the wash heater (260 - 280°F) before returning to the digester wash zone. It gradually increases in temperature as it picks up heat from the down-flowing chips and reaches the lower extraction at about 290°F to provide the quench at the end of the cook zone. The wash heater control point is, therefore, set to arrive at the proper quench temperature and it is affected by the production rate, cooking temperature, and dilution factor.

Chips, upon reaching the outlet device, are now ready to be discharged from the digester. A load reading ammeter on the outlet device motor serves to indicate the consistency in the bottom of the digester. It has a variable speed drive and the speed at which it runs directly affects the consistency; the faster it runs, the higher the consistency and vice-versa. The reason for this is that the arms of the outlet device are designed to scrape the chips from the bottom of the column and carry them into the discharge port. Through experience, the operator learns the best speeds for each production rate. It can also be seen from the above that the outlet device is used in the fine control of the digester chip level.

The chips then enter a 12-inch blow line and goes to a small cigar shaped vessel called the blow unit. The blow unit is equipped with an agitator and two exit lines to the blow tank. The purpose of the agitator is to act as a consistency indicator for the digester operator by a torque or power-sensing device. As the consistency goes up or down, the power required to turn the agitator goes up or down. The variation is recorded on a chart at the control panel.

The chips and liquor flow out of the blow unit into one of the blow lines, and the flow is measured and recorded by a magnetic flowmeter. Cooked chips are at digester pressure up to the final ball valve before the blow tank. As they pass through, they are subjected to a sharp pressure drop which causes the chips to explode and break up into individual fiber bundles which are a form of raw pulp. The pressure drop is from digester pressure to atmospheric in the blow tank.

As in the top circulation line, there are two isolation valves against digester pressure. There is a large isolation valve between the digester pressure and the blow unit. If the blow unit is empty and the valve is opened under full digester pressure, the sudden surge severely damages the blow unit and valves. The blow unit must, therefore, be filled with liquor and pressurized before the large valve can be opened in a similar manner to the top circulation lines. A pressure switch prevents the valve from opening until the blow unit pressure is increased to at least 175 psig.

The pulp flows to the blow tank, which is simply a storage tank with a predetermined retention time, before it goes to the next stage in the pulping group, pulp washing and high density storage.

Valve: HV-87 Blow line pressurization

This valve provides dilution and pressurization in the blow line prior to the opening of the blow valve.

- Typical process conditions:
  - — Fluid: Washer filtrate
  - — T = 170°F
  - — P = 225 – 350 psig
  - — dP = 10 – 50 psid
  - — Q = 165 gpm
- Typical valve selection:

  — It is typically a NPS 2 valve. Kamyr has specified a V300 valve with stainless steel body and ball. The valve should be offered with a Nitronic 50 shaft, PEEK bearings, and an HD metal seal. A piston actuator is normally specified.

Valve: FV-12A Blow line flow control

- Typical process conditions:
  - — Fluid: High consistency pulp (10%)
  - — T = 180°F
  - — P = 170 psig
  - — dP = 80 psi
- Typical valve selection:

  — The requirement for full bore is based on the potential for plugging as large deposits come out of the digester. This is a very demanding and critical loop. The shape of opening and flow area of the V300, by design, has a lower potential for plugging than a full bore valve. Recommended valve construction includes: SST body with alloy 6 insert, alloy 6 V-notch, alloy 6 taper key, alloy 6 silver plated bearings, alloy 6 HD seal, and PTFE ENVIRO-SEAL packing. An oversized, piston actuator is also suggested. In addition, the valve should be sized to operate at >60% opening.

Valve: FV-12B Blow line flow control

- Typical process conditions:
  - — Fluid: High consistency pulp (10%)
  - — T = 180°F
  - — P = 170 psig
  - — dP = 80 psi
- Typical valve selection:

  — The requirement for full bore is based on the potential for plugging as large deposits come out of the digester. This is a very demanding and critical loop. The shape of opening and flow area of the V300 valve, by design, has a lower potential for plugging than a full bore valve. Recommended valve construction includes: SST body with alloy 6 insert, alloy 6 V-notch, alloy 6 taper key, alloy 6 silver plated bearings, alloy 6 HD seal, and PTFE ENVIRO-SEAL packing. An oversized piston actuator is also suggested. In addition, the valve should be sized to operate at >60% opening.

Valve: HV-81B Blow line isolation valve

This valve is an on/off valve that serves to isolate the digester blow line.

- Typical valve selection:

  — It is specified by Kamyr as a full bore ball valve.

Valve: HV-90A and B Blow line isolation valves

- Typical process conditions:
  - — Fluid: High consistency pulp (10%)
  - — T = 180°F
  - — P = 70 psig
  - — dP = 4 psi
- Typical valve selection:

  — These valves are generally the same valves as the flow control valves with the exception that they are often one line size larger and used for isolation only. These valves are on/off valves but are usually equipped with positioners so that they can be used as backup flow control valves.

Control Valve Selection

The following charts list Fisher valve selections for a typical Kamyr process. Control valve metallurgy has usually been 316 SST except for some valves on the bleach plant. On the C/D, D1 and D2 extractions and stock flow to these stages, the valves are usually titanium and sometimes 317 SST. More recently, the use of carbon steel valves on steam and some filtrate service has been considered. Metal seated ball valves are used where the service requires a scraper seat (HD design) such as white liquor and cooking circulations on the digester. Metal seats are also sued on throttling service that have high pressure drops where the metal seat is more resistant to erosive wear at the resultant high velocity. The heavy duty butterfly valve (Special 8500) is used almost exclusively for digester circulation switching. The main features of this valve for this service are the stellite bearings, double packing, and extra heavy design shaft. There are no seats in this valve so that it will not jam due to scale buildup. It is also sometimes used on throttling service where tight shutoff is not required, but where there is a scaling tendency. The history of valve selection has not been determined solely by the process requirement but in many cases by what valve technology was available at the time. The choice is sometimes limited due to Kamyr's requirement for flanges on all except butterfly valves.

KAMYR TAG#	KAMYR CONTINUOUS DIGESTER		FISHER CONTROL VALVE PRODUCT DESIGN						
	Application Description	**Control Function**	**V150**	**V200**	**V300**	**V500**	**CV500**	**8580**	**Typical Valve Sized**
FV-3A	High Pressure Feeder Purge White liquor flow control to purge High Pressure Feeder end bells	T			P				2”
FV-3B	White Liquor to Bottom Circulation Controls white liquor to Bottom Circulation	T			P				2”
FV-3C	White Liquor to Bottom Circulation Controls White Liquor to Bottom Circulation	T			P				2”
FV-3D	White Liquor to Modified Cooking Circulation Controls white liquor to Modified Circulation	T			P				3”
FV-3F	White Liquor Flow to Make-Up Liquor Line this is the white liquor flow to the Impregnation Vessel	T			P				3”
FV-4	Black Liquor Flow Washer filtrate is sent to black liquor line from Level Tank to cool black liquor	T	P						3”
FV-12A	Blow Line Flow (a) Controls flow from main Digester. 10-12% consistency	T			P				6”
FV-12B	Blow Line Flow (B). See FV12A	T			P				6”
FV-14	Inner − Counterwash Flow Controls liquor flow to pulp washing section	T			P				4”
FV-60[1]	Bottom Circulation Flow Black liquor added to outlet of Impregnation Vessel to raise temperature of chips and liquor to Digester	T			P				8”
FV-61[1]	Impregnation Vessel Bottom Dilution (Lower) Adds liquor to dilution zone to assist discharge of chips and liquor from Digester	T			P				6”
FV-61A[1]	Impregnation Vessel Bottom Dilution (Upper) See FV61 except upper zone	T			P				6”
PDV-18	Digester Outlet Device Differential Pressure Adds liquor to assist in chip discharge from Digester and regulate consistency	T			P				4”
LV-6	Chip Chute Level Controls liquor level in Chip Chute	T	P						8’
LV-7	Level Tank Level Valve controls liquor level in tank. Full 300 psi drop across valve is possible	T			S		P		6”
LV-16	No. 1 Flash Tank Level Controls level in No. 1 Flash tank	T						P	30”
LV-17	No. 2 Flash Tank Level Controls level in No. 2 Flash tank	T						P	20”
PV-5	Steam Vessel Pressure provides low pressure steam to Steaming Vessel	T	P						8”
PV-5A	Steaming Vessel Safety Relief Relief valve for Steaming Vessel	T	P						8”
PV-10	Digester Pressure Relief this valve relieves excess liquor from top screens to Flash Tank No. 2	T					P		4”
PV-11	Digester Pressure This valve regulates digester pressure and controls temperature using washer filtrate in the discharge zone	T			P				6”

1. Dual vessel only.
CODE: P = Primary selection, S = Secondary selection, T = Throttling, O/O = On/Off

KAMYR TAG#	KAMYR CONTINUOUS DIGESTER		FISHER CONTROL VALVE PRODUCT DESIGN						
	Application Description	**Control Function**	**V150**	**V200**	**V300**	**V500**	**CV500**	**8580**	**Typical Valve Sized**
PV-16	No. 1 Flash Steam Pressure this valve controls pressure in No. 1 Flash Tank	T						P	10”
PV-17	No. Flash Steam Pressure This valve controls pressure in No. 2 Flash Tank	T						P	18”
PV-30(1)	Impregnation Vessel Pressure Relief Relieves excess liquor from Impregnation Vessel to No. 2 Flash Tank	T					P		4”
TV-2	Chip Bin Temperature Takes steam from flash tank #2 to provide steam for atmospheric presteaming in Chip bin	T						P	18”
TV-2A	Chip Bin Temperature Provides alternate source of steam from low pressure steam line to Chip Bin	T	P						8”
TV-19H	Modified Cooking Circulation Temperature Valve controls steam to Modified Cooking Heater which controls temperature of liquor to upper wash zone	T			P				6”
TV-20H	Wash Circulation Temperature Controls low pressure steam to Wash Circulation Heater of the Digester	T			P				6”
TV-60A(1)	Bottom Circulation Temperature Valve controls steam to Bottom Circulation Heaters which control temperature of liquor leaving heaters to bottom zone of the Impregnation Vessel	T			P				6”
TV-60B(1)	Bottom Circulation Temperature Same as TV60A	T			P				6”
TV-60C(1)	Bottom Circulation Temperature Same as TV60A	T			P				6”
HV-5	Steaming Vessel Relief Relief Valve, sends steam to Condenser	T	P						6”
HV-5A	Steaming Vessel Relief Screen Blowback This valve is used to blow back fresh steam to clean relief screen	O/O	S			P			1.5”
HV-8(1)	Trim Liquor Downflow Controls liquor extracted from upper screens and sends it to bottom Circulation Heater	T			P				8”
HV-16	Digester Extraction to No. 1 Flash Tank this valve controls extraction flow from extraction screens KV16A, B, C, D to Flash Tank #1	T					P		8”
HV-19	Modified Cooking Circulation Flow Control liquor flow to modified cooking zone from Modified Cooking Heater	T						P	8”
HV-20	Wash Circulation Flow − Controls wash liquor from bottom of digester to the Wash Circulation Heater of the main Digester	T			P				4”
HV-51(2)	Top Circulation Isolation − Isolation valve for liquor being sent back to High Pressure Feeder from Impregnation Vessel. Special male flanges	O/O							14”
HV-52(2)	Top Circulation Isolation − this valve isolates high pressure feeder from the Impregnation Vessel. Installed on main chip/liquor feedline	O/O							14”

1. Dual vessel only.
CODE: P = Primary selection, S = Secondary selection, T = Throttling, O/O = On/Off

KAMYR TAG#	KAMYR CONTINUOUS DIGESTER		FISHER CONTROL VALVE PRODUCT DESIGN							
	Application Description	**Control Function**	**V150**	**V200**	**V300**	**V500**	**CV500**	**DSV**	**8580**	**Typical Valve Sized**
HV-54	Top Circulation Pressurization This valve supplies cooking liquor to top circulation line to pressurize it before pumping	T			P					3”
HV-62(1)(2)	Bottom Circulation Isolation This valve isolates Impregnation Vessel. It is on the discharge line feeding the digester	O/O								12”
HV-65(1)	Impregnation Vessel Cooling Liquor Flow filtrate from blow line is added to the Impregnation Vessel to bottom dilution zone	T			P					6”
HV-81(2)	Blow Line Isolation Valves isolates digester blow line	O/O								10”
HV-87	Blow Line Dilution Blow line dilution and pressurization line prior to opening HV81	T			P					2”
HV-90A	Blow Line Isolation (A) Valve isolates blow line A from blow line B	T			P					8”
HV-90B	Blow Line Isolation (B) See HV90A	T			P					8”
HV-120(2)	Sample Valve (Digester) This valve is used to monitor pulp quality	O/O								1-1/2”
HV-120B(2)	Sample Valve (Blow Line) See HV120A	O/O								1-1/2”
QV-27	White Liquor to Sand Separator This valve is a purge for the Sand Separator	O/O				P				1”
KV-8A(1)	Trim Liquor Switching − This valve extracts liquor through screens to Bottom Circulation Heaters.	O/O						P		6”
KV-8B(1)	Trim Liquor Switching Same as KV8A	O/O						P		6”
KV-16A	Digester Extraction Switching These valves provide screened liquor extraction from upper wash zone to Flash Tank No. 1	O/O						P		8”
KV-16B	Digester Extraction Switching See KV-16A	O/O						P		8”
KV-16C	Digester Extraction Switching See KV-16C	O/O						P		8”
KV-16D	Digester Extraction Switching See KV-16A	O/O						P		8”
KV-19A	Modified Cooking Extraction Switching These valves extract liquor in the modified cooking zone and send it to the Modified Cooking Heater	O/O						P		8”
KV-19B	Modified Cooking Extraction Switching See KV-19A	O/O						P		8”
KV-19C	Modified Cooking Extraction Switching See KV-19A	O/O						P		8”
KV-19D	Modified Cooking Extraction Switching See KV-19A	O/O						P		8”
KV-20A	Wash Extraction Switching − This valve extracts wash water to the wash heater	O/O						P		8”
KV-20B	Wash Extraction Switching See KV20A	O/O						P		8”
KV-24(2)	Sand Separator Dump Valve This valve is known as the pocket valve	O/O								

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KAMYR TAG#	KAMYR CONTINUOUS DIGESTER		FISHER CONTROL VALVE PRODUCT DESIGN							
	Application Description	**Control Function**	**V150**	**V200**	**V300**	**V500**	**CV500**	**DSV**	**8580**	**Typical Valve Sized**
KV-60A[1]	Bottom Circulation Return Switching These valves extract liquor from digester and send it to bottom circulation heaters. *Digester switching valve	O/O						P		14”
KV-60B[1]	Bottom Circulation Return Switching See KV-60A	O/O						P		14”
KV-60C[1]	Bottom Circulation Screen Backflush This valve works with KV-60A	O/O							P	6”
KV-60D[1]	Bottom Circulation Screen Backflush This valve works with KV-61C	O/O							P	6”
LV-19	M.C. Heater Condensate Level This valve controls level in Modified Cooking Heater. *Not shown on schematic	T				P				1.5”
LV-20	Wash Heater Condensate Level This valve controls Wash Heater Level. *Not shown on schematic	T				P				2”
LV-60A	B.C. Heater “A” Condensate Level This valve controls level in Bottom Circulation Heater A. *Not shown	T				P				1.5”
LV-60B	B.C. Heater “B” Condensate Level See LV60B except heater B	T				P				1.5”
LV-60C	B.C. Heater “C” Condensate Level See LV60A except heater C	T				P				1.5”
LV-81	Condensate Flash Tank Level Not shown on schematic	T	P							3”
CV-80A	Condensate Conductivity to Tank *Not shown on schematic	O/O			P					6”
CV-80B	Condensate Conductivity to Dump *Not shown on schematic	O/O			P					6”
CV-80C	Water Conductivity to Dump *Not shown on schematic	O/O	P							3”

1. Dual vessel only.
CODE: P = Primary selection, S = Secondary selection, T = Throttling, O/O = On/Off

KAMYR TAG#	KAMYR CONTINUOUS DIGESTER		FISHER CONTROL VALVE PRODUCT DESIGN							
	Application Description	Control Function	V150	V200	V300	V500	CV500	8580	EZ	Typical Valve Sized
LV-23	First Stage Backflush Tank Level	O/O						P		4”
LV-24A	First Stage Filtrate Tank (Bypass) This valve takes black liquor from Filtrate Tank to weak black liquor storage	T						P		6”
LV-24B	First Stage Filtrate Tank (Makeup) This valve takes wash water to add to weak black liquor from Filtrate Tank	T						P		6”
LV-33	Second Stage Backflush Tank Level This valve controls level in Backflush Tank	O/O						P		4”
LV-34	Second Stage Filtrate Tank Level Makeup This valve controls level in second stage Filtrate Tank	T						P		6”
QV-22	First Stage Backflush	O/O						P		10”
QV-32	Second Stage Backflush	O/O						P		10”
PV-23	First Stage Backflush Tank Pressure Controls pressure in Backflush Tank No. 2	O/O							P	1/2”
PV-33	Second Stage Backflush Tank Pressure Controls pressure in Backflush Tank No. 2	O/O							P	1/2”
FV-27	First Stage Wash Flow This valve controls flow of first stage wash in Diffusion Washer	T						P		8”
FV-28	Wash Water Flow for Float Out	T	P							2”
FV-37	Second Stage Wash Flow This valve controls flow of filtrate to second stage wash	T						P		8”
HV-21A[(2)]	Blow Line Isolation Valve isolates blow line from Diffusion Washer	O/O								16”
HV-21B[(2)]	Blow Line Isolation Valve isolates blow line from high density storage	O/O								8”
HV-22	First Stage Extraction Flow This valve controls flow of filtrate from first stage to Filtrate Tank	T	P							8”
HV-30	Second Stage Wash Isolation	O/O	P							8”
HV-32	Second Stage Extraction Flow This valve controls filtrate flow from second stage to Filtrate Tank	T	P							10”
TV-13	Filtrate to Digester Temperature This valve control temperature of washer filtrate to Digester	T	S					P		6”

1. Dual vessel only.
TCODE: P = Primary selection, S = Secondary selection, T = Throttling, O/O = On/Off

Chapter 11

Black Liquor Evaporator & Concentrator

The evaporator/concentrator system serves as a bridge between the pulp mill and powerhouse. This is the first step in reclaiming spent cooking chemicals. The evaporator receives weak black liquor from the pulp washers (or continuous digester) and concentrates the solution by evaporating a large portion of the water content. The concentrated black liquor is then sent to the powerhouse for combustion in the recovery boiler. A portion of the water content must be removed to maintain safe and efficient combustion in the recovery boiler. Although various methods exist for this process, the primary purpose of economical evaporation of water is a common goal.

Multiple-Effect Evaporator

The most common method, referred to as a multiple-effect evaporator, uses a series of evaporator bodies to remove water from weak black liquor. These evaporator bodies typically receive weak black liquor at 12 - 15% solids concentration and evaporate a portion of the water to raise the solids concentration to 50 - 60%. “Solids” refers to the organic wood constituents and inorganic cooking chemicals. The product is referred to as heavy or strong black liquor.

The primary advantage of multiple evaporator bodies is steam economy. A series of evaporator bodies makes it possible to remove 4 - 6 pounds of water per pound of motive steam used. This is accomplished by connecting the bodies in series so the vapor generated from one evaporator becomes the steam supply for the next evaporator in the series. Effects are numbered in order of the steam flow. Weak black liquor starts at the last effect, thus moving in a counter-current flow to steam. Although the number of effects may vary, six, or a sextuple-effect, is most common. Capital cost usually offsets any increase in steam economy if more effects are used.

A typical sextuple-effect evaporator set is shown in figure 11-1. Each individual evaporator consists of a heating element and a vapor head. Each heating element consists of a tube bundle with upper and lower tube sheets. Liquor flows on the inside of the tubes and steam on the outside of the tubes. Some designs use plate-type heating elements instead of tubes. In either design, the transfer of heat causes the liquor to boil and the vapor that forms is carried to the next effect to continue the evaporation process. Condensate formed by condensing steam vapor is also removed.

Motive steam is fed to the first effect and weak black liquor feed split between the 5th and 6th effects. The black liquor increases in solids content and boiling temperature as it progresses toward the first effect. In order for boiling to take place, the pressure on the liquor side of the tubes must be less than the pressure on the steam side. Thus, the pressure must be different in each effect and decrease from a high in the first effect of 30 - 40 psig to a low in the sixth effect of 20 - 25 inches of Mercury (Hg) vacuum. Maintaining this partial vacuum is accomplished by piping vapors from the sixth effect to a condenser and removing non- condensible gases with an ejector or vacuum pump.

Evaporator Types

As mentioned earlier, the most common type of evaporator is the multiple-effect type. However, many variations of this concept are used. The largest installed base of evaporators is the rising film or long tube vertical (LTV) type (see figure 11-1). This was the prevalent design until the late 1970s. In this design, the liquor enters a cavity

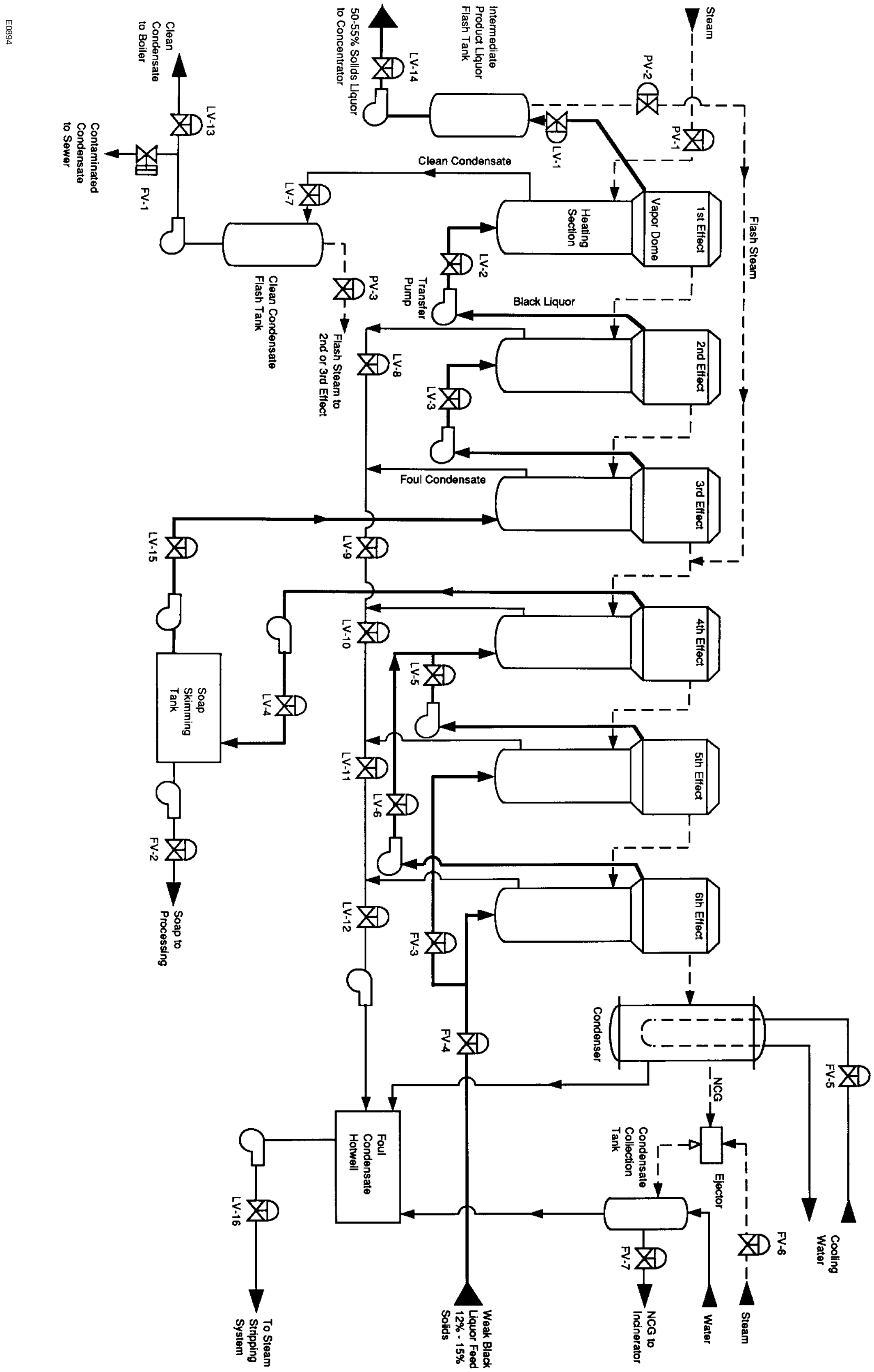

Figure 11−1. *Multiple-Effect Evaporator Six Effect / Rising Film / LTV* below the lower tube sheet. As it boils or percolates, a thin film of liquor rises up the inside of the tube or plate. The liquor overflows the upper tube sheet and falls via a downcomer pipe to a transfer pump. The vapor exits via a centrifugal separator and is piped to the next effect. This design provides high evaporation capacity at a low cost, but is sensitive to scaling and plugging above 50% solids.

Although the rising film design is predominant in installed base, the falling film design has become increasingly popular since the early 1980's and is now the most common type of evaporator. This design looks like an upside-down rising film evaporator (vapor dome at the bottom and the tube bundle extending upward). As its name implies, liquor is fed into the upper tube sheet area and flows as a thin film down the inside of the tubes. The liquor collects in the lower dome and is discharged from the evaporator body. Since the liquor flow is in the same direction as gravity and flowing in a thin film, higher heat transfer coefficients are realized. The higher coefficients allow for lower temperature differentials (vapor vs. liquor) resulting in the ability to achieve higher solids concentration and less scaling than a LTV design. The main disadvantage is associated with the high pumping cost of multiple-pass forced circulation employed on most falling film designs.

A number of alternative systems and variations to the classical multiple effect system has emerged recently in an effort to obtain higher solids concentrations, and reduce fouling of heating surfaces. Some of the variations to the classical sequence involve changing the feed liquor input location and using lower solids liquor to wash surfaces where higher solids liquor are normally made. This extends the time between general washings or "boilouts".

A recent alternative system involves combining rising and falling film evaporator bodies in a multiple effect system. In this design, the first two or three effects are falling film evaporators and the last three or four effects are rising film evaporators. This gives the advantage of pumping energy conservation on the "back end" where solids and scaling potential are lower and the resistance to fouling on the "front end" as solids increase.

Another system has emerged in recent years known as mechanical vapor recompression (MVR). This system typically employs a single evaporator body, a compressor, and heat exchangers. This system reuses vapors by raising the temperature and pressure with a compressor. It is used mainly where steam supply is inadequate and electrical power is economical.

Auxiliary Equipment

Various pieces of auxiliary equipment are required to support the operation of an evaporator set. Some of this equipment is briefly described below:

- **Soap Skimming/Removal**

Soap or tall oil soap is composed of fatty and resin acids found in wood products. During evaporation, the soap will not stay dissolved beyond 25 - 30% solids concentration. Failure to remove the soap results in excessive foaming and a lower efficiency for the entire recovery cycle. Typically, liquor leaving the fourth effect is diverted to a skimming tank where the soap is removed for processing. After the soap is removed, the liquor is transferred to the third effect to continue evaporation.

- **Flash Tanks**

Flash tanks are used to recover heat from flashing liquor or condensate to a lower pressure. Typical flash tank locations are product liquor and clean steam condensate from the first effect. The flash steam is then used for process heating.

- **Condenser and NCG Removal**

As mentioned earlier, a condenser is used to maintain a vacuum at the "back end" of the evaporator set. The condenser is connected to the vapor duct from the sixth effect. The condensed vapors from the sixth effect, referred to as foul condensate, contains contaminants such as sulfur gases and black liquor organics. These contaminants are removed by a steam stripping system since they create odor and pollution problems.

Non-condensible gases (NCG) such as hydrogen sulfide, mercaptans, and carbon dioxide also tend to accumulate in the condenser. These gases are removed with a steam or air fed ejector system and sent to an incinerator. Failure to remove these gases will limit an evaporator set by reducing the available vacuum and temperature differential.

- **Foul Condensate Stripping**

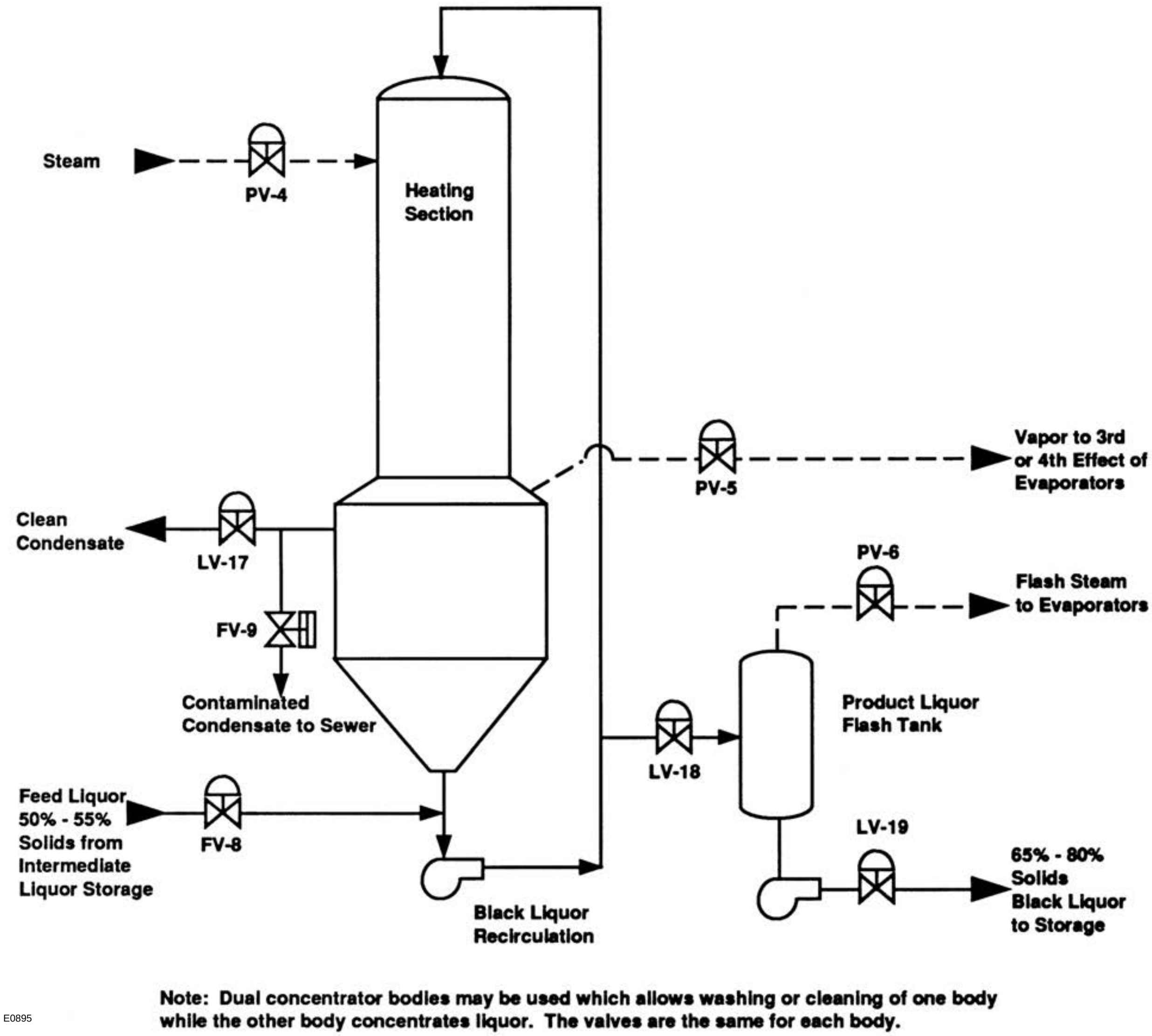

Figure 11-2. *Falling Film Concentrator*

Foul condensates are formed in both the evaporators and digesters. The primary reason for stripping foul condensate is pollution control. A common method of treatment involves feeding the condensate to a stripping column or tower, which is supplied with fresh steam. The steam tends to remove most of the contaminants and leaves clean condensate suitable for pulp washing. The contaminants are usually carried in a gaseous form to an incinerator.

Concentrators

Concentrators are an extension of the evaporation of water from black liquor. As mentioned earlier, evaporators are typically limited to 50 - 60% solids concentration due to scale build-up of sodium salts on heating surfaces. Concentrators accept the 50 - 60% solids from the evaporators and further concentrate it to 65 - 80% solids. A typical falling film concentrator is shown on figure 11-2.

- **Direct Contact Concentrators**

The first type of concentrator used in the pulp and paper industry was a direct heated type. Even though it served the same basic purpose as today's concentrator, it was often referred as a direct contact evaporator. The two most widely used types, the cyclone and cascade evaporators, utilized hot flue gas exiting the recovery boiler to further concentrate the black liquor. However, the direct contact of flue gas and black liquor strips sulfur compounds from the liquor which results in air pollution and sulfur loss. Most mills have eliminated direct contact evaporators in favor of more modern indirectly heated concentration equipment.

- **Forced Circulation Concentrators**

To overcome the limitations of direct contact evaporators, indirectly heated concentrator bodies are used for final liquor concentration. This type of installation typically involves one or more additional effects ahead of the first effect in the multiple-effect evaporator set. The first effect is fed with a separate supply of steam and concentrates the product liquor from the first effect of the multiple-effect evaporators.

The concentrator effects are generally used in a switching arrangement such that one effect is concentrating high solids black liquor while the other effect is concentrating lower solids liquor. This type of arrangement uses the lower solids liquor to wash deposits left from concentrating high solids liquor.

- **Falling Film Crystallizers**

One of the most recent concentrator designs is referred to as a falling film crystallizing concentrator. As mentioned earlier, salt crystals tend to form once black liquor becomes saturated at about 55% solids. In typical evaporators these crystals tend to stick to heat exchange surfaces and prohibit heat transfer. Crystallizers are designed to control crystal formation such that newly formed crystals will bond to crystals contained in the recirculating liquor rather than the heating surfaces. This allows for extremely high solids concentration (up to 80%) with reduced risk of fouling. The FFC concentrator can be used for all effects in an evaporator system where crystallization will occur.

- **Other Designs**

A couple of other designs may also be used as concentrators. One type is a single concentrator body with two or three separate sections. In this design one section(s) is washed with weak liquor from the evaporators while the other section(s) are used to achieve final liquor concentration. A second type combines preheat, falling, and rising film sections in one body. These units typically use forced circulation and are complicated to operate.

Although figures 11-1 and 11-2 indicate many of the critical control valves, other general service control valves are required for the successful operation of an evaporator/concentrator set. Many of the valves are on mill supply water, instrument air, plant air, or low pressure steam heating lines.

Control Valve Selection

Black liquor is a thick media which can be erosive, corrosive, or cause scaling problems in valves. Valves must be able to perform in both control and tight-shutoff applications, with special consideration give to valves where black liquor is the thickest; typically before entering and exiting the concentrator.

In applications where black liquor has lower solids content, the Control-Disk butterfly valve may be used. However, in most cases, the Vee-Ball segmented ball valve is the primary valve of choice.

Valve Tag #	EVAPORATORS/CONCENTRATORS		FISHER CONTROLS VALVE PRODUCT DESIGN					
	Application Description	Control Function	V150	V500	8580/ Control-Disk	A81	E−Body	Typical Valve Size
LV-1	1st Effect Liquor Level	T	P		S			6″
LV-2	2nd Effect Liquor Level	T	P		S			6″
LV-3	3rd Effect Liquor Level	T	P		S			6″
LV-4	4th Effect Liquor Level	T	P		S			8″
LV-5	5th Effect Liquor Level	T	P		S			8″
LV-6	6th Effect Liquor Level	T	P		S			6″
LV-7	1st Effect Condensate Level	T	P		S			4″
LV-8	2nd Effect Condensate Level	T	P		S			4″
LV-9	3rd Effect Condensate Level	T	P		S			6″
LV-10	4th Effect Condensate Level	T	P		S			6″
LV-11	5th Effect Condensate Level	T	P		S			8″
LV-12	6th Effect Condensate Level	T	P		S			8″
LV-13	Clean Condensate Flash Tank Level	T		S			P (ET)	4″
LV-14	Intermediate Product Liquor Flash Tank Level	T	P		S			6″
LV-15	Soap Skimming Tank Level	T	P		S			8″
LV-16	Foul Condensate Hotwell Level	T	S				P (ED)	8″
LV-17	Concentrator Condensate Level	T	S				P (ET)	4″
LV-18	Concentrator Liquor Level	T	P		S			6″
LV-19	Product Liquor Flash Tank Level	T	P					6″
PV-1	Steam to 1st Effect	T	S				P (EWD)	12″
PV-2	Flash Steam from Intermediate Product Flash Tank	T			P			8″
PV-3	Flash Steam from Clean Condensate Flash Tank	T			P			8″
PV-4	Steam to Concentrator	T	S				P (EWD)	10″
PV-5	Vapor from Concentrator	T			P			14″
PV-6	Flash Steam from Product Liquor Tank	T	P		S			8″
FV-1	Contaminated Condensate to Sewer	O/O				P		6″
FV-2	Soap to Processing	T	P		S			6″
FV-3	Liquor Feed to 5th Effect	T	P					6″
FV-4	Liquor Feed to 6th Effect	T	P					6″
FV-5	Cooling Water to Condenser	T			P			18″
FV-6	Steam to NCG Ejector	T	S				P (EZ)	2″
FV-7	NCG to Incinerator	T	P		S			6″
FV-8	Feed Liquor to Concentrator	T	P					6″
FV-9	Contaminated Condensate to Sewer	O/O				P		6″

P=Primary Valve Choise
S=Secondary Valve Chice
T=Throttling Service
O/O=On/Off Service

Chapter 12

Kraft Recovery Boiler – Black Liquor System

The kraft recovery boiler is the heart of a complex series of chemical processes referred to as the kraft recovery cycle. The two main functions of the kraft recovery boiler are to:

1. Reclaim digester cooking chemicals, sodium and sulfur, in a suitable form for regeneration of cooking liquors.

2. Provide efficient heat recovery and steam generation from combustion of organics in black liquor fuel.

Since the kraft recovery cycle is far removed from the finished product of the paper mill, it sometimes does not receive the attention it deserves. However, efficient chemical and heat recovery have a critical impact in overall mill efficiency and profitability.

Recovery Process Overview

As mentioned earlier, the recovery boiler is a major component of the kraft recovery cycle. However, other components perform important functions in the cycle. For continuity, a brief description is given to indicate the role of the recovery boiler in the overall cycle.

The basic components of the kraft recovery cycle are:

Digester(s)

Wood chips are mixed with a solution of cooking chemicals called white liquor (sodium sulfide and sodium hydroxide). The contents are cooked under pressure with steam to dissolve the glue-like lignin, which holds the wood fibers together. After cooking, the contents are blown into a holding tank.

Washers

The holding tank contents, known as pulp or stock, are transferred to the washers where water is used to wash residual cooking chemicals from the wood fibers. The wash water is sent to the evaporators and washed pulp to paper making.

Evaporators

The wash water, containing wood by-products and cooking chemicals, is transferred to the evaporators. This solution is commonly known as weak black liquor. Evaporators employ a series of effects or bodies using steam which evaporates much of the weak liquor water content. The final product is referred to as strong black liquor.

Recovery Boiler

Strong black liquor is transferred to the recovery boiler for combustion. The combustion process burns the organics (for steam production) and transforms the chemicals to a molten liquid known as smelt. The smelt flows from the boiler into a tank of water (or weak wash) and produces green liquor.

Recausticizing Plant

The green liquor is transferred to a series of components which add lime to regenerate the cooking chemicals or white liquor. Clarified white liquor is then pumped to the digesters to begin the cooking process again.

Black Liquor Preparation

As stated in the overview, black liquor preparation for the recovery boiler actually begins with the evaporators; however, other components (see figure 12-1) presented in this guide also play important roles.

Two components commonly employed on older, or conventional boilers, are direct contact evaporators and black liquor oxidation systems. Direct contact evaporators may be the cascade evaporator or cyclone evaporator type.

Black Liquor Oxidation

Black liquor oxidation is the exposure of black liquor to air (oxygen) to form more stable sulfide compounds. This exposure prevents the release of hydrogen sulfide and mercaptans when the liquor is exposed to hot flue gas in the direct contact evaporators. Release of these gases results in sulfur loss and odor emission. The oxidation process is commonly performed by a blower forcing compressed air into a liquor filled tank via a sparger ring.

Direct Contact Evaporators

Direct contact evaporators are used for final liquor concentration from 45-50% solids to 60-65% solids. They are so named because the boiler induced draft fan pulls the hot flue gas into direct contact with the black liquor to evaporate water prior to combustion.

The cyclone evaporator, commonly used with Babcock and Wilcox recovery boilers, consist of a cylindrical vessel with an opening which allows flue gas to enter tangentially. Black liquor is sprayed into the swirling gas to allow mixing and evaporation of water.

The most common type of evaporator for the past two decades has been the falling film or cascade evaporator. This evaporator consists of a rotating assembly of hot plates or tubes that are alternately submerged and then exposed to hot flue gas. These tend to be more efficient and versatile.

Due to the high flue gas temperatures and the presence of black liquor fuel, the potential for a fire exist in both types of evaporators. A common method employed to combat this potential is the injection of steam to displace oxygen and smother a fire.

Low Odor Design

As mentioned earlier, both black liquor oxidation and direct contact evaporators are employed on older or conventional type boilers. However, most modern designs referred to as low odor type use indirectly heated concentrators (similar to evaporators) to raise the black liquor solids concentration to the 65-70% range. Similar to the falling film evaporator, concentrators eliminate the need for direct contact evaporators, which, in turn, eliminates the need for black liquor oxidation. Lower sulfur and odor emissions are a result of the flue gas and liquor having no direct contact. This design also requires additional boiler economizer section(s) to absorb the flue gas heat which had been removed in the direct contact evaporators. The concentrator is more energy efficient and environmentally friendly than its predecessors.

Precipitator Ash

Following preparation by concentrators or black liquor oxidation, liquor is transferred to the electrostatic precipitator. Ash, consisting primarily of salt cake (Na_2SO_4 or sodium sulfate), is collected from the flue gas and mixed with the liquor. In some older designs, referred to as wet bottom, the liquor fills the precipitator bottom and salt cake falls directly into the pool. Since this presents a potential fire hazard and a source for odor emissions, most newer precipitators have the dry bottom design. In this design, chains or screws convey the dry ash into a liquor filled sluice tank.

Salt Cake Mix Tank

Before introduction to the recovery boiler furnace, the liquor is mixed with more ash and salt cake in the blending tank or salt cake mix tank. Salt cake addition is required due to small chemical losses occurring in the recovery cycle. Salt cake is typically added from two sources. One source is via fallout hoppers below the steam generating and economizer sections of the boiler. A second source is purchased make-up. Direct steam heating of the tank is typically used to maintain liquor viscosity at suitable values for pumping.

In order to reduce emissions, some mills have eliminated salt cake as a soda makeup chemical because of its high sulfur content. Caustic soda (NaOH) and soda ash (Na_2CO_3) have been substituted since they are sulfur free chemicals.

Liquor Divert

Black liquor is typically at 65-70% solids before it is sent to the recovery furnace for combustion. Density, or percent solids, is usually measured between the liquor heater and liquor guns via magnetic flow meters. If solids drop below 60%, auxiliary fuel is added due to the potential of a smelt/water explosion or bed “blackout”. If solids fall below 57-58%, the liquor is diverted from the furnace to the mix tank until solids reach an acceptable level. Each individual liquor feed line typically has a valve connected to emergency shutdown interlocks. These valves snap close on a trip or shutdown signal.

Black Liquor Heating

A final preparation stage for the liquor involves heating. Liquor is typically heated to 230°F-250°F to impart the desired viscosity and burning characteristics before spraying into the furnace. Many older designs employ direct steam heaters, but most newer designs are using indirect steam heating. The indirect heating does not add water content to the liquor which is a safety and efficiency consideration. Recirculation systems and steam desuperheating are often used with indirect heating.

Liquor Flow/Pressure Control

A common method used to control the flow or pressure of black liquor to the furnace is recirculation to the mix tank. This allows the nozzle pumps to run at a constant speed and keep the liquor moving to avoid potential plugging of transport piping.

Auxiliary Fuel

Black liquor is not used as a fuel to start-up a recovery boiler. Natural gas or fuel oil is typically used to bring the boiler up to a prescribed temperature before black liquor fuel is introduced. This is done primarily as a safety consideration due to the potential of a smelt-water explosion in the lower furnace.

Kraft Recovery Boiler

While recovery boiler design considerations vary among each manufacturer, their basic two-fold purpose of chemical recovery and steam production is common to all. Since the primary function is chemical recovery, black liquor flow to the furnace is a constant and steam production is a by-product. This requires the recovery boiler steam outlet header to be piped to a common header with a power boiler steam outlet. Swinging steam demands due to mill processes are accommodated by manipulating fuel to increase steam production of the power boiler.

Combustion Air

Air required for combustion in the furnace is introduced separately from the black liquor. Ambient air is forced into the boiler through an air heater via the forced draft fan(s). The air heater typically uses steam coils to heat the incoming air. Most modern designs introduce air at three levels: primary, secondary, and tertiary. These various levels are used to ensure chemical reduction, complete combustion of organics, and proper shape of the smelt bed. The primary air ports are located a few feet above the hearth and carry the responsibility to provide as low a velocity as practical while still supplying between 50-65% of the total air requirement. Secondary and tertiary ports establish higher velocities to ensure complete mixing and combustion of the unburned gases. Combustion flue gas is pulled from the furnace section to the convective section of the boiler via induced draft fan(s). This creates a slightly negative pressure inside the boiler. This action prevents hot gases from leaving boiler openings and is commonly referred to as “balanced draft”.

Black Liquor Combustion

Black liquor is introduced into the recovery furnace via nozzles or liquor guns. The guns produce a spray of coarse droplets exposed to hot flue gas. Depending on the manufacturer, the guns may be stationary or oscillating, and spray the liquor on the walls or into the center of the furnace. The flow of this black liquor to the guns is controlled by a valve. When selecting a control valve for this application, it is crucial to select proper materials due to corrosion. As the organics burn and release heat to the flue gas, the remaining char, consisting of the sodium and sulfur cooking chemicals, falls to the smelt bed on the furnace floor.

Sootblowers

Application Summary:

The efficiency of a fossil-fuel boiler is highly dependent on the heat transfer effectiveness of the boiler tubes. These tubes are fairly delicate, and hot spots (due to soot buildup cannot) be tolerated as a leak could result. A cleaning process for the boiler tubes is needed even while the boiler is in operation. This process is called soot blowing.

Process:

When firing fuels such as coal, oil, biomass or other waste products fouling of the boiler tubes becomes a concern. Deposits from the combustion process can collect on the heat exchanging tubes reducing thermal efficiency and can cause operational difficulties. In order to keep the unit operating, an online cleaning method must be used. This is usually accomplished by using what are called sootblowers.

Most sootblowing systems utilize either air or steam. Widespread use of water has been limited due to the possibility of thermal shock on the tube banks. Air or steam systems each have their own advantages, but one is not considered better than the other.

Air systems have much simpler piping arrangements. This is due to the elimination of condensate drain piping. The number of compressors, compressor capacity and the sootblower flow requirement; however, limits this system.

Steam systems have an advantage in terms of expansion. The supply of steam (typically removed after the primary superheater) is virtually unlimited, but leads to additional maintenance concerns related to the numerous valves required. Also, as stated above, the steam systems require additional piping to address the possibility of condensate in the steam lines.

As high pressure air or steam is required to remove the deposits from the boiler tubes, the control valve must be able to withstand high pressures. Steam systems present a greater challenge due to the combination of high pressure and temperature. Because of the high inlet pressure, downstream pressure and pipe size, the valve must also withstand issues with noise and vibration. As the sootblowers operate intermittently, tight shutoff (class V) is required for valve trim protection and when using steam, maintaining unit efficiency. These valves modulate over a wide range of flows and are required to maintain downstream pressure.

Design Considerations and Service Conditions:

- High pressure class rating due to the pressures and temperatures.
- Tight shutoff so valves don’t leak valuable steam.
- Large pressure drops can create noise, vibration, and excessive wear to trim.
- Cyclic conditions as valve are operated numerous times a day.

Typical Process Conditions:

- P_1 = 800 - 1400 psig
- P_2 = 0 psig
- T = 400 - 800°F

Typical Specification:

ES flow-down for on/off sootblowers.

To conserve energy, mills have moved to throttling sootblower valves. Use an ED.

Tight shutoff not needed as sootblower nozzles have tight shutoff.

Model:

ES for on/off, flow down, quick opening cage, Class V
ED for throttling, =% cage, flow down, Class II
These units provide high pressure and temperature capability along with the tight shutoff required.
Drilled-hole cage (flow-up)

Body: WCC

Trim: Quick opening cage or Whisper cage for noise attenuation
Cage: S31600 CoCr-A seat and guide
Plug: 316 CoCr-A
Seat: R30006 (alloy 6)
Seat Ring Retainer: R30006 (alloy 6)
Stem: Nitronic 50. Optional oversized stem or oversized VSC

Bonnet:: PTFE packing

Actuator: 667 spring-and-diaphragm or 585C piston

Positioner: DVC6010 c/w performance diagnostics

Fisher Engineered Specification:

The Fisher ES and ED cage-guided globe valves provide maximum stability and ruggedness in high pressure drop applications. The ES is offered with an unbalanced plug and the ED with its balanced plug to minimize actuator thrust requirements. Both designs have hardened trim for superior erosion resistance. The plug and stem assembly is reinforced through the use of high tensile materials and oversized valve stem connection.

High noise levels are often present in high pressure drop, high flow steam applications. Noise attenuation can be achieved with engineered valve trim combined with an inline diffuser for additional noise reduction when required. Typically Whisper Trim™ I and a Fisher 6011 downstream diffuser are the most practical and economical solution; however, there are other options available that allow for full attenuation at the valve such as the Fisher Whisper Trim III or WhisperFlo™ trim. There are many factors to consider such as capacity, turndown, line size, and overall economics when selecting an appropriate solution.

Chemical Reduction

Chemical reduction occurs via the char bed at the floor of the recovery furnace. The molten liquid bed typically operates at temperature of 1600°F - 2500°F. The introduction of air via the primary air ports provides the oxygen required to burn the carbon and reduce the sulfate to sulfide. The molten smelt, consisting primarily of Na_2CO_3 and Na_2S, flows by gravity to the dissolving tank. The dissolving tank is filled with weak wash to cool the smelt and produce a solution suitable for pumping. The solution formed, known as green liquor, is then transferred to the recausticizing area for addition of lime and regeneration of white liquor.

The dissolving tank is vented to the atmosphere via a tall stack. Since the sodium and sulfur compounds in the smelt present a source of odor emission, the vented gas is often treated with a scrubber. Although the scrubbers vary in design and complexity, a solution of weak wash is often used as the scrubbing medium.

Control Valve Selection

Although table 12-1 indicates many of the critical control valves, other general service control valves are required for the successful operation of a recovery boiler. Many of the valves are on mill supply water, instrument air, plant air, or low pressure steam heating lines.

Table 12-1. *Kraft Recovery Boiler / Black Liquor System Valve Selection*

PROCESS			FISHER VALVE PRODUCT DESIGN					
Valve Tag	Kraft Recovery Boiler / Black Liquor System		V150/ V300	V500	Control-Disk	A81	E-Body	Typical Valve Size
	Application Description	Control Function						
LV-1	BLOX Tank Level Control	T	P		P			6″
LV-2	Sluice Tank Level Control	T	P		P			6″
LV-3	DCE Level Control	T	P		P			6″
FV-1	Black Liquor Emergency Divert	O/O	P			S		6″
FV-2	Black Liquor Emergency Divert	O/O	P			S		6″
FV-3	Black Liquor Recirculation Flow or Pressure Control	T	P					2″
FV-4	Auxiliary Fuel/Natural Gas	T					P	3″
FV-4	Auxiliary Fuel/Fuel Oil	T					P	2″
FV-5	Black Liquor Shutoff	O/O	P					6″
FV-6	Green Liquor from Dissolving Tank	T	S	P				6″
FV-7	Weak Wash to Dissolving Tank	T	P					4″
FV-8	Weak Wash to Scrubber	T	P					2″
FV-9	Sootblower Steam	O/O		P			S	4″
FV-10	Smothering Steam to Precipitator	O/O	S				P	2″
FV-11	Smothering Steam to DCE	O/O	S				P	2″
TV-1	Steam to Mix Tank	T	S				P	2″
TV-2	Steam to Black Liquor Heater	T	S				P	2″
TV-3	Steam to Air Preheater	T	S				P	2″
P=Primary Valve Choice S=Secondary Valve Choice T=Throttling Service O/O=On/Off Service								

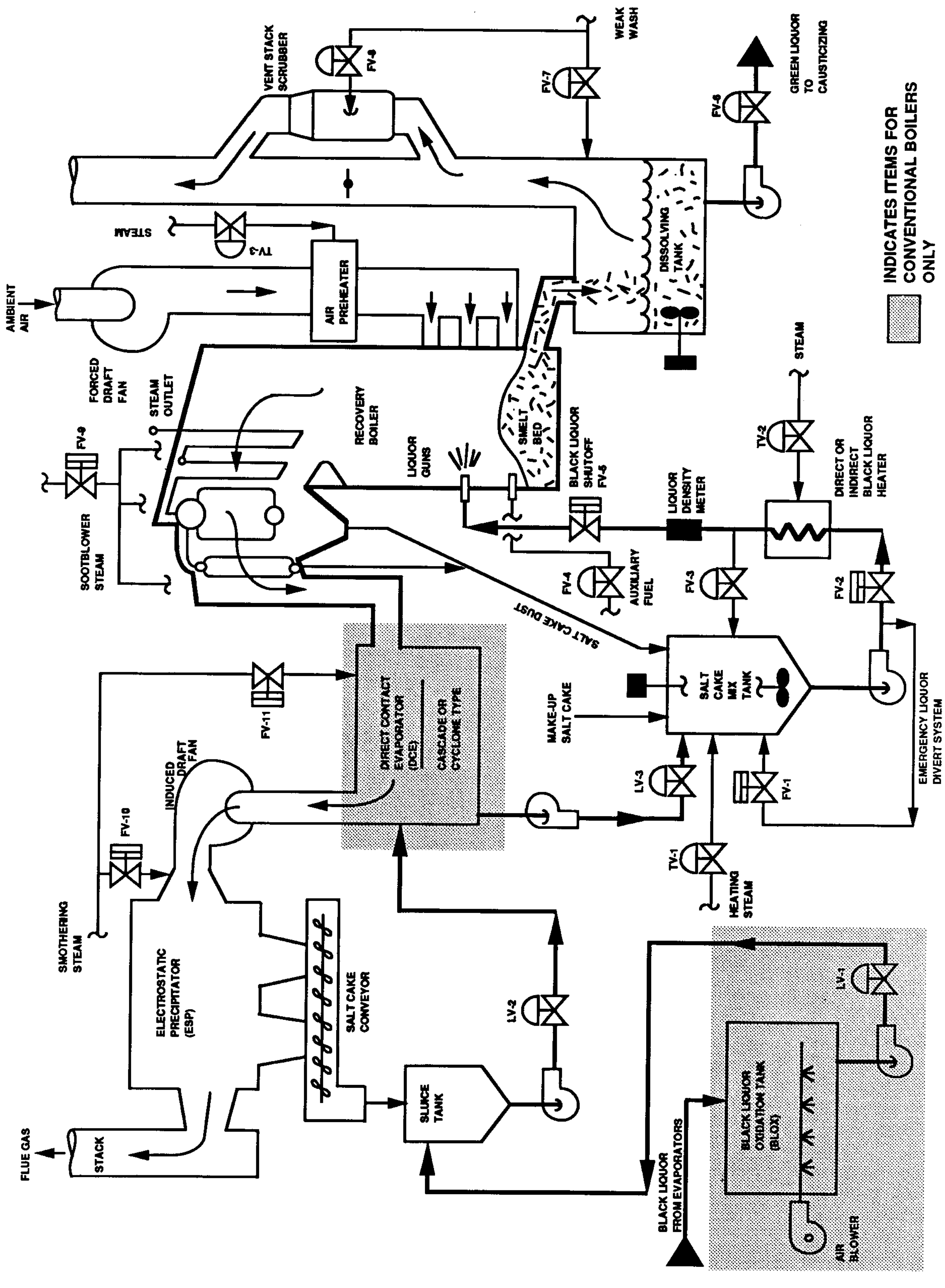

Figure 12-1. *Kraft Recovery Boiler Black Liquor System*

Chapter 13

Recausticizing and Lime Recovery

The recausticizing and lime recovery plant is the final step in the Kraft recovery process. It serves as a link between the Kraft recovery boiler and the digester. The function of the recausticizing area is to convert the inorganic chemicals in the green liquor from the recovery boiler dissolving tank to white liquor for cooking chips in the digester. This process consumes lime and produces lime mud. The purpose of lime recovery is to convert the lime mud back into lime for the recausticizing process. Proper control of the recovery and reclaim of the cooking chemicals is essential in the economic success of a Kraft recovery mill.

Recausticizing

As mentioned earlier, the recausticizing process involves reclaiming the cooking chemicals contained in the green liquor and converting or regenerating them to produce white liquor. The white liquor is then used to cook wood chips in the digester. A typical flow sheet is shown in figure 13-1.

Dissolving Tank

Green liquor is produced in the recovery boiler dissolving tank by mixing weak wash and smelt. Smelt, consisting primarily of Na_2CO_3 and Na_2S, is produced by burning black liquor in the recovery boiler furnace. Weak wash, which is basically water, is a product of lime mud washing. In addition to the chemical components, the green liquor contains impurities known as dregs which consist of unburned carbon and inorganic impurities such as calcium and iron.

Valve: FV-9 Weak wash to dissolving tank

- Typical process conditions:
  - — Fluid: Secondary condensate
  - — T = 176°F
  - — P = 70 - 75 psig
  - — ΔP = 40 - 45 psig
- Typical valve selection:
  - — NPS 6 valves with alloy 6 scraper seats due to concerns with scaling. A SST valve with an alloy 6 HD seal and alloy 6 bearings should be used in this application. Depending upon process conditions, the Control-Disk could act as a great alternative.

Green Liquor Clarifier

The dregs, which cause the green color, are impurities that must be removed from the green liquor. These fine particles are removed by pumping the green liquor to a sedimentation tank or clarifier. Since the density of the dregs is greater than the green liquor, settling of the dregs by gravity occurs. A slow moving rake pulls the material to a discharge cone in the center of the clarifier where it is concentrated and removed. The clarified liquor exits via overflow piping to a storage tank.

Dregs Washing

Before disposing of the dregs, they must be washed to recover any residual cooking chemicals. This is important from an economical and environmental aspect. Most mills employ a pre-coat filter to wash the dregs. The system consists of a rotating cylindrical filter in a vat. Lime mud is admitted to precoat the outside of the filter. A vacuum is maintained on the inside of the filter with a vacuum pump. The dregs slurry is pulled through the lime mud and filter media. A knife blade removes the lime mud as it becomes saturated with dregs. The lime mud/dregs are hauled to a landfill and the clear filtrate is recycled to the green liquor clarifier.

Valve: LV-1 Dregs Precoat Filter Level

- Typical process conditions:
  - Fluid: Lime mud
  - T = 212°F
  - P = 55 - 65 psig
- Typical valve selection:
  - These are typically NPS 2 or NPS 3 SST valves with solid VTC (ceramic) internals and alloy 6 bearings.

Valve: FV-3 Dregs Slurry Underflow from Green Liquor Clarifier

Please reference the lime mud underflow information below as this application closely resembles its process.

Slaker

The slaker is the heart of the recausticizing operation. At this point, clarified green liquor is mixed with lime to produce white liquor. The reburned lime (CaO) from the lime kiln and makeup lime are added and react with the water in the green liquor to form calcium hydroxide ($Ca(OH)_2$). This reacts with Na_2CO_3 in the green liquor to form sodium hydroxide (NaOH) or caustic and precipitate calcium carbonate ($CaCO_3$) or lime mud. A retention time of approximately fifteen minutes is allowed in the slaker. Recausticizing efficiency is improved by steam heating the incoming green liquor to near boiling and adding an agitator to the slaker.

Valve: FV-5 Green Liquor to Slaker

- Typical process conditions:
  - Fluid: Green liquor
  - T = 212°F
  - P = 80 - 85 psig
  - ΔP = 5 - 10 psig
- Typical valve selection:
  - NPS 6 valves with alloy 6 scraper seats due to concerns with green liquor scaling. A SST valve with an alloy 6 HD seal and alloy 6 bearings should be used in this application.

Causticizers

The retention time in the slaker is not enough to allow a complete reaction between the lime and green liquor. Causticizers consist of a series of two or more agitated tanks having a total retention time of 1-1/2 - 3 hours. The white liquor slurry usually flows by gravity from the slaker and through the causticizers.

White Liquor Clarifier and Lime Mud Washer

The white liquor clarifier is essentially the same as the green liquor clarifier described earlier. The white liquor slurry is pumped in from the last causticizer and the lime mud solids ($CaCO_3$) settle to the bottom of the clarifier due to density differential. The lime mud, at 35-40% suspended solids, is raked to a center discharge cone where it is concentrated and removed. The clarified white liquor containing sodium hydroxide and sodium sulfide overflows and is pumped to the digester for cooking wood chips.

The lime mud underflow from the white liquor clarifier must be washed to recover residual cooking chemicals. The lime mud washer is very similar to a white liquor clarifier with the possible exception of multiple compartments. The feed to the washer is from a mix tank, which accepts filtrate streams from the lime mud filter and lime kiln scrubber in addition to the lime mud underflow. The washed lime mud is removed at 45-50% suspended solids and sent to storage. The overflow, referred to as weak wash, is sent to weak wash storage and primarily used in the recovery boiler dissolving tank.

Valves: FV-6/FV-8/FV-16/FV-19 Lime Mud Underflow

- Design Considerations and Service Conditions
  - Lime mud is extremely erosive and difficult to handle due to fine particulate and high solids concentration.
  - The underflow valve is throttled to control mud density which directly impacts the

operation and efficiency of the lime kiln. An accurate and reliable control valve is required for optimum performance.

— The underflow valve must be appropriately sized to ensure the mud level in the tank never reaches the filter socks. The filter cannot operate properly if this occurs.

- Typical Process Conditions:
  - — Fluid: Lime mud
  - — P_1 = 20 - 50 psi
  - — P_2 = 0 - 5 psi
  - — T = ~175 °F
  - — Q = 100 - 300 USGPM
  - — SG = 1.36
- Typical Valve Selection:
  - — NPS 3 - NPS 6 V500 ANSI 150/Reverse flow/Trim #4 for erosive service
  - — Plug: VTC Ceramic on alloy 6 Hub
  - — Seat: Solid VTC Ceramic
  - — Shaft: Oversized, 17-4PH Stainless Steel
  - — Retainer: Solid alloy 6 with Ceramic bore
  - — Bearings: Sealed alloy 6 construction
  - — Packing: PTFE
  - — Actuator: 2052, fail closed
  - — Positioner: FIELDVUE DVC6200 with Performance Diagnostics

White Liquor and Lime Mud Pressure Filters

Although white liquor clarifiers and lime mud washers are predominate in installed base, the trend in recent years has been to substitute filtration equipment. This is possible because of the relatively large size of lime mud particles. A typical filtration system is shown in figure 13-2.

The white liquor pressure filter performs the same function as the white liquor clarifier. The vessel is divided into two compartments by a tube sheet. The tube sheet supports a number of perforated tube filter elements. Each perforated tube is covered with a polypropylene filter sock. The white liquor slurry must pass through the filters to reach the upper compartment. As lime mud builds up on the filters backflushing is required to restore normal operation. Backflushing is accomplished by recirculating the feed white liquor back to the causticizer. This allows the level to drop and the air cushion at the head of the vessel to expand and force the liquor into the socks. This knocks the lime mud from the sock filters. The lower portion of the pressure filter acts as a settling zone for the lime mud following backflushing. Clarified white liquor is removed from the upper compartment above the filter elements.

The lime mud pressure filter performs the same function as the lime mud washer and the principle of operation is the same as the white liquor pressure filter. The lime mud is removed from the bottom of the unit and the filtrate known as weak wash is removed from the upper compartment above the filter elements.

Valve: FV-17 Lime Mud to Filter

- Typical process conditions:
  - — Fluid: Lime mud
  - — T = 176°F
  - — P = 50 - 60 psig
- Typical valve selection:
  - — These valves can range from NPS 4 to NPS 10. A SST body with 316 CRPL ball, alloy 6 hard faced seat and alloy 6 bearings should be used in this application.

Valve: FV-18 Lime Mud Recirculation to Lime Mud Mixer

- Typical process conditions:
  - — Fluid: Lime mud
  - — T = 176°F
  - — P = 50 - 60 psig
- Typical valve selection:
  - — NPS 2 or NPS 3 SST valves with solid VTC (ceramic) internals and alloy 6 bearings.

Lime Mud Filter

Lime mud from storage at 45-50% suspended solids is pumped to a precoat filter for dewatering. Dilution water is added at the intake of the transfer pump to dilute the solution to 25% suspended solids. The lime mud slurry is pumped to a vat containing a rotating filter. The lime solids build to a sufficient thickness on the filter and are dewatered by means of a vacuum maintained on the inside of the filter with a vacuum pump. A fresh water spray may also be used for further washing of cooking chemicals from the lime mud. The dewatered lime mud is removed with a scraper blade and the filtrate sent to a mix tank feeding the lime mud washer (or pressure filter). The operation is very similar to the dregs precoat filter.

Valve: FV-10 Dilution water for lime mud transfer

- Typical Process Conditions:
  - Fluid: Clean condensate
  - T = 176°F
  - P = 30 - 40 psig
  - ΔP = 5 - 10 psig
- Typical valve selection:
  - NPS 2 carbon steel valves with 316 CRPL ball and TCM plus seat to achieve class VI shutoff. Depending upon process conditions, the Control-Disk could serve as a great alternative.

Valve: FV-11 Lime Mud to Filter

- Typical process conditions:
  - Fluid: Clean condensate
  - T = 176°F
  - P = 50 - 60 psig
  - ΔP = 5 - 10 psig
- Typical valve selection:
  - These valves can range from NPS 4 to NPS 10. A SST body with 316 CRPL ball, alloy 6 hard faced seat and alloy 6 bearings should be used in this application.

Lime Recovery

Lime recovery, lime reburning, or calcining are terms commonly used to describe this portion of the chemical recovery cycle. As mentioned earlier, the lime recovery area accepts the lime mud ($CaCO_3$) from the lime mud filter and converts it to lime (CaO) for use in the slaker. This solves any problems associated with lime mud disposal and also has a significant economic impact by reducing the need to purchase lime. With lime recovery, purchased lime is only required to make up system losses.

The conversion of the lime mud to lime is usually accomplished in a rotary lime kiln. A rotary kiln is a large steel tube lined with refractory bricks. The cylinder is mounted on an incline, supported on rollers, and rotated at a slow speed with an electric motor/gear reducer set.

The lime kiln accepts the lime mud from the lime mud filter at 60-70% solids. It is conveyed from the upper to lower end by the rotation of the kiln. A burner, utilizing oil or gas, is installed at the lower end. The heat of the flame evaporates the remaining moisture and yields lime and carbon dioxide from the lime mud. This process also causes the lime mud powder to agglomerate into pellets which can be handled.

The lime product is conveyed to a storage silo for use in the slaker. A scrubber is also used to alleviate the dusting and pollution problem associated with the exiting flue gas.

Valve: FV-12 Natural gas to lime kiln burner

- Typical process conditions:
  - Fluid: Fuel gas
  - T = 86°F
  - P = 50 - 60 psig
  - ΔP = 1 - 3 psig
- Typical valve selection:
  - NPS 4 carbon steel valves with 316 CRPL ball and TCM plus seat to achieve class VI shutoff. Depending upon process conditions, the Control-Disk could serve as a great alternative.

Valve: FV-13 Fuel Oil to lime kiln burner

- Typical process conditions:
  - Fluid: Fuel Oil
  - T = 260°F
  - P = 210 - 220 psig
  - ΔP = 20 - 25 psig
- Typical valve selection:
  - These valves are usually NPS 2 carbon steel valves with SST internals.

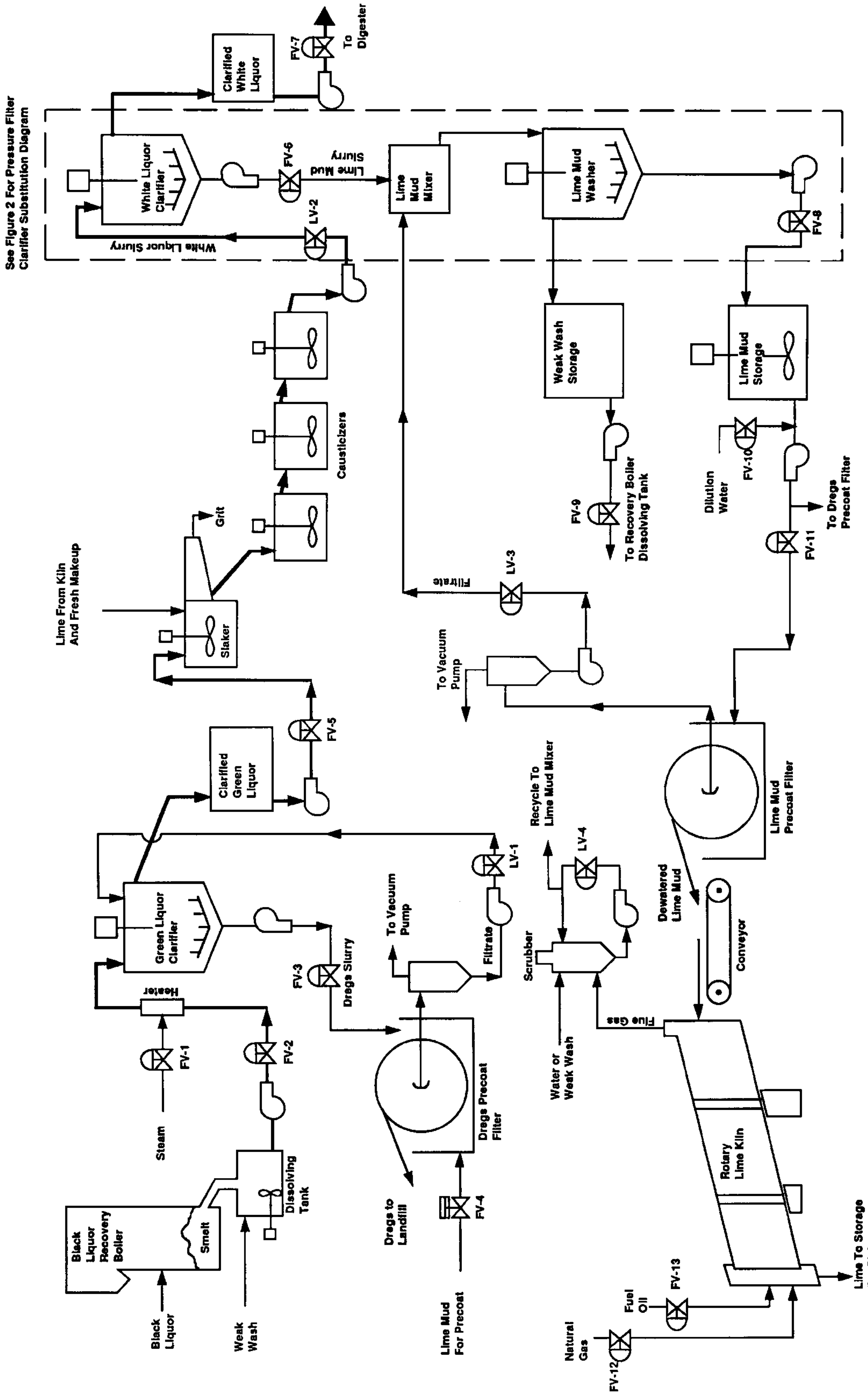

Figure 13-1. *Recausticizing and Lime Recovery*

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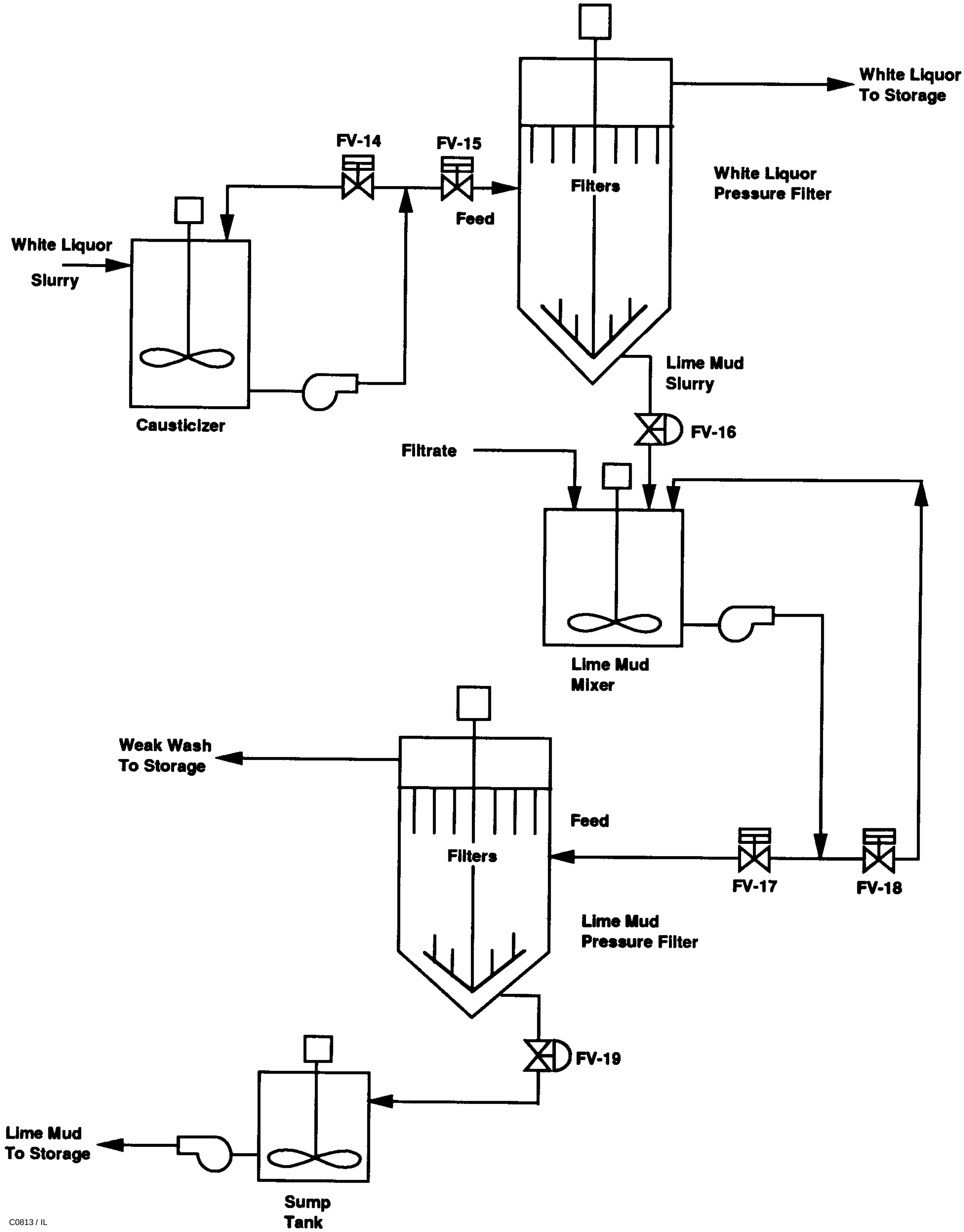

Figure 13- 2. White Liquor and Lime Mud Pressure Filters

Control Valve Selection

PROCESS			FISHER VALVE PRODUCT DESIGN					
	Recausticizing and Lime Recovery							
Valve Tag #	Application Description	Control Function	V150/ V300	V500	Control-Disk	A81	E–Body	Typical Valve Size
FV-1	Steam to Green Liquor Heater	T		S			P	1″
FV-2	Green Liquor from Dissolving Tank	T	S	P				6″
FV-3	Dregs Slurry Underflow from Green Liquor Clarifier	T		P				2″
FV-4	Lime Mud to Dregs Filter	O/O		P				1-1/2″
FV-5	Clarified Green Liquor to Slaker	T	P					6″
FV-6	Lime Mud Slurry Underflow from White Liquor Clarifier	T		P				3″
FV-7	Clarified White Liquor to Digester	T	P		S			6″
FV-8	Lime Mud Washer Underflow	T		P				3″
FV-9	Weak Wash to Dissolving Tank	T	P		S			6″
FV-10	Dilution Water for Lime Mud Transfer	T		S			P	2″
FV-11	Lime Mud to Filter	T		P				4″
FV-12	Natural Gas to Lime Kiln Burner	T	P		S			4″
FV-13	Fuel Oil to Lime Kiln Burner	T	S				P	2″
FV-14	White Liquor Recirculation to Causticizer	O/O				P		18″
FV-15	White Liquor Feed to Pressure Filter	O/O				P		18″
FV-16	Lime Mud Slurry Underflow from White Liquor Pressure Filter	T		P				6″
FV-17	Lime Mud Feed to Pressure Filter	O/O				P		18″
FV-18	Lime Mud Recirculation to Lime Mud Mixer	O/O				P		18″
FV-19	Lime Mud Pressure Filter Underflow	T		P				6″
LV-1	Dregs Precoat Filter Level	T	S	P				2″
LV-2	Causticizer Level	T		P				6″
LV-3	Lime Mud Filter Level	T	S	P				4″
LV-4	Lime Kiln Scrubber Level	T	P					2″

P=Primary Valve Choice
S=Secondary Valve Choice
T=Throttling Service
O/O=On/Off Service

Chapter 14

Bleaching and Brightening

Bleaching and Brightening

If the kraft pulp being produced is going to be bleached, then pulping is allowed to proceed until 90% or more of the lignin originally found in the wood is removed; however, the small amount of lignin that is left gives unbleached pulp its characteristic light brown color. Bleaching is the way to remove the residual lignin while causing minimal damage to the fibers and produce white pulp.

The differences between bleaching and brightening are as follows:

Bleaching — This process removes the lignin and is used to increase the brightness of chemical pulps.

Brightening — This process converts chemical groups in lignin to forms that do not darken pulp, thereby making it whiter. This process is used for mechanical or chemi-mechanical pulps that still contain vast amounts of lignin.

The Process

Oxygen Delignification

This process is typically found midway between pulping and bleaching. Oxygen can be used in sodium hydroxide (NaOH) solution under pressure to delignify (i.e. remove lignin for the wood) unbleached pulp (see figure 14-1). Up to one-half

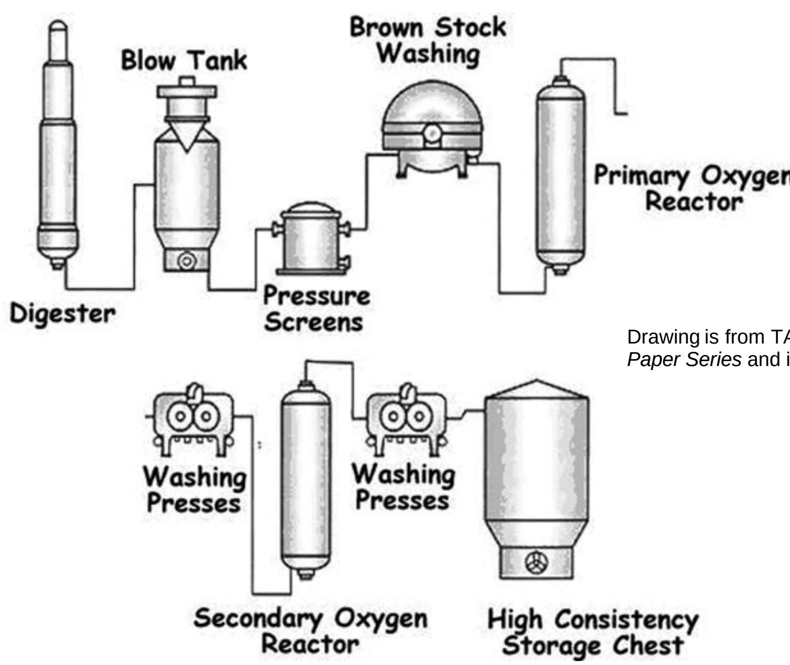

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Figure 14-1. *Oxygen Delignification Diagram* of the remaining lignin can be removed; further delignification would cause excessive cellulose degradation. Lignin removal in oxygen delignification significantly reduces the amount and cost of the bleaching which follows, and reduces the load on effluent treatment facilities because the filtrate from the post-oxygen washers goes back to the brown stock washers and the chemical recovery system.

Oxygen delignification is typically done at a medium to high consistency. Although good results are obtained from both high and low-consistency systems, medium-consistency is favored because of its lower capital costs and inherently safe operation.

In a medium-consistency system, pulp coming from the brown stock washer at about 10-14% consistency is delignified. It is then preheated in a low pressure steam mixer and pumped through one or more medium-consistency gas mixers to an upflow pressurized reaction tower. Steam and oxygen are added upstream of the consistency mixer or added directly to the pulp slurry. The most recent mills have two consecutive stages in order to improve the chemical efficiency of the treatment.

Bleaching

Pulps that have or have not been delignified are bleached in a continuous sequence of process stages, typically three, four, or five. The chemistry changes in each stage and the pulp is washed between stages.

The common bleaching chemicals and nomenclature are:

Chlorination (C): Reaction with elemental chlorine in an acidic medium (Cl)

Alkaline Extraction (E): Dissolution of reaction products with sodium hydroxide (NaOH) - ref

Chlorine Dioxide (D): Reaction with chlorine dioxide in acidic medium (ClO_2) - ref

Oxygen (O): Reaction with molecular oxygen at high pressure in alkaline medium (O_2) - ref

Hypochlorite (H): Reaction with hypochlorite in alkaline medium (ClO^-) - ref

Peroxide (P): Reaction with peroxide in alkaline medium - ref

Ozone (Z): Reaction with ozone in acidic medium (O_3) - ref

For many years, chlorination was always the first stage of bleaching. However, since the 1990’s, it has largely been replaced by chlorine dioxide to avoid the formation of dioxins. This is due to the environmental push for all pulp and paper mills to be ECF, or elemental chlorine free. A few paper mills are TCF, or totally chlorine free.

Conventional Bleaching

The equipment is the most common aspect of the stages. This includes: a steam mixer to heat the pulp suspension with direct steam, a pump to transport the pulp, a chemical mixer to combine the pulp with the aqueous bleaching agent, a retention tower to allow time for the bleaching to occur, and a washer to separate the spent bleaching solution from the pulp.

Referring back to the common bleaching nomenclature, a typical bleach plant has a $DE_{OP}DED$ sequence, or a low-consistency chlorine dioxide first stage with one or two chemical mixers, an upflow tower, and a rotary vacuum drum filter for pulp washing. The chlorine dioxide comes to the mixer at a solution concentration of about 10 grams per liter in cold water. The pulp suspension is around 3.5% consistency and has been heated to about 140°F. After mixing, the pulp and chlorine dioxide go to the retention tower to react for about 45 minutes. The pulp is then washed afterward.

Each bleaching stage has its own set of process conditions. The amount of bleaching agent, consistency of the pulp, pH, temperature, and time may all vary in each stage. Pulp consistency is around 3-4% in the chlorine dioxide stage and about 10% in all subsequent stages. The temperature is the lowest in the first stage at 140°F, and between 140-176°F, in the other stages. How much bleaching agent required depends on which chemical, which stage in the sequence, and what kind of pulp. With chlorine dioxide, progressively less is used as you go along the sequence (figure 14-2).

The objective of bleaching is to remove the residual lignin from the unbleached pulp. Chlorine dioxide is the preferred bleaching reagent worldwide. It is selective in dissolving residual lignin without degrading the cellulose and hemicelluloses. In a bleaching sequence, chlorine dioxide stages are always interspersed with alkaline extraction stages (see figure 14-2). This

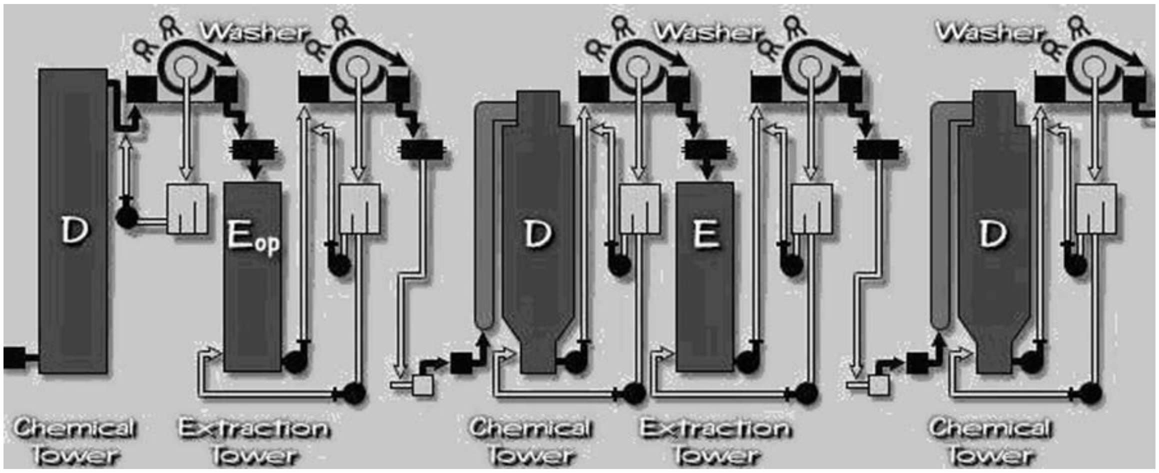

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Figure 14-2. *Conventional Bleaching Process*

alternating pattern of acidic and alkaline stages helps to break down the increasingly smaller amounts of residual lignin, ultimately dissolving the majority of the lignin so it can be washed out of the pulp.

Pulp brightness only increases modestly in oxygen delignification and does not increase uniformly across the bleaching sequence. This is due to the action that each chemical has on the lignin. Brightness increases substantially in the first and second chlorine dioxide stages and modestly again in the final chlorine dioxide stage (see figure 14-2). The alkaline extraction stages do not chemically whiten the pulp, they actually darken. The alkaline stages are there to dissolve and remove the lignin which has already been broken down by the chlorine dioxide. Kraft market pulps are normally bleached to a final brightness of 90% or higher; however, the final brightness is based solely on customer's standards and needs for the marketplace.

The filtrate flow in a bleach plant is counter-current, or opposite that of the pulp flow. In this case, there are actually two filtrate flows (see figure 14-3). Filtrate from the final chlorine dioxide stage washer is used as shower water on the third chlorine dioxide stage washer, and its filtrate is used on the first chlorine dioxide stage washer. Some of the acidic filtrate from the first chlorine dioxide stage washer is used to dilute and control the consistency of the pulp effluent treatment. Chlorine dioxide is always used with other chlorine dioxide stages and not mixed with the alkaline stages.

The filtrate flows of the two alkaline stages are connected in a similar fashion (see figure 14-4). Filtrate flow from the second extraction stage is used as shower water on the first extraction stage and the filtrate from the first extraction stage washer goes to the effluent treatment. Unlike the yellowish acidic filtrate stream, the effluent from this process is brown due to the lignin.

Fiberline

The fiberline refers to the equipment and processes that the pulp travels through as it is being processed from chips to final bleached pulp (figure 14-1). Kraft pulp's strength declines along a fiberline. This loss is due to the degradation of the cellulose fibers during the pulping and bleaching process. Chip quality, appropriate pulping equipment, and good operating practices are key aspects to produce strong kraft pulps.

Other quality aspects of bleaching includes pulp cleanliness, i.e. no dark particles caused by bark, pitch, small stones, and a minimal amount of extractives such as resins, which cause problems in the papermaking process. Fiber bundles, known as shives, have to be removed and reconverted into good pulp fibers. Metal ions must be removed via chelation, or the binding of ions similar to calcium being removed by a water softener.

Totally Chlorine Free

As previously mentioned, a few paper mills are TCF. This process eliminates organo-chloride compounds from bleach plant filtrates and makes it possible to recycle these filtrates back to

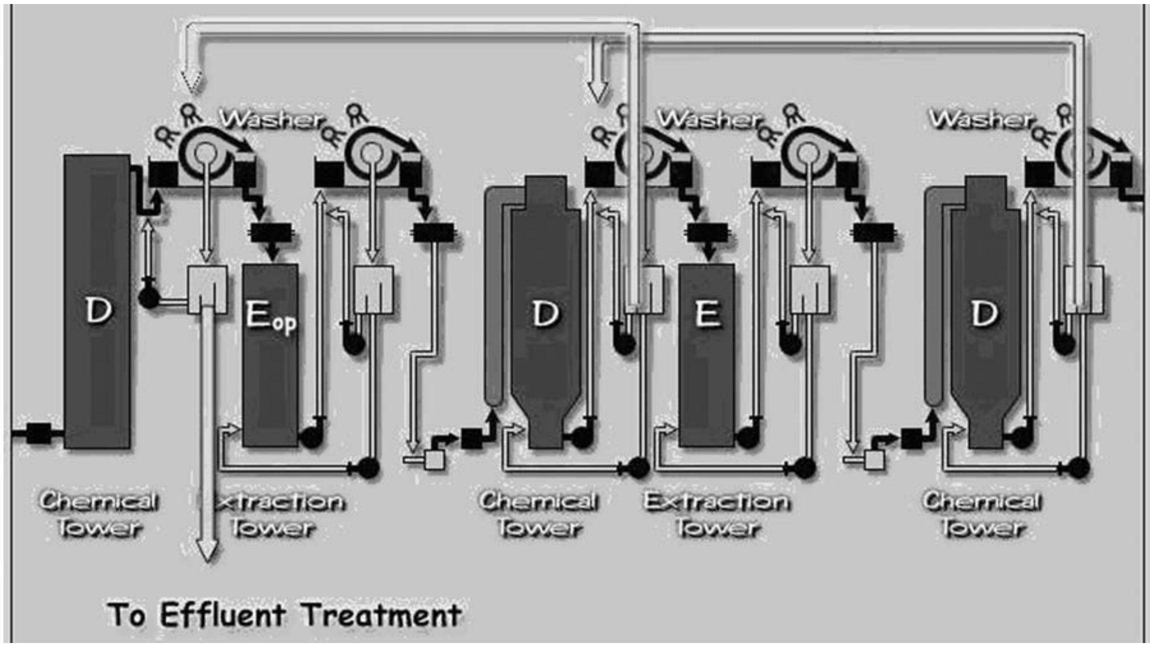

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Figure 14-3. *Chlorine Dioxide (ClO_2) Filtrate Flow*

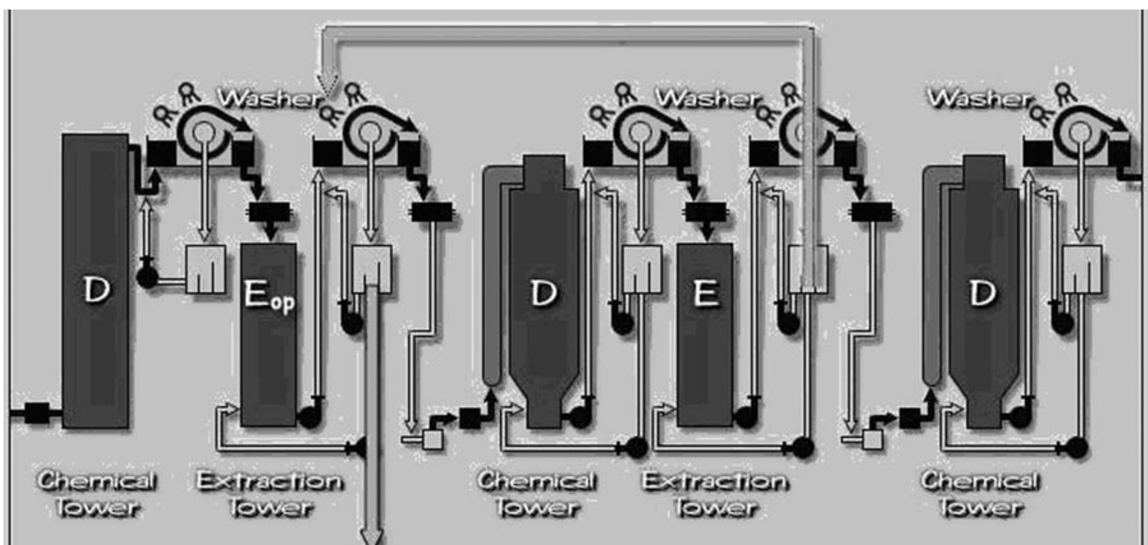

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Figure 14-4. *Alkaline Filtrate Flow*

chemical recovery plants. TCF sequences use various combinations of oxygen-alkali chemistry, hydrogen peroxide, and ozone. This process tends to be more expensive, have lower brightness, and is susceptible to strength loss problems.

Mechanical Pulping

This process dissolves most of the lignin in the original wood. High-yield mechanical pulps cannot be bleached the same way because they contain too much lignin. Bleached or brightened mechanical pulps will never receive the high brightness like that of a chemical pulp. The brightness effect is even reversible when the final product is exposed to sunlight.

Mechanical pulping bleaching is done with sodium hydrosulfite (Na_2S_2O4) and hydrogen peroxide (H_2O_2). A two-stage alkaline sequence can be used to raise the brightness of chemi-thermomechanical pulp to 85% or higher. Both hydrosulfite and peroxide attack the chemical groups that can cause darkening of the paper. Unlike the case in chemical pulp bleaching, lignin is not removed in brightening.

Caustic (NaOH) Valve Applications

Sodium hydroxide (NaOH) solution is a caustic chemical used to break down the lignin that binds cellulosic fibers. This is a highly used chemical but requires precise control so accurate addition to the wood chips is provided. Poor control can lead to economic loss both in NaOH solution and wood chip degradation.

Chips are fed via a screwfeeder into the top of a digester where it is mixed with cooking liquor where it is then cooked to a schedule. In modern Kraft mills, the lignin is removed by the action of sodium hydroxide and sodium sulfide under heat and pressure. This solution is known as white liquor. As the chips are cooked the lignin and other components are dissolved, and the cellulose fibers are released as pulp.

Design Considerations

- Material choice highly temperature dependent
- Low flows require low flow trims
- Tight shutoff

Typical Specification

Body:

Fisher V150 in CG8M (317SST)
CW2M (Hastelloy-C) premium selection

Trim:

Ball: CG8M chrome coated (Microscratch, Micronotch, or Macronotch)
Seal: Alloy 6 HD (Alloy 255HD also acceptable)
Shaft: Nitronic 50

Bearings:

Alloy 6 (PEEK if temperature allows)

Packing:

PTFE

Actuator:

Spring-and-diaphragm

Positioner:

FIELDVUE DVC6200 PD level

Chlorine Dioxide Applications

Due to environmental restrictions many mills are going to elementally chlorine free (ECF) bleaching practices. This has pushed the mills of today to a new chemical compound to bleach and brighten their pulp rather than the traditional pure, elemental chlorine. Chlorine dioxide (ClO_2) has been the choice by the majority of mills today. This is because the compound minimizes degradation to the cellulose fibers while still achieving higher final brightness to the pulp. However, it is an expensive chemical to generate and highly corrosive, so proper care must be given to choose the correct solution.

Depending on the type of furnish created at each mill, pulp from the digester can head toward the bleaching section of the mill. Bleaching is done by removing the lignin whereas brightening pulps changes the chemical groups in lignin to forms that do no darken pulp. Chlorine dioxide is rapidly becoming an industry standard as a bleaching agent because of its high selectivity in destroying lignin without degrading the cellulose fibers, thus preserving pulp strength while still providing a stable brightness.

After the oxygen delignification stage (typically found in modern mills), the medium consistency stock (10-14% bone dry) heads to the conventional bleaching sequence which can vary from four to six separate stages depending on the end-user’s brightness requirements. A standard mill would utilize a $DE_{OP}DED$ sequence, or an alternating sequence of chlorine dioxide (D) and alkaline extraction stages (E) and an oxygen (O) and peroxide (P) brightening stage.

One will always see chlorine dioxide stages interspersed with alkaline extraction stages. This alternating pattern of acidic and alkaline stages helps to break down the increasingly smaller amount of residual lignin. But this combination of chlorine dioxide and alkaline mixture also makes this a very corrosive solution and potentially erosive due to the percentage of stock content.

Design Considerations

- Highly corrosive chemical (not the same as chlorine applications)
- Erosive depending on stock consistency and velocity through valve
- Accurate control needed due to cost for chlorine dioxide
- Material choice dependent on chemical concentrations; high concentrations must be titanium. Hastelloy C (CW2M) can be used.

Typical Specification

Model:

V150 or V300
(V150S with titanium and ceramic trim can also be used. No liner required.)

Body:

Titanium C3 (R50550) or Hastelloy C (CW2M)

Trim:

Ball: Titanium C3 (R50550) or Hastelloy C (CW2M)
Seal: TCM Plus
Shaft: Titanium Grade 5 or Hastelloy C (N10276)
*Pin and Taper Key should also be Titanium or Hastelloy C

Bearings:

Titanium C3 (R50550) or Hastelloy C (N10276) lined with PTFE

Packing Box:

ENVIRO-SEAL PTFE

Actuator:

Spring-and-diaphragm

Positioner:

FIELDVUE DVC6200 digital valve controller with Performance Diagnostics (PD)

The following diagrams are typical valve layouts for the various bleaching stages.

Chlorine Dioxide (D) Stage

Valve Tag #	Application Description	Control Function	Vee-Ball™	High Pressure Butterfly Valve (HPBV)	V150E
1	Medium Consistency (MC) Control	T	S		P
2	Pulp/Chemical Mixing	O/O	P	S (8580)	
3	Filtrate Valve	O/O		P (8580)	
4	Bleaching Agent Valve	T	P		
5	Bleached Pulp Valve	T	P		
6	Washed Pulp Valve	T	P		
7	Filtrate Valve	O/O		P (8580)	
8	Filtrate Valve	O/O		P (8580)	
CODE: P = Primary selection, S = Secondary selection, T = Throttling, O/O = On/Off					

Alkaline Extraction (E), Hypochlorite (H), Peroxide (P) and Ozone (Z) Stages

Valve Tag #	Application Description	Control Function	Vee-Ball	HPBV	V150E
1	MC Control	T	S		P
2	Pulp/Chemical Mixing	O/O	P	S (8580)	
3	Filtrate Valve	O/O		P (8580)	
4	Bleaching Agent Valve	T	P		
5	Bleached Pulp Valve	T	P		
6	Washed Pulp Valve	T	P		
7	Filtrate Valve	O/O		P (8580)	
CODE: P = Primary selection, S = Secondary selection, T = Throttling, O/O = On/Off					

Oxygen (O) Stage

Valve Tag #	Application Description	Control Function	Vee-Ball	HPBV	V150E
1	MC Control	T	S		P
2	Bleaching Agent Valve	T	P		
3	Pulp/Chemical Mixing	O/O	P	S (8580)	
4	Control Valve	T	P		
5	Pump Valve	O/O		P (8580)	
6	Control Valve	T	P		
7	Discharge Tank Valve	T	P		
8	Washed Pulp Valve	T	P		
9	Filtrate Valve	O/O		P (8580)	
CODE: P = Primary selection, S = Secondary selection, T = Throttling, O/O = On/Off					

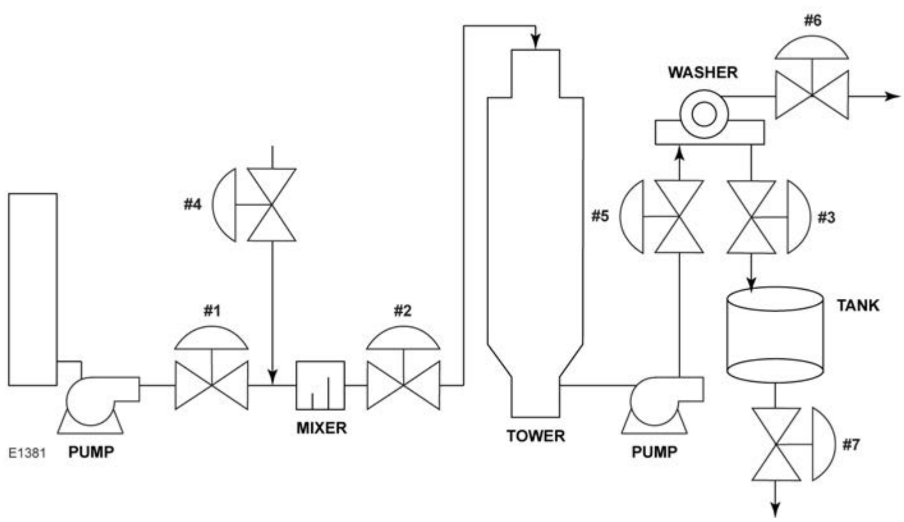

Figure 14-5. *Alkaline Extraction (E), Hypochlorite (H), Peroxide (P) and Ozone (Z) Stages*

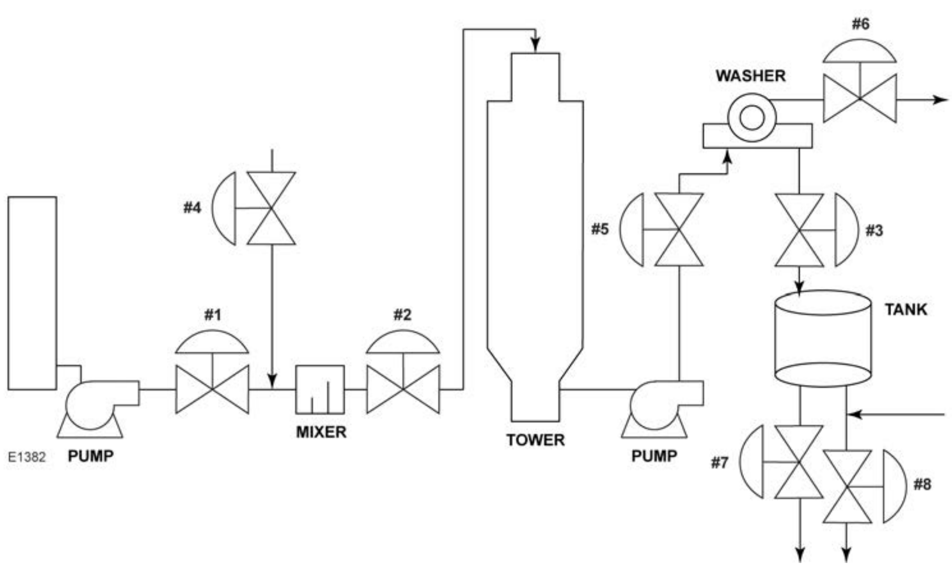

Figure 14-6. *Chlorine Dioxide (D) Stage*

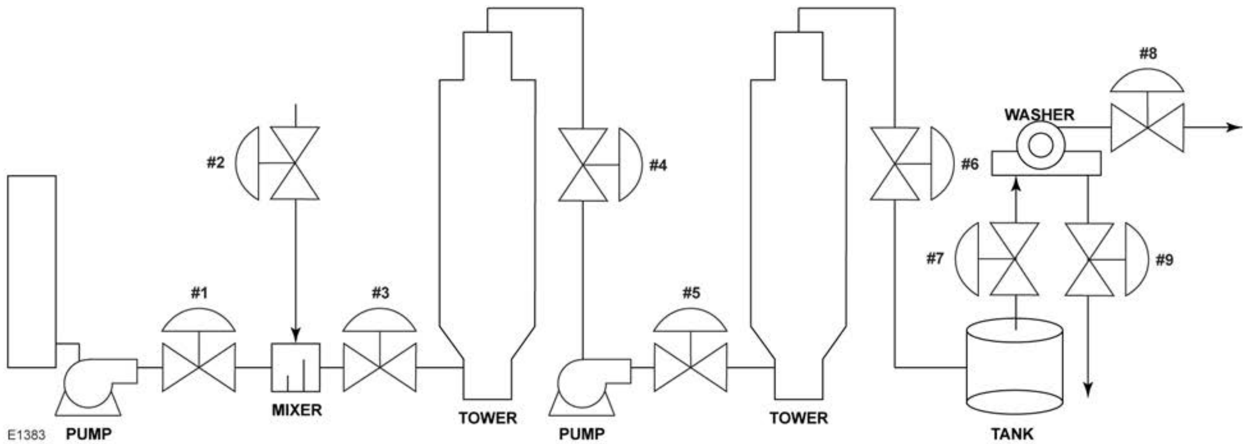

Figure 14-7. *Oxygen (O) Stage*

Chapter 15

Stock Preparation

Stock preparation is the start of the papermaking process and is the controlling factor over final paper quality and how well the paper machine runs. To be more specific, this process prepares the fibers for the paper machine. In order for this to occur, the fibers must be blended and the consistency—or the percentage of fibers in the water—controlled. Any contaminants must be removed from the slurry and fibers mechanically abraded or refined so they will bond well in the papermaking process to form a clean sheet.

The stock flows through the various preparation steps where additives including sizing agents, fillers, starch, retention and drainage agents, and dyes are added to the fiber furnish. The stock is then further diluted to the final consistency so the slurry can be pumped to the headbox and on to the paper machine wire.

The stock preparation system can be broken down into two main areas:

1. **Thick stock system (figure 15-1):** The initial part of the stock prep system where fibers are screened, refined, and blended to prepare the slurry for each grade of paper to be made. This process has a consistency of 3% to 5% solids.

2. **Thin stock system:** This system cleans, screens, and dilutes to papermaking consistency. This process has a consistency of 0.4% to 1.0% solids.

Thick Stock Process

This process begins with in-coming bales of purchased pulp, secondary fiber that might be found in the high density storage chests, or fibers from the pulp mill. The pulp is broken down and

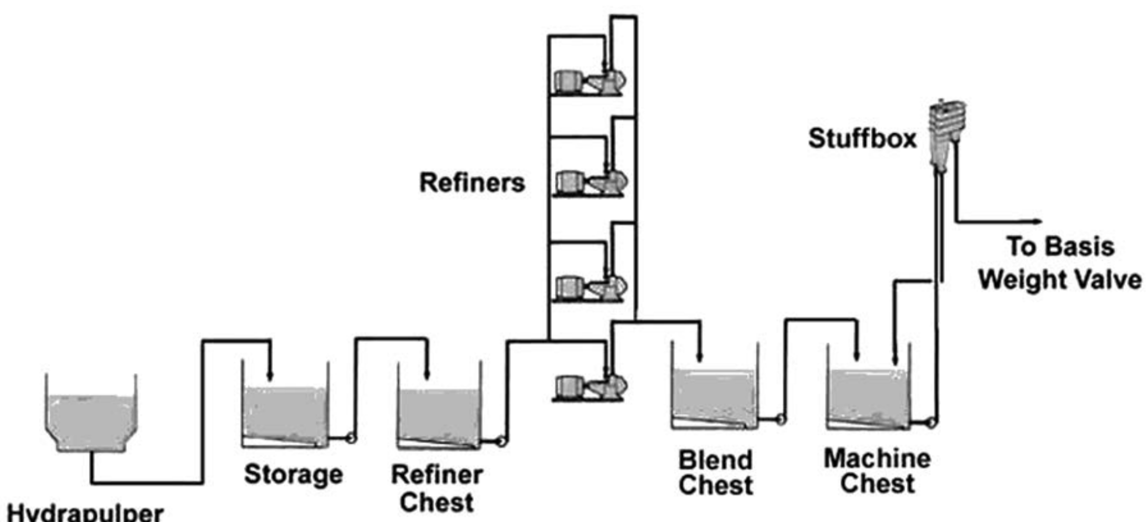

Figure 15-1. *Thick Stock System*

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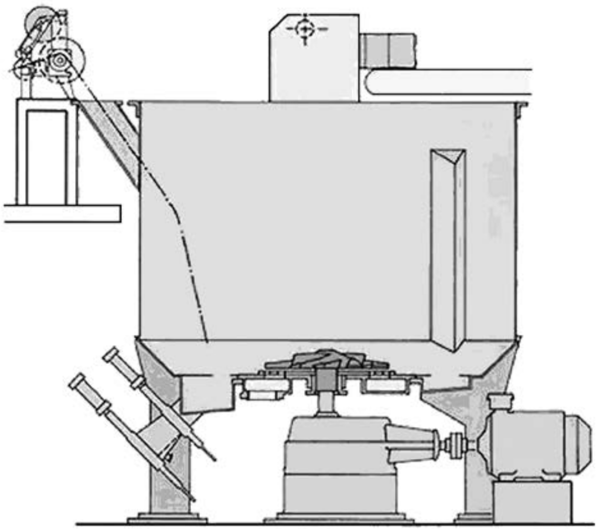

Figure 15-2. *Pulper*

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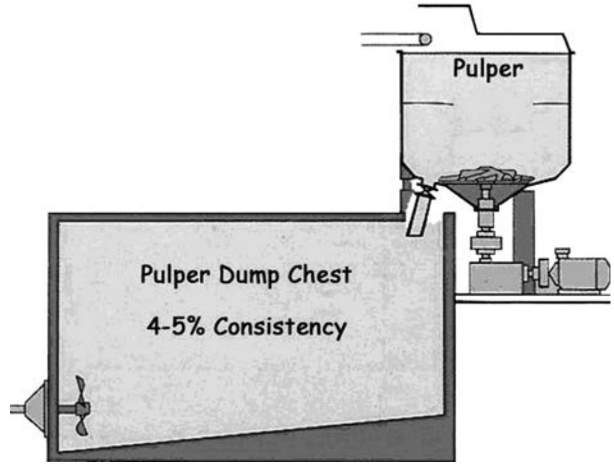

Figure 15-3. *Pulper Dump*

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diluted to a slurry in order to break the fibers apart before they are pumped toward the paper machine.

Pulpers

Pulpers, also known as repulpers or slashers, help to break down the bales into individual fibers (figure 15-2). The bales of pulp or waste paper are fed to the pulper, either by a forklift truck or by a conveyor. In some mills, different fiber components are re-pulped separately and blended together later in stock prep. Water is added to the pulper, the pulp bales are added, and the remaining water is added to bring the pulp to the right consistency; typically around 4 to 5% solids for low consistency pulpers or up to 18% solids for high-consistency pulpers.

Pulping can be done by one of two types of pulpers:

- **Batch pulper:** Typically, this process is completed in a single vessel.

- **Continuous pulper:** Supplemental in-line treatment is commonly used following the pulper to ensure complete dispersion.

The agitator in the bottom, or side, of the pulper provides the repulping action. Steam is often added along with sodium hydroxide or caustic to raise the pH of the slurry. Dyes and fillers can also be added at this point.

Depending on the type of pulp, a batch pulper might take 30 minutes or more to break up the fibers. Once all the fibers are individually broken apart, the pulp slurry can be pumped into the pulper dump or storage chest (figure 15-3). Once the broken apart pulp is pumped away, a new batch of bales is re-filled into the pulper.

A continuous pulper is similar to a batch pulper except the bales of pulp are continually added and the slurry is continually removed through an extraction plate under the rotor. The extraction plate has holes of 3/8 to 5/8-inch.

Refining

This process helps the individual pulp fibers to bond together by employing both mechanical and hydraulic forces to alter the fiber characteristics. This is done by imposing shear stress on the fibers through rolling, twisting, and other tensional actions occurring in a refiner. This process can be performed by two different types of continuous refiners.

1. **Disc refiner:** The most common type of refiner, this unit has a rotating disc and a set of stationary plates, typically with a plate on each side of the disc (figure 15-4). These discs are set closely together so only a small passage between the bars exists. Stock can flow in a parallel arrangement (duo-flow) or a series arrangement (mono-flow). Fibers pass between the moving bars where they are mechanically abraded. The water can then enter the walls of the fiber and cause it to swell. This process also helps to break off the extra small pieces of fiber, called fines.

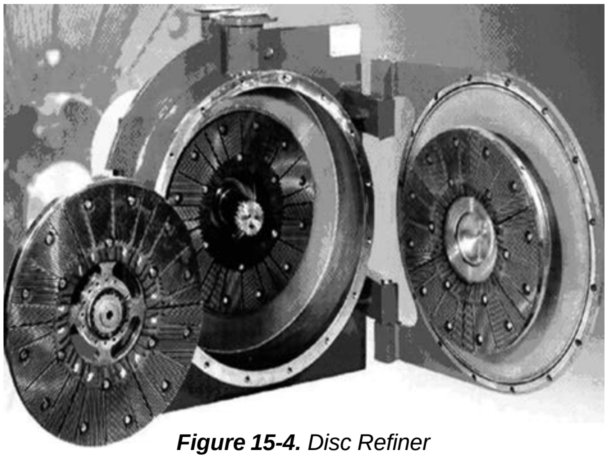

Figure 15-4. *Disc Refiner*

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2. **Jordan (or Conical) refiner:** In this type, the rotating plug (rotor) and its housing (stator) are fitted with metal bars oriented lengthwise. The fibers flow parallel to the bars. The position of the plug determines the clearance of the bars and controls the amount of work done on the fibers for a constant stock throughout.

It has been shown that having a disc refiner is more advantageous to a mill. They have lower no-load energy consumption, which lowers energy costs. They have greater versatility of their refiner plate designs and, because of these designs, can take on higher stock consistencies. They are more compact than the Jordan and are a lower capital investment.

Blend Chest

All the furnish components including hardwood pulp, softwood pulp, and broke are mixed together in the blend chest. All components must be well blended before the stock is diluted down to papermaking consistency.

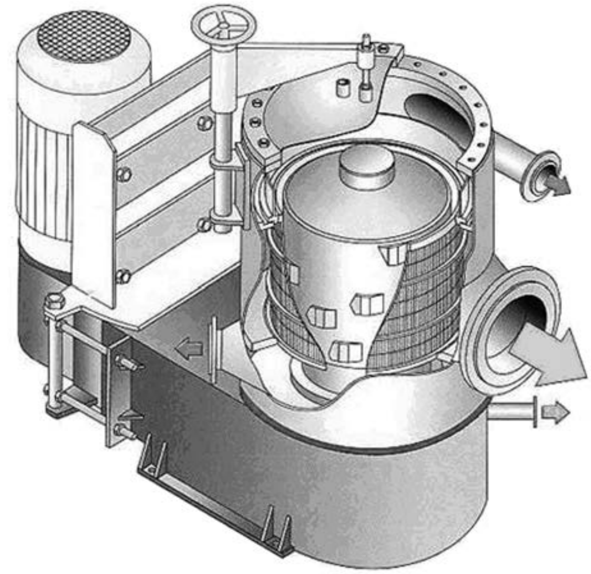

Figure 15-5. *Fine Slotted Screens*

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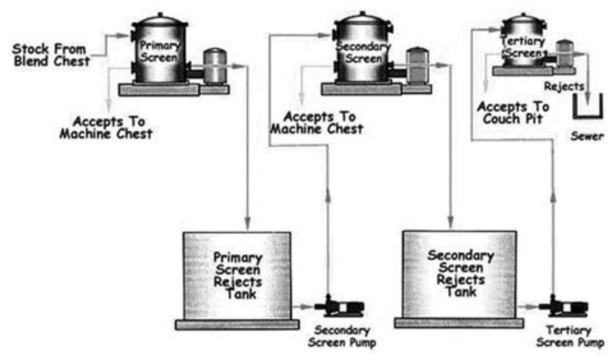

Figure 15-6. *Stock Screening Process*

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Stock Screening

In some mills, this process follows the blend chest. High consistency pulp of around 4% is run through fine slotted screens to remove hard debris that could cause defects in the sheet of paper (figure 15-5). Arranged in multiple stages, the screens generally have a protection screen followed by two stages of fine slotted screens using 6 to 10 thousandth of an inch, although this size varies based on the furnish or grade of paper (figure 15-6). The first two stages run at a high consistency, but the final tailing screen runs at a somewhat lower consistency, around 1.0 to 1.5%, in order to make a better split between good fiber and debris.

Machine Chest

This is the last chest in the thick stock part of stock prep. By this point, all the fibers have been blended and the consistency controlled. It is important that the consistency, anywhere from 3% to 4%, is controlled when going forward in the system as this stock controls the basis weight of the paper. It is from here the stock will enter the thin stock portion of stock prep.

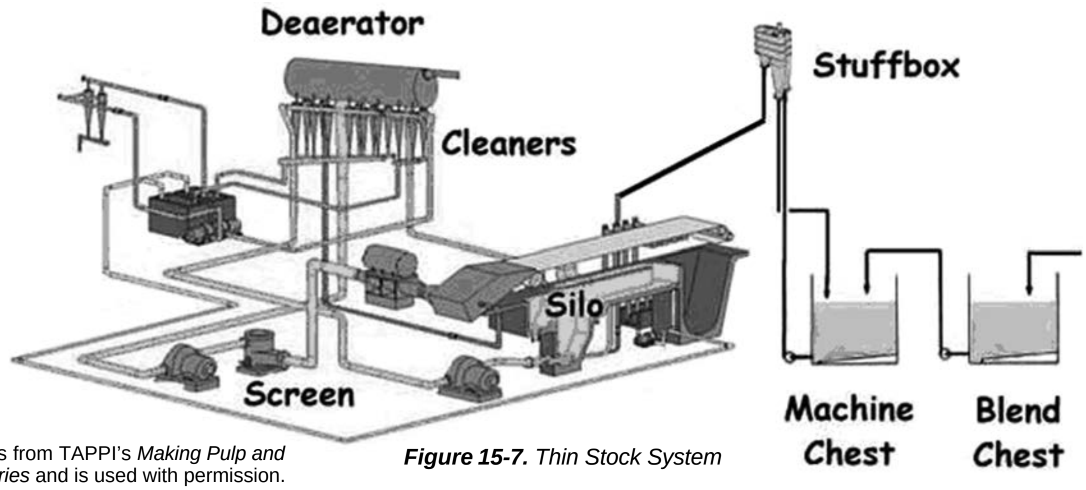

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Figure 15-7. *Thin Stock System*

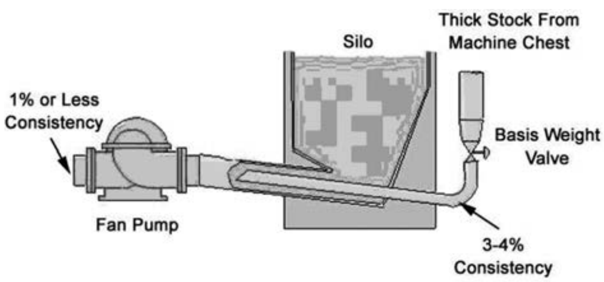

Figure 15-8. Fan Pump

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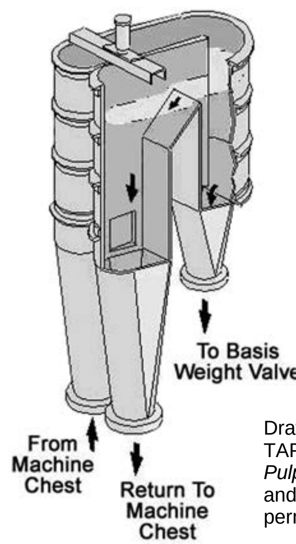

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Figure 15-9. Stuffbox

Thin Stock Process

This section will describe the thin stock processes of cleaning, screening, and diluting to papermaking consistency (figure 15-7). The thick slurry in the machine chest is pumped to the suction-side of a fan pump and is diluted to 1% or less with white water drained from the sheet forming process into a stuffbox (figure 15-8).

Stuffbox

The stuffbox is located high in the air, near the wet-end of the paper machine, and ensures the basis weight valve has enough, and constant pressure so the stock flow can be accurately controlled to the paper machine (figure 15-9). Stuffboxes are frequently replaced with variable speed pumps that supply the basis weight valve directly.

Basis Weight Valve

The stock from the stuffbox flows by gravity through a pipe leading down into the basis weight valve (figure 15-10). It influences moisture, caliper, brightness, opacity, draws, strength, machine stability, and product uniformity. If it is not within acceptable limits, machine performance and product quality will suffer. Most paper machines use a precision basis weight valve to control the amount of stock going to the fan pump. Basis weight is the key variable in paper quality control.

Typical Specification

- Fisher Vee-Ball V150 with either a 2052 actuator or SKF actuator.
- FIELDVUE DVC6200 digital valve controller with Performance Diagnostics

White Water

The water used to dilute thick stock in preparation for forming the paper sheet comes from the

Figure 15-10. *Fisher Vee-Ball and SKF Actuator Basis Weight Valve*

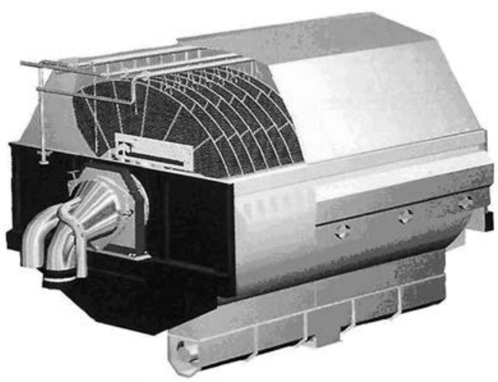

Figure 15-11. *Disc Saveall*

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forming section of the paper machine and is continually recycled back to the headbox. The water, called white water due to its cloudy appearance, is collected in a silo under the paper machine. White water has fiber, fillers, and other valuable chemicals, so it must be collected and recycled. Most of the valuable components in the white water are eventually retained by the sheet forming process.

Saveall

The excess white water is sent to this device where the fiber and fillers are removed from the white water. A disc saveall is made up of screen-covered segments (figure 15-11). A vacuum is applied after the segments enter the white water and the fibers collect in a mat on the outside of the screen. The water that filters through is called clear water and can be used for

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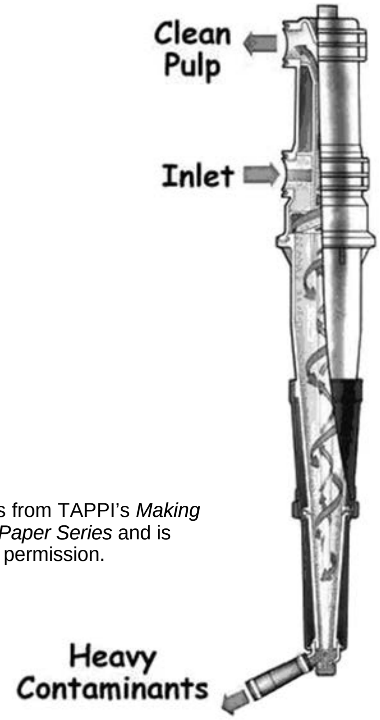

Figure 15-12. *Cleaner*

diluting water on consistency control or other uses.

The collected fibers are washed off the segments as they leave the white water pond. The recovered fiber is diluted and blended with the other fiber sources in the blend or machine chest.

Cleaners

The fibers, after being diluted by white water in the silo, then proceed to the cleaners (figure 15-12). Each cleaner is only capable of handling a small portion of the total flow so many are needed for cleaning. The stock enters the cleaner tangentially causing the flow to form a vortex. The spinning action causes the heavy particles to be thrown outside the vortex. These heavy contaminants move down the inner wall of the cleaner and are rejected through the bottom discharge hole of the cleaner. Lighter fibers stay near the center and exit through the top.

Some of the good fiber is rejected through the bottom. In order to reclaim this good fiber, the rejects will flow from the primary to the secondary cleaners (figure 15-13). The rejects enter a secondary cleaner to reclaim the good fibers. There can also be tertiary, a fourth and fifth cleaner as well if needed (figure 15-14). Each

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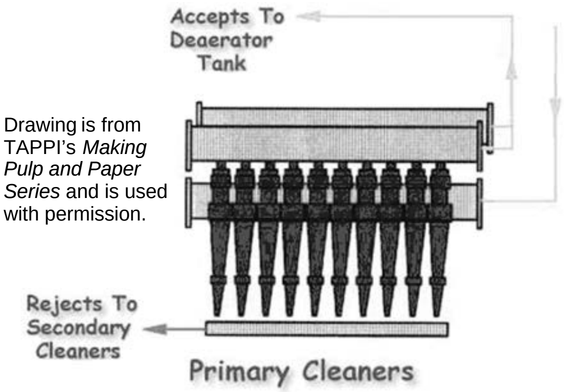

Figure 15-13. *Primary Cleaners*

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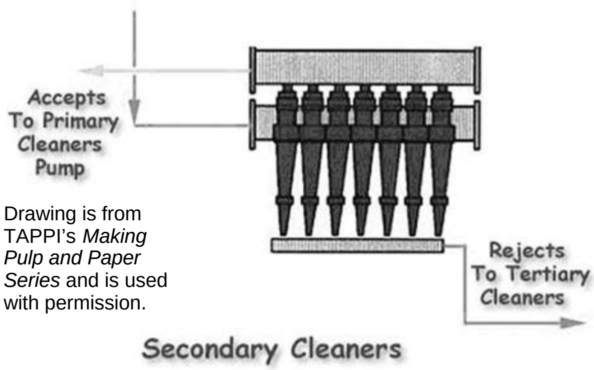

Figure 15-14. *Secondary Cleaners*

successive bank of cleaners contains fewer individual units than the previous bank.

Deaeration Chamber

Depending on the stock, small air bubbles can form around the fibers. This slows drainage during the sheet forming process and can cause pinholes in the sheet. In order to remove these bubbles, a deaeration chamber is used (figure 15-15).

The chamber or tank is connected to a vacuum pump so the stock in the tank is also under vacuum. This vacuum allows the stock to boil even though the stock temperature is below 100°C. This boiling action helps to release air in the stock.

Screens

Almost all paper machines have a screen before the headbox to remove contaminants from the furnish. These screens have a basket of either holes or slots that allow fibers to pass through that collects shives, pieces of plastic, or fiber flakes. These slots are generally 10 thousandths of an inch wide and are more efficient at removing small debris than holes.

These screens also have a way to backflush the holes to prevent plugging. Generally, this is done with a rotor and hydrofoils. The foil passes over the hole and produces a low-pressure pulse followed by a high vacuum pulse. These pressure pulses keep the openings in the basket from binding.

Broke Handling

Broke is better known as internal waste paper generated by the paper mill. This might be from the wet-end from the forming or press sections, or the dry end from the dryer section, reel, winder, or other finishers. Broke contains good fiber and chemicals that should not be lost.

Broke is generally captured in an under the machine repulper or broke pulper. The broke either drops down into the pulper along a chute or is conveyed or blown into the repulper. Wet-end broke is easy to break up into the individual fibers, but fully dried broke requires more aggressive agitation. Sometimes, broke is sent through a high density centrifugal cleaner to remove large heavy particles. This then goes through a deflaker, which mechanically breaks up the underfibered flakes.

Compact Stock Process

Recently, some paper makers have moved to a more simplified stock prep. Rather than relying on large volumes to reduce variation, there is more reliance on modern process control to make the necessary adjustments to correct for variations (figure 15-16). For instance, for thick stock blending and feeding, instead of having two chests to blend the various components and then feed the stock to the fan pump, those functions are handled by a small mixing tank (figure 15-17). As for deaeration, one can replace the large silo and deaeration chamber with a small centrifugal deaeration pump (figure 15-18). This new system has quicker response time and less total volume.

Brown Stock Rejects Valve

Process impurities have a negative affect on end product quality. These impurities may damage process equipment and cause runnability problems. As such, all solids contaminants have to be removed from pulp. Some contaminants can be

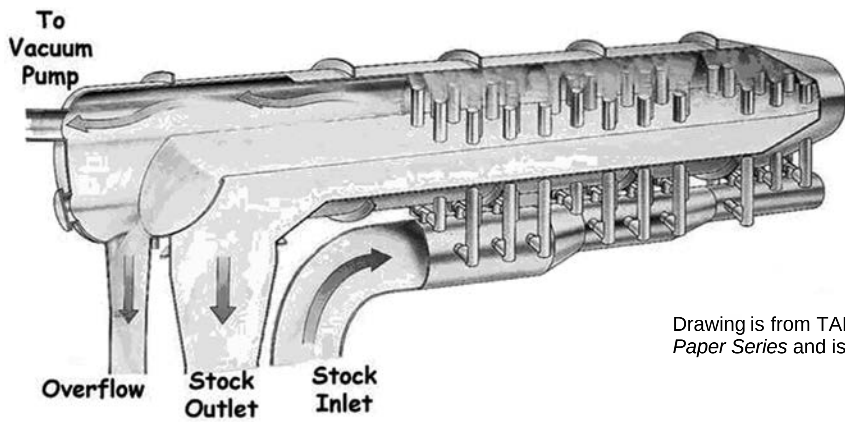

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Figure 15-15. *Deaeration Chamber*

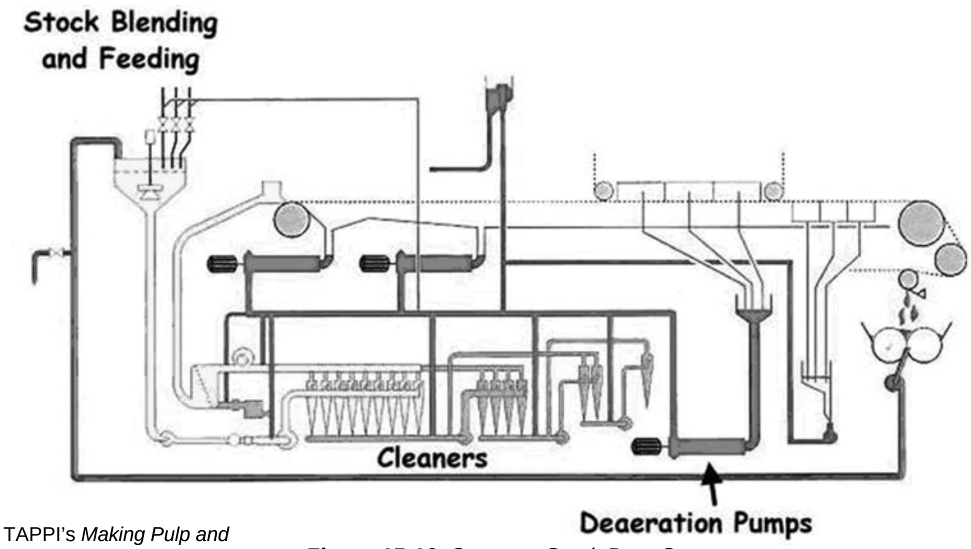

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Figure 15-16. *Compact Stock Prep System*

separated from pulp on screens, whereas others similar or smaller than fibers may be removed by other methods (figure 15-19).

Pulp from cooking always contains some unwanted solid material. Some of the chips may not have been fiberized properly, and some of the fibrous material may not be completely in the form of individual fibers. The main purpose of the pulp screening process is to separate harmful impurities from pulp with minimal fiber loss, and at an acceptable cost level. Bark, sand, shives, and rocks are typically found within the cooked chips and must be removed. There are multiple ways to separate out the impurities. This can be done mechanically by screen plates where separation is based on particle size, whereas gravimetric or centrifugal force field is needed for weight-based particle separation. However, pressure screening in multiple stages is the preferred method for removal of impurities such as sand and shives from the pulp. These operate by separating the feed pulp into either acceptable (impurity free) or rejects (impurity rich). The acceptable pulp passes through the device, and the rejected pulp is removed for further processing. This is accomplished in stages since most pressure screens cannot sufficiently concentrate the impurities in only one screening stage due to thickening of the reject on the screen itself. The purpose of the rejects stages is to concentrate the impurities in the reject stream, and to return the good fibers to the main process line.

Design Considerations

- Tight shutoff not required.
- Hardened materials to protect valve body from wear.
- Ball valve to shear through impurities.

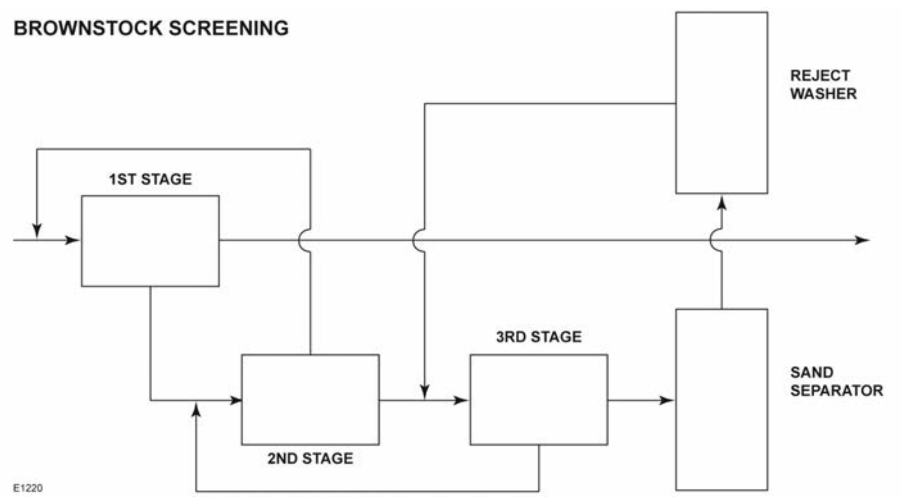

Figure 15-19. *Centrifugal Deaeration Chamber*

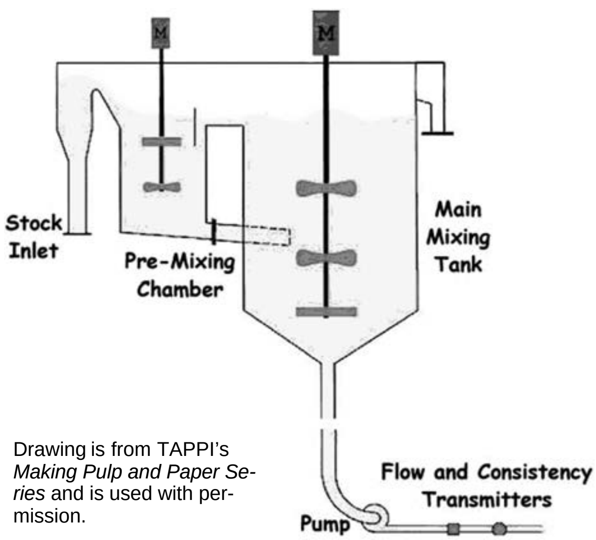

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Figure 15-17. *Compact Stock Mixing Tank*

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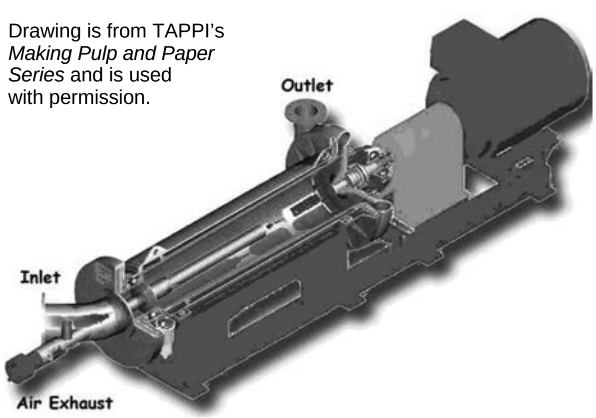

Figure 15-18. *Centrifugal Deaeration Chamber*

Typical Specification

- Fisher Slurry Vee-Ball V150S with high chrome iron trim.

Medium Consistency (MC) Pump Valve

The medium consistency centrifugal pump (MC pump) is used for continuously pumping pulp stock up to 18% bone dry (BD) consistency and can be located in numerous areas of the mill. In processes where the flow control valve is responsible for controlling the pumps head pressure, special care should be given to the valve selection.

In some cases, concerns of pulp stock flow behavior and buildup are addressed by specifying an expanded outlet valve. Many MC pump manufacturer's require expanded down stream piping.

Design Considerations:

- Expanded Outlet
- Ball valve to shear through impurities
- Precise control

Typical Specification:

- Fisher Vee-Ball V150E

Chapter 16

Wet-End Chemistry

In this chapter, we will be discussing materials, other than fibers, that are added to the slurry of fibers before paper is formed. It is important to keep in mind that there are two types of additives.

1. **Functional additives—**These additions are treatments necessary to meet the particular needs of an end-customer.

2. **Process additives—**These additions modify the properties of the paper. They can be used in a multitude of different fashions.

Sizing

The purpose of sizing is to enable paper products to resist penetration by fluids. This is critical for printing operations. If appropriate sizing is not taken into account, the ink will diffuse into the sheet and cause severe quality problems. Sizing can be achieved by using wet-end additives or by applying a coating to the surface of the dried paper.

The traditional wet-end sizing agent is a modified rosin, better known as "rosin size." This additive can actually make paper repel water under acidic papermaking conditions. Rosin size comes from softwoods as a byproduct during the Kraft pulping process. To make rosin work as a sizing agent, papermakers also add aluminum sulfate ($Al_2(SO_4)_3$), better known as "papermaker's alum." This combination is an effective way to make paper resist water and other fluids. The process is also known as "acid sizing" as this combination works well in acidic aqueous environments.

Internal Strength

Many natural and synthetic polymeric substances can be added to stock at the wet-end to improve the physical properties of the dry paper sheet. They are to reinforce the fiber-to-fiber bonds thereby improving tensile strength, reduce "fuzz" or lint on the paper surface, and can reduce the rate of water penetration.

Traditional internal strength additives are natural and modified starches and gums. Starches are polymers of glucose whereas gums are polymers of mannose and galactose. However, the trend is now toward the use of synthetic polymers as latexes and polyacrylamides used in combination with starches and gums. These new products have now met a wider range of specific requirements for greater paper strength with different degrees of stiffness and stretch.

Wet-Strength Resins

The purpose of wet-strength resins is to tie fibers and fines together with additional bonds that are not taken apart by water. Wet-strength paper is defined as paper that retains more than 15% of its tensile strength when wet.

The most common wet-strength agents are ureaformaldehyde, melamine-formaldehyde, and polyamide resins, and are water soluble. These long-chain polymers can be used on paper for juice containers or other liquid containers so the fibers remain strong even after getting wet. However, because these agents are water soluble, they must be fixed onto fibers with the help of retention fillers.

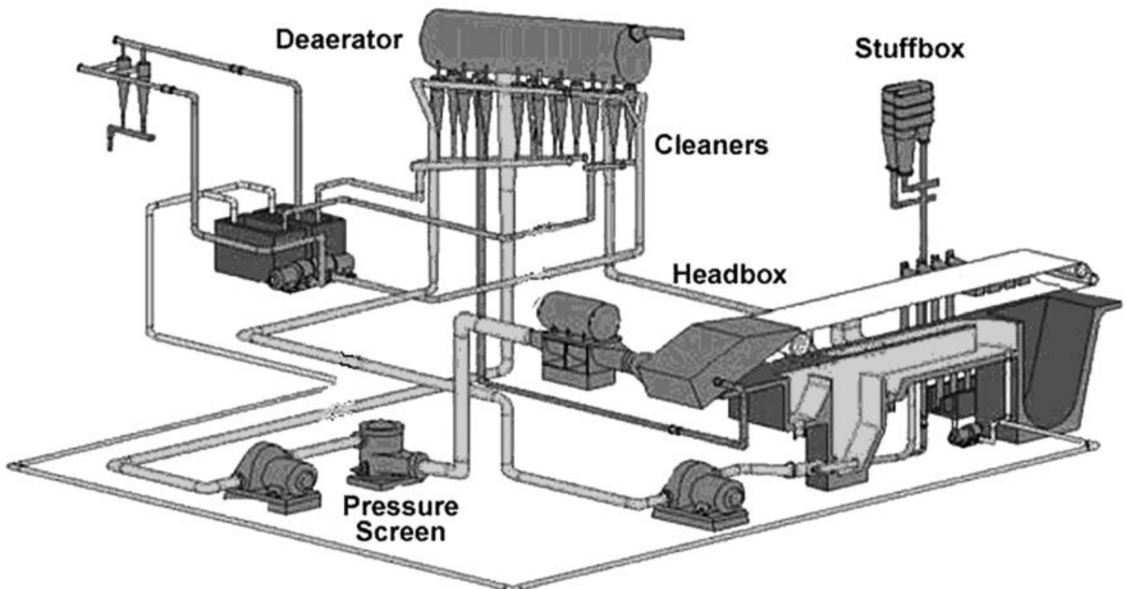

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Figure 16-1. *Stock Approach System*

Fillers

For most copy paper, around 15 - 30% of the papers are fillers; the majority of which is clay and PCC — precipitated calcium carbonate. These additions are generally made to lower the overall cost of materials and can be used for brightness, opacity, or even the smoothness of the paper. However, fillers do not bond together in the same way cellulose fibers do, so they reduce the strength of the paper.

This limits the amount one can put in the sheet. Another difficulty is trying to get the filler to remain with the fiber during the sheet forming process. It is not uncommon to lose fillers while on the moving wire or forming fabric. Additives are used to increase the retention of the fillers so they are not lost during this process.

All of these wet-end additives are either soluble in water or are small enough to fit through the small openings of the forming fabric. To keep these additives from falling out of the process, retention aids are added. These retention aids insure that the fillers attach to the fibers. These are typically added just before the headbox or before the headbox screen (figure 16-1). They are added late in the process because excess agitation could break up the polymer chains.

The size and shape of mineral additives can greatly affect the properties of the paper. For instance, most grades of paper have a thickness specification. Papermakers want to make the paper as thick as possible all while using the least amount of fiber. The more flat the microscopic filler, the more dense the paper. However, many times these fillers are so small the filler gets between the fibers and makes the paper smoother.

The common papermaking fillers are clay, calcium carbonate ($CaCO_3$), talc, and titanium dioxide (TiO_2). Clay is the most popular since it is cheap, stable, and generally provides good performance. Calcium carbonate is a better opacifier than clay and has higher brightness. Titanium dioxide is the brightest and most effective opacifier, however, is high cost. Talc is used as a "soft" filler that helps to give paper a soft, silky feel to the product.

Finally, due to the amount of water being pumped through the system, foam can be formed. This can create spots or pinholes in the paper. To alleviate this problem, defoamers are added to help the bubbles coalesce into bigger bubbles. These larger bubbles will then rise to the surface and break. The water and warm temperatures can also create a wonderful environment for bacteria and fungal slimes. These are called "bugs" in the paper mill. These bugs can lead to holes and spots in the paper and frequent sheet breaks but can be controlled with the addition of biocides to the paper machine "white water" system.

Titanium Dioxide (TiO_2) Applications

Titanium dioxide is used as a paper additive to increase brightness and opacity. It is a fine white powder that is added at a low flow rate as a slurry to pulp stock. The process is very erosive and requires fine control and tight shutoff.

Typical Specification

- Fisher Vee-Ball V150 Micro-Scratch, Micro-Notch, Macro-Notch with Ceramic Trim
- V500, Reverse Flow with ceramic trim

Chapter 17

Paper Machine

Wet End

The paper machine is essentially a series of processes all tied together (figure 17-1). These processes are designed to take fibers in a dilute slurry of water and produce a dried web of paper. The paper machine is described in two parts: the wet end, which is the forming section, and the dry end, which includes the pressing and drying operations.

Fourdrinier Single-Ply Process

The following are the steps taken to form the fibers onto the wet end of the paper machine in new and more modern pulp and paper mills:

Tapered Manifold

The stock heading toward the headbox is coming from the headbox pressure screen (figure 17-2). This stock is to be spread uniformly over the entire width of the paper machine where some machines are up to 400 inches wide. This is accomplished by using a tapered manifold (figure 17-3).

The tapered manifold starts large at the inlet end and tapers down over the length of the device. This allows the pressure to remain the same even though stock is being diverted through numerous tubes to the headbox. At the end of the manifold is a recirculation line that allows one to balance the manifold for different flow rates.

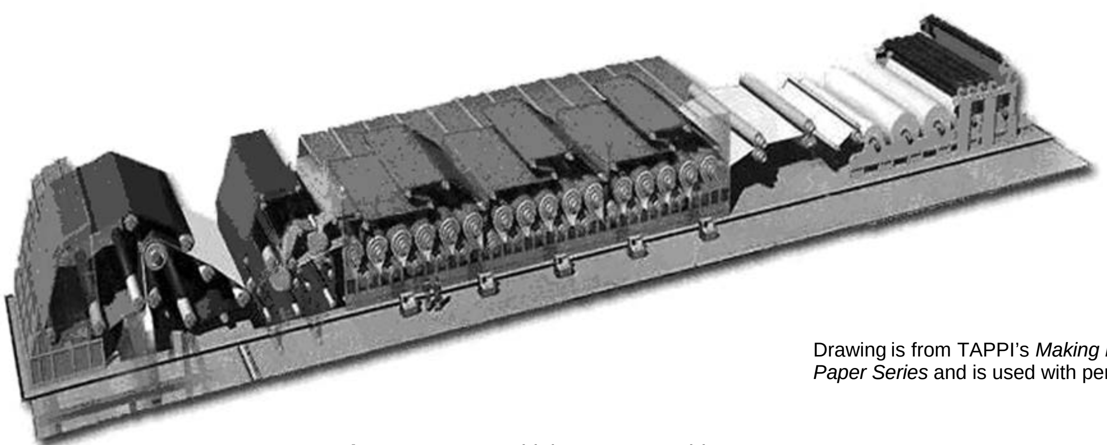

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Figure 17-1. *Fourdrinier Paper Machine*

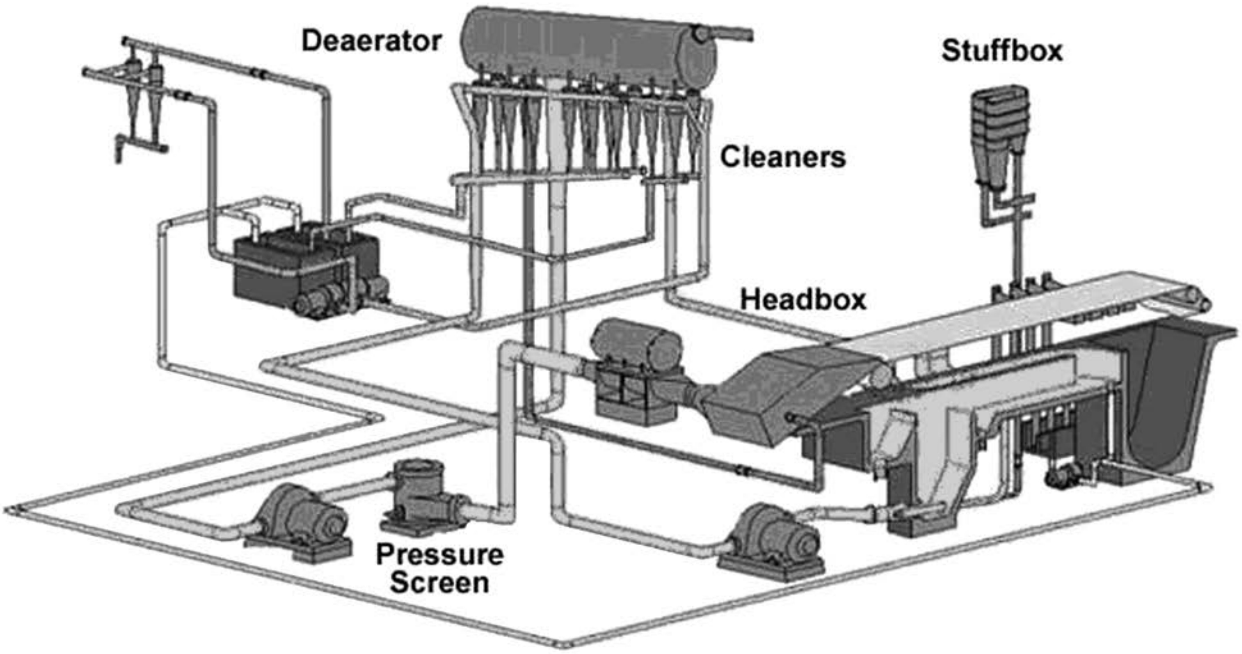

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Figure 17-2.

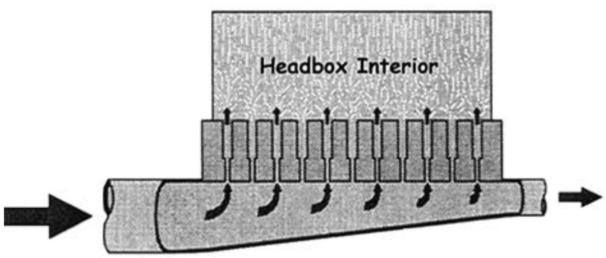

Figure 17-3. *Multitube Tapered Manifold*

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Headbox

From the manifold, stock enters the headbox through a series of tubes. The headbox has several purposes. It needs to eliminate the turbulence coming out of the tubes from the manifold, it has to break up the fiber flocs, and it must ensure the amount of stock coming out of the slice is uniform all the way across the width of the machine. Below are the major types of headboxes:

- **Rectifier Roll (Air-padded) —** This type of headbox has a number of hollow rolls within the stock stream, inside the headbox. The rolls are perforated with approximately one inch diameter holes throughout the surface of the roll (figure

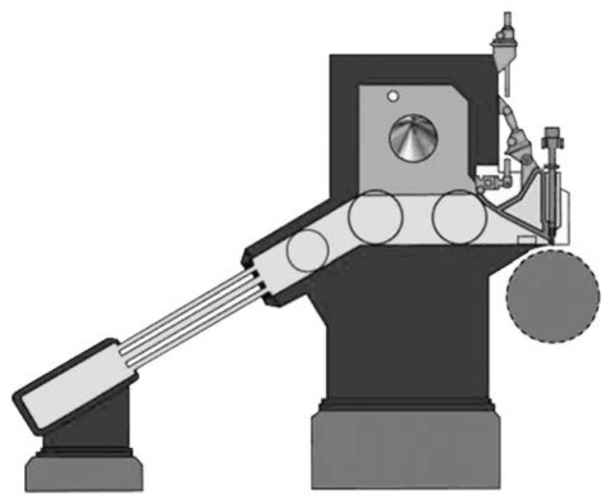

Figure 17-4. *Rectifier Roll (or Air-Padded) Headbox*

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17-4). Typically, there is one roll at the entrance of the box, a second roll in the main pond area, and a third roll near the discharge of the headbox. The stock fills the box almost to the top of the rectifier roll so a cushion of air remains above the stock. This cushion of air helps to lessen pressure variations, thus lessening changes in the basis weight of the paper being produced. The rolls rotate slowly to help eliminate any large-scale

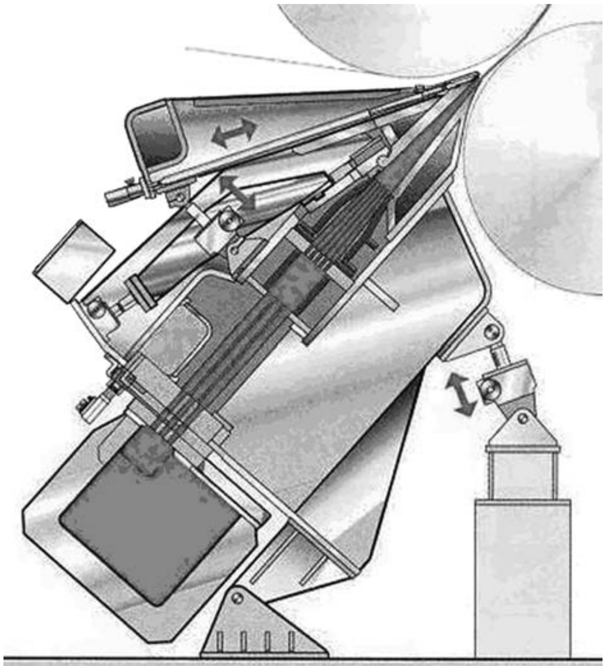

Figure 17-5. *Hydraulic Headbox*

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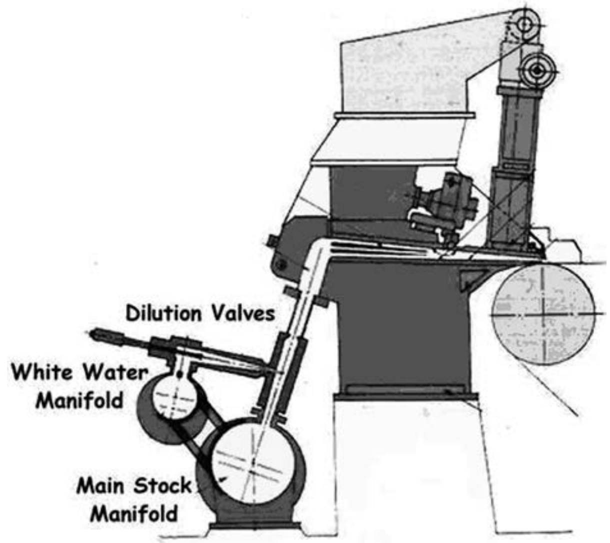

Figure 17-6. *Dilution Control Headbox*

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turbulence inside the headbox and to break up the fiber flocs so fibers are well distributed. This type is good for slower paper machines and specialty machines with a wide range of flow requirements.

- **Hydraulic —** These devices are completely filled with stock. Because no air cushion exists many hydraulic headboxes use a pressure attenuator at the headbox manifold to reduce any pressure variations. Since hydraulic headboxes have no rectifier rolls, they are designed to deflocculate the stock by changes in velocity as the stock passes through tube bundles or across flat sheets. The discharge velocity from the slice depends directly on the feeding pump pressure. This type of headbox can be found on most new paper machines (figure 17-5).

- **Dilution Control —** This type uses dilution or consistency control across the width of the headbox to correct errors in basis weight (figure 17-6). By opening a particular dilution valve, the computer will add dilute white water to the inside of the headbox in precisely the right point to dilute a heavy streak. If the sheet is too light, the computer removed some of the dilute water by closing the valve. There can be as many as one hundred or more dilution valves located along the back of the headbox, all of which are individually controlled.

Each type of headbox contains a headbox slice. The slice is a full-width orifice or nozzle with a completely adjustable opening to give the desired flowrate. The jet of stock emerging from a typical headbox slice contracts in thickness and deflects downward as a result of slice geometry. The jet thickness, together with the jet velocity, determines the volumetric discharge rate from the headbox.

Every slice has a top lip and an apron (bottom lip), both constructed of suitable alloy materials to resist corrosion. The top lip is adjustable up or down as a unit (main slice) and also in local areas by the use of individual micro-adjusters. These small adjustment rods are attached to the slice lip and, with manual adjustments or the help of a computer system, can improve the distribution of the stock and allow for a more uniform basis weight across the width of the paper machine. The rectifier and hydraulic headboxes utilize adjustable slices in the same way.

Forming Wire

The stock leaving the headbox slice, typically between 0.5 - 1% solids, is deposited onto a synthetic forming fabric (or wire). Water immediately begins to drain through the forming fabric producing a mat of fiber on the fabric surface. The jet velocity at which the stock is deposited onto the fabric is very important. This process controls fiber alignment and affects the strength properties in the direction of web travel. This wire will continuously travel the length of the wet-end of the fourdrinier machine providing time for sufficient water removal.

Forming Board

This is the first static element under the wire used to remove additional water. This element supports the wire at the point of jet impingement. This device is needed to prevent wrinkles in the forming fabric. This is accomplished by correctly spacing the blades of the forming board at the correct angle so jet delivery can be optimized for best sheet formation. This element also serves to retard initial drainage so fines and fillers are not washed through the sheet.

Foil Units

Following the forming board, water is drained from the sheet over foil units. These foil units have a blade with a high slope or angle towards the rear of the blade. This creates a small vacuum which pulls more water through the mat. The foils also create turbulence to help break up any cellulose flocs that are beginning to form. The higher the foil angle, the greater the vacuum created thus more turbulence and water drainage.

Flatboxes

The sheet on the forming fabric is still very wet as the action of the foils is not enough to remove any more water. A flatbox, or vacuum box, is a narrow box positioned under the forming fabric, across the width on the paper machine and is connected to large vacuum pumps that provide a differential pressure or vacuum that is needed for further removal of water. These vacuums are capable of increasing the sheet to around 15% solids.

Couch Roll

The final device used to remove water on the forming section, the couch roll, consists of a hollow outer shell that rotates with the wire and a stationary inner vacuum box. The vacuum box is connected to a large vacuum pump. The holes in the shell allow the vacuum inside to remove water from the sheet. This removes water to make the consistency 20 - 25% solids. The overall goal of this final section is to get the sheet as dry as possible to improve the strength of the sheet before it is peeled, or couched, from the wire and sent for further de-watering to the press section of the paper machine.

Fourdrinier Multi-Ply Process

This process is exactly the same as the single-ply process except multiple layers or plies are eventually combined into a single sheet. This can be accomplished in a multitude of ways:

- **Stratified Headbox —** This device is capable of depositing two or three different layers of stock on the fourdrinier wire at the same time (figure 17-7).

- **Secondary Headbox —** This device is simply a common paper machine with a second headbox to put a secondary layer on top the preexisting layer.

The above two options still have an issue; all drainage occurs through the bottom layer thus, causing some mixing of the fibers. To alleviate this problem, papermakers have devised a few other options.

- **Multiple Fourdriniers —** These machines actually have multiple fourdrinier machines running on top of one another. The sheets all wind into a central area where the sheets are pressed together to make a multi-layer paper.

- **Cylinder Former —** This device consists of a vat and a large diameter wire-covered cylinder (figure 17-8). The sheet is formed on the wire as the cylinder rotates through the dilute stock slurry. The water is then drained into the cylinder. The wet sheet is then consolidated and couched off onto a wet felt. This is most effective in the multi-ply process as each cylinder lays down an individual ply of paper, which are each individually couched to the previous ply, thus, making a heavyweight paperboard.

Twin Wire Formers

This device now holds the speed and production record for the majority of paper grades. This technology is becoming more popular than the fourdrinier machine because:

- Water can drain from both sides of the sheet rather than one, leading to the top and bottom of the sheet being more alike.

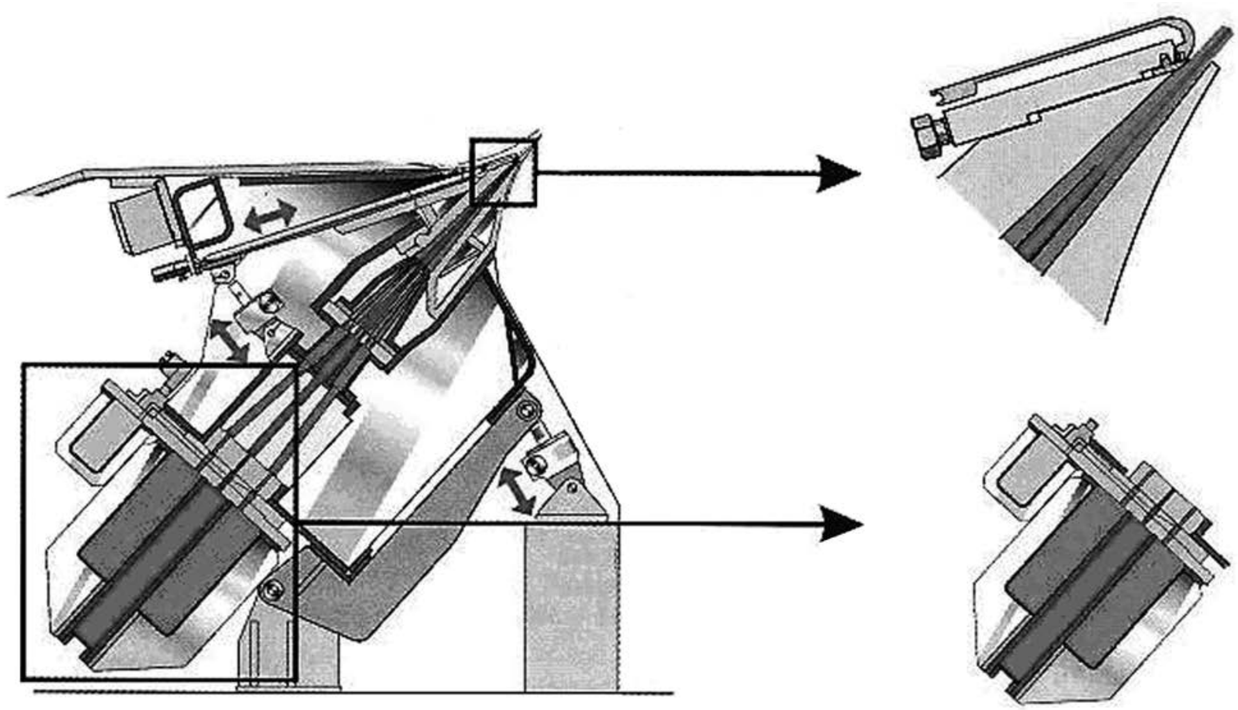

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Figure 17-7. *Stratified Headbox*

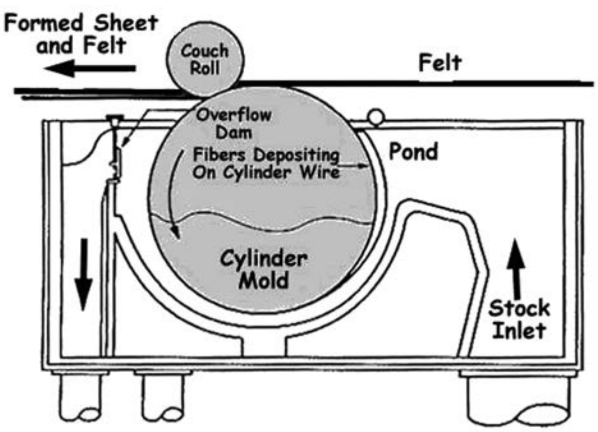

Figure 17-8. *Cylinder Former*

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- Water can be drained in a much shorter distance.

- The technology is much faster than a fourdrinier machine.

These twin-wire formers can be broken up into two types.

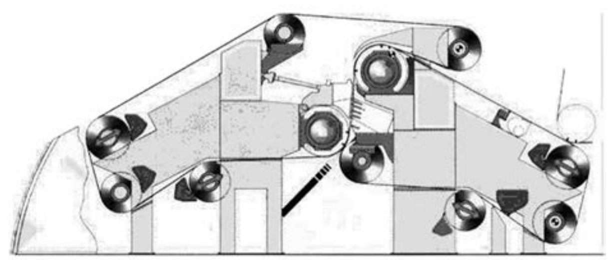

Figure 17-9. *Gap-Wire Former*

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- **Gap Formers —** These devices inject the headbox jet between two converging wires (figure 17-9). Many gap formers have a large forming roll where the majority of the sheet drainage occurs. There are also several high vacuum boxes and a suction couch roll where the two wires eventually separate and the sheet is taken into the press section.

Gap formers hold the speed records for single-ply grades of paper such as newsprint or copy papers. This technology is also becoming competitive in the multi-ply paperboard market.

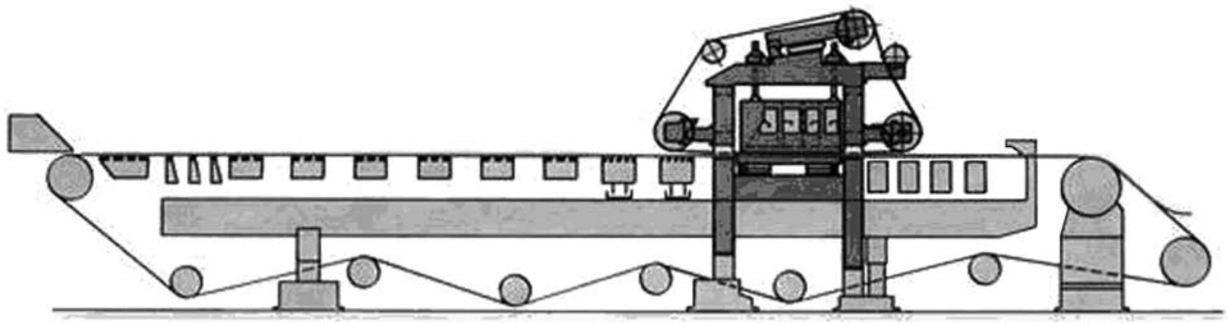

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Figure 17-10. *Top-Wire Former*

- **Top-Wire or Hybrid Formers —** This device sits on top of a conventional fourdrinier single-wire former and deposits a jet from the headbox onto the single wire (figure 17-10). The wire passes over an expanse called the "free drainage zone" where the initial drainage is downward. The second wire then covers the top of the sheet allowing dewatering to occur in both directions. Multiple configurations can be found with vacuum shoes and blades throughout the forming area to help the dewatering process.

What makes this device more advantageous to a Gap Former is that a top-wire unit can be readily fitted to an existing fourdrinier to improve sheet quality and allow for machine speedup.

Dry End

After the forming section of the paper machine, the sheet is still approximately 20% solids. Now that the forming section cannot take or vacuum out any additional water, we must mechanically press out the water.

Before discussing the press section, one must understand the nip. Most paper machines have at least two nips, and can have as many as five. The nip is a process of removing water by mechanical means by passing the wet paper sheet, almost always with a felt, between two rotating press rolls. Nips generally follow these steps:

1. Compression of the sheet and felt between two rolls begins. Air flows out of both structures until the sheet is saturated.

2. Now that the sheet is saturated, hydraulic pressure within the sheet structure causes water to move from the paper into the felt. Once the felt becomes saturated, water moves out of the felt. This phase brings the paper to its maximum hydraulic pressure.

3. The nip expands until the hydraulic pressure in the paper is zero, corresponding to the point of maximum paper dryness.

4. In this phase, both paper and felt expand and the paper becomes unsaturated. Although a negative pressure is created in both structures, a number of factors cause water to return from the felt to the paper; also known as "rewetting."

The top roll is mechanically loaded to create the desired pressure within the nip. The higher the pressure applied at each nip, the more effective the water removal. However, too much pressure at the nip will take the felt and sheet beyond the point of saturation. This condition is called "crushing" and significantly weakens the sheet strength in the nip. Operating a nip at the point of crushing will cause the sheet to break. At faster machine speeds, higher pressure will have a diminished effect because of the brief residence time in the nip.

Press

The primary objective of the press section is to remove water from the sheet and consolidate the paper web. This section can also provide other product requirements such as providing surface smoothness, reducing bulk, and promoting higher wet web strength.

The oldest style of presses is a straight through press arrangement (figure 17-11). For the more modern arrangements, the most widely used presses can be described in full below.

- **Roll —** This press consists of two large-diameter rolls, loading arms to supply pressure, and a press felt (figure 17-12). As the

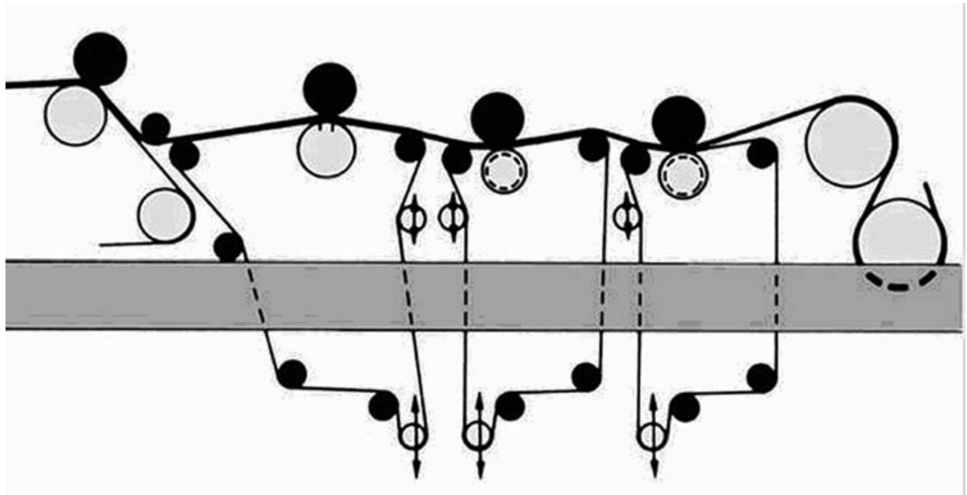

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Figure 17-11. *Straight-Through Press*

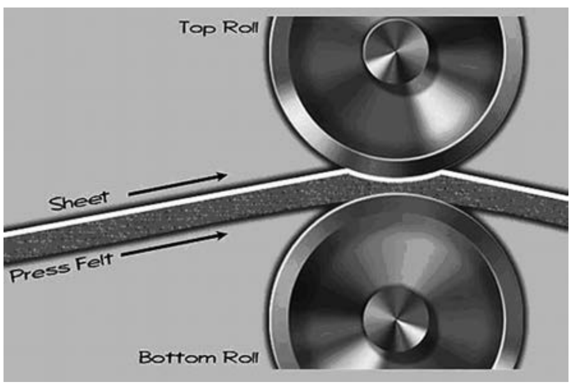

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Figure 17-12. *Roll Press*

sheet enters the ingoing nip between the two rolls, pressure builds and the sheet is compressed. As pressure continues to rise, the water in the sheet is forced out of the sheet into the press felt. This pressure can be anywhere from 500 - 2,000 pounds per square inch where the higher the pressure, the dryer the sheet will become.

However, press rolls normally have rubber covers that essentially smash together. The "footprint" that is created on the rolls, better known as the nip width, can be larger or smaller depending on how hard we press the rolls together. Past the mid-point of the nip, the pressure begins to decrease and some of the water is actually sucked back into the sheet or re-wetted. How dry the press can get paper is also determined by the nip time. Generally, the roll press can increase sheet consistency to 38 - 32% solids.

- **Shoe —** Rather than a roll press, some paper machines use a shoe press (figure 17-13).

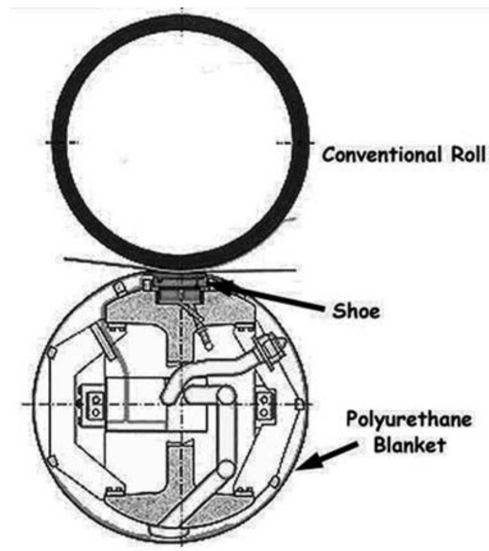

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Figure 17-13. *Shoe Press*

This type of device has a stationary roll that is actually a hydraulically loaded stationary shoe which is concave shaped in order to fit the other roll. The shoe is covered by a rotating polyurethane blanket lubricated with oil to eliminate any type of friction between the shoe and blanket. This creates a high pressure and long time in the nip thus allowing for better drying (figure 17-14). This drying can get the sheet to approximately 50% solids.

- **Fabric Press —** For this type, a multiple-weave, non-compressible fabric belt passes through the nip between the felt and the rubber-covered roll to provide void volume to receive the water. The water is removed from the

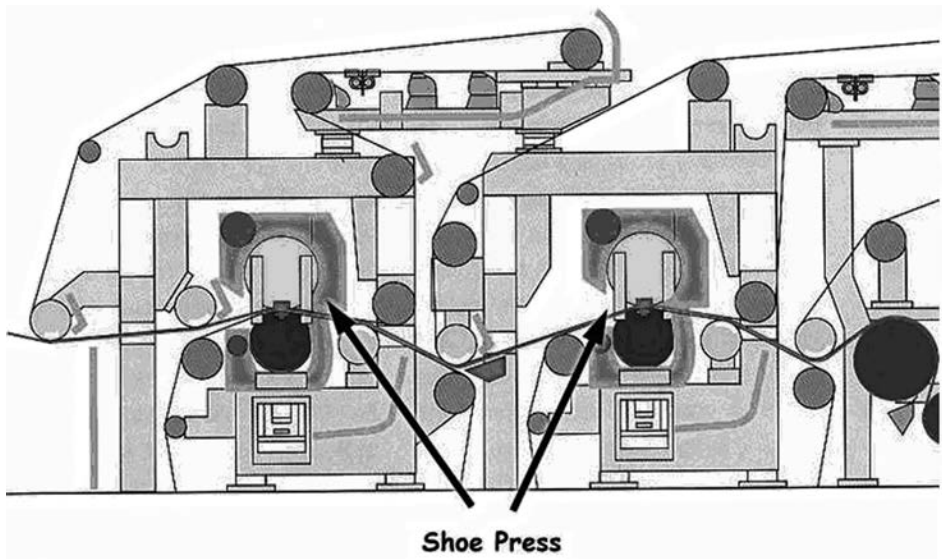

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Figure 17-15. *Modern Straight-Through Press*

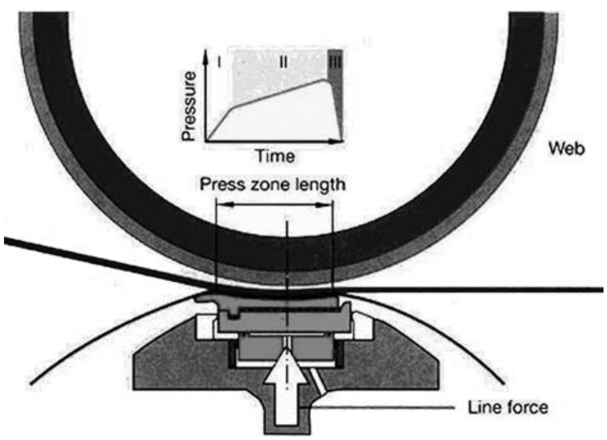

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Figure 17-14. *Shoe Press Nip*

fabric by passing over a suction box on the return run.

- **Extended Nip —** This type of press features a wide nip to give the sheet a long dwell time at high pressure. When used as the last nip, this press provides not only a much drier sheet, but also a stronger sheet due to improved consolidation of the web structure.

Mechanically pressing the water from the sheet is eight times cheaper than trying to dry the sheet. Because less drying would be needed, faster machine speeds and production can also be achieved.

One of the most important things on the press is the press felts. In the past, these were woven woolen blankets. Now, these are commonly composted of a woven synthetic base fabric and fiber matt, attached by a sewing punching process. These must be strong enough to withstand the compression of the rolls while still providing void volume for the water that is removed from the sheet in the press nip.

Press Arrangements

Below are the typical press arrangements that can typically be seen in pulp and paper mills.

- **Straight-Through —** The oldest and simplest of the press arrangements, this type can still be found on paper and board machines. Each press within this design has a smooth top roll and a bottom felted roll so only the top surface of the sheet received smooth roll contact. Later, an inverse second press allowed the bottom of the sheet to be in contact with the smooth roll.

- **Modern Straight-Through —** This unit has two, double felted presses, which is common in new paper machines (figure 17-15). In this design, the sheet is fully supported off the couch, between the individual presses, and into the dryer section. Depending on the weight of paper, the more shoe presses are necessary for water removal.

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Figure 17-16. *Two-Tier Drying System*

Drying

After pressing, the sheet is conveyed through the dryer section where the residual water is removed by evaporation. This is due to the cellulose fibers being hydrophilic and wanting to hold onto water. At this stage, the wet web is approximately 40 - 45% solids.

Most paper is dried on cast iron or steel drying cylinders, each cylinder being 60 - 72 inches in diameter, that are fed with steam from the boiler with pressures between 15 - 150 psi, depending on the type of paper. The wet web is held tightly against the cylinders by a synthetic, permeable fabric called the dryer felt. The evaporated water is carried away by ventilation. The final result of the dryer section is paper with 5 - 8% moisture.

Most paper machines have three to five independently-felted dryer sections, each with their own speed control to maintain sheet tension between sections and adjust for any sheet shrinkage. The two-tier configuration is the most common arrangement for dryers. The sheet passes from dryer to dryer where it is tightly pressed against the dryer cylinders by the dryer fabric (figure 17-16). The paper passes unsupported between each of the dryers. Once the remaining water in the sheet rises to its boiling temperature, water is converted into steam. This steam is collected in a containment hood to remove the water vapor. On the inside of the dryer cylinders, the steam is condensed back into water, or condensate. This conversion of steam into water supplies the majority of the energy that dries the paper.

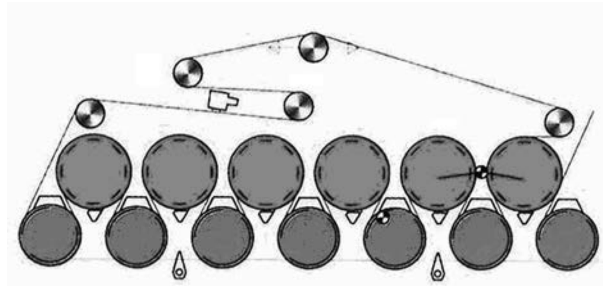

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Figure 17-17. *Single-Tier Dryer Section*

At high speeds, the unsupported paper between the dryers can flutter and occasionally break. Because of this, many modern paper machines are going with a single-tier or "Uni-run" arrangement where the dryer fabric is in constant contact with the sheet (figure 17-17). This allows for the machine speed to increase.

The condensate that collects within the dryer cylinders must constantly be removed. This is the job of the siphons.

Steam and Condensate System

The heat energy for paper drying comes from steam as it condenses inside the dryer cylinders. This is known as latent heat. Steam always condenses at the saturation temperature, as defined by the pressure in the system. This is important when trying to have uniform drying across the machine. The condensate that forms in the dryer cylinders is removed by a specially designed pipe assembly called a siphon. On slower machines, the condensate collects in a puddle at the bottom of the cylinder. For high-speed machines, a true rimming condition can be reached where the condensate covers the entire inside surface due to centrifugal force.

In siphoning, differential pressure pushes the condensate through the siphons (figure 17-18). The siphons carry the condensate from the dryer to a separator that collects the condensate and recycles any steam that has been blown through. The condensate is reused by sending it back to the mill's boiler feedwater system (figure 17-19).

Hood Ventilation

It is important to realize that a ventilation hood exists over the entire dryer section beginning from the press section up to calendaring. Depending on

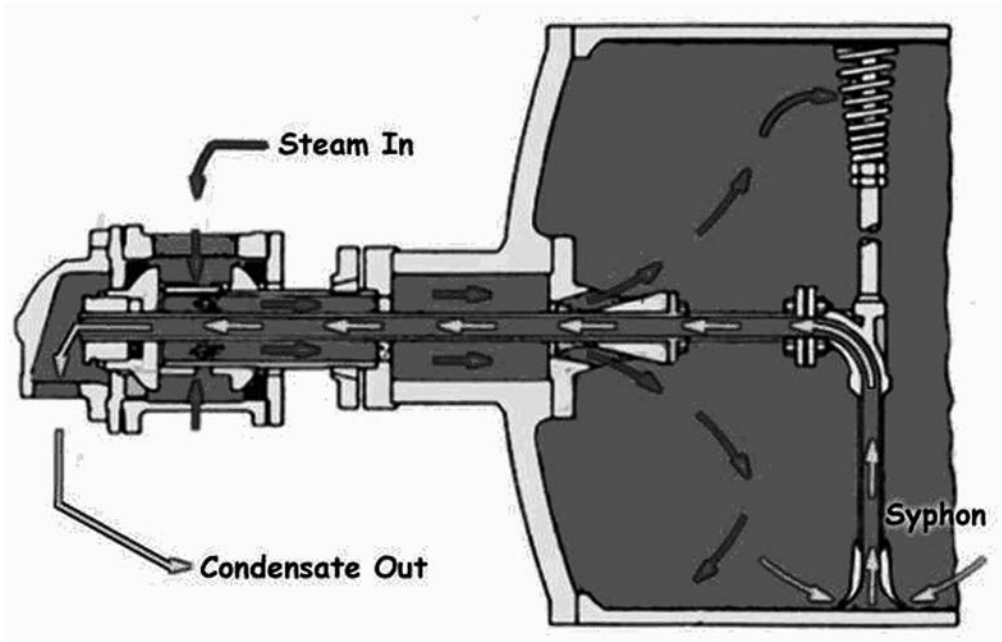

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Figure 17-18. *Steam Drum and Siphon*

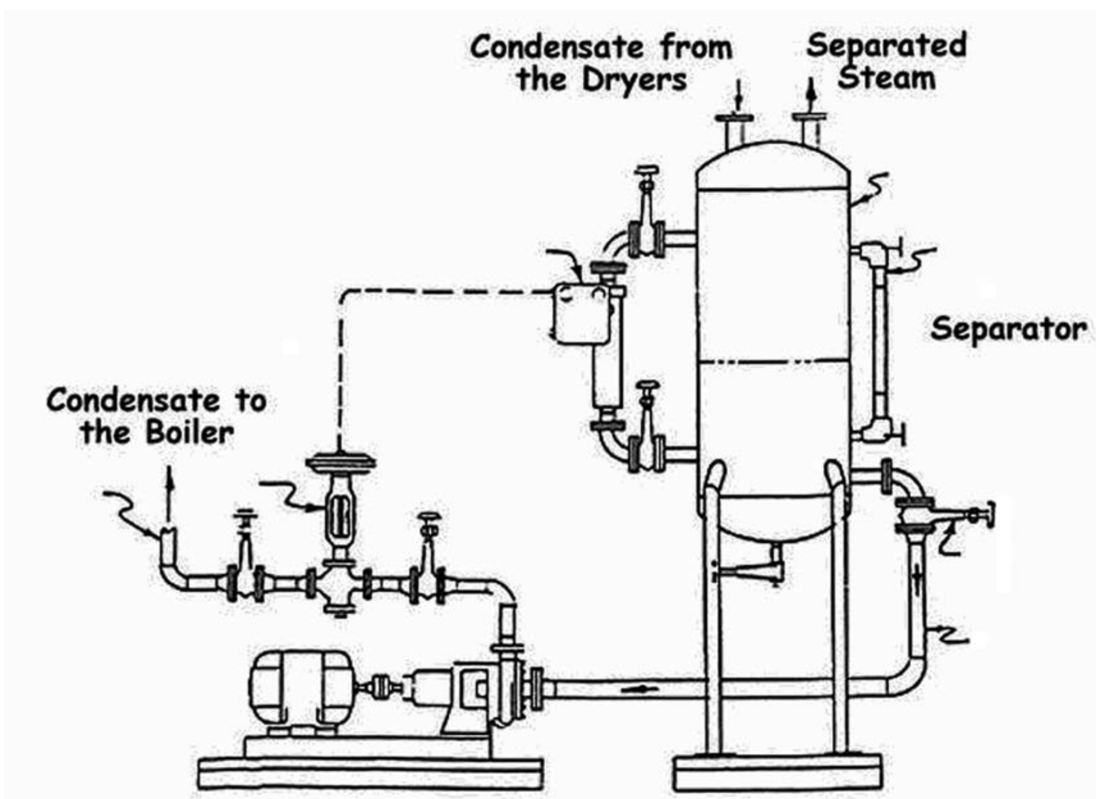

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Figure 17-19. *Condensate Process* the type of hood arrangement, 7 - 20 pounds of air are utilized for each pound of water evaporated. To prevent drips, buildup and corrosion within the hood, the volume and temperature of exhaust air must be sufficient to avoid localized condensation.

Modern generation hoods, also called “high-dew point hoods”, are well sealed and insulated. Diffusion air is totally eliminated, and the amount of fresh makeup air is sharply reduced by operating at high temperature with high recycle.

Size Press

Sizing solution is commonly applied within a two-roll nip which gives the name size press. This device is found about three quarters of the way down the dryer section where starches and other materials can be applied at this station in order to improve sheet surface, internal strength, smoothness, and resistance to water penetration. The objective is to flood the entering nip with sizing solution so the paper absorbs some of the solution.

The basic mechanisms that incorporate starch solutions into the sheet is the sheet’s ability to absorb the sizing solution and the amount of solution film passing through the nip. Sheet absorption is greatly affected by sheet moisture as higher sheet moisture promotes absorption. However, the level is typically controlled to 4 - 5 percent or less to ensure the sizing agent is kept nearer to the surface.

Modern paper machine speeds can create turbulence due to changing nip pressures. This affects the size press’ ability to evenly distribute the solution. To overcome this issue, most size presses have larger diameter rolls to keep solution turbulence more manageable. Others have begun to use a metering size press, which applies the starch to the surface of the size press rolls by metering the amount applied to the sheet with a blade or rotating rod.

Today, the size press can also be used for coating applications; including pigmented coatings and other specialized surface applications. Some manufacturers are beginning to include pigment in the starch application.

Calendaring

This process helps to smooth and flatten the sheet, better known as the thickness or caliper variation of the sheet. This is done by compressing the higher areas in the sheet more than the lower. Surface smoothness improves so the paper prints better. Sheet density is increased so the paper becomes thinner and denser. Making the sheet denser also makes the paper less stiff.

Calendaring changes the surface and interior properties of the sheet by passing the web through one or more two-roll nips where the rollers may or may not be of equal hardness. By using extreme pressures, the objective is to press the paper against the smooth surface with sufficient force by using one of the calendaring types below.

- **Hard-Nip —** Both rolls are made of either iron or steel. Although this type smooths the sheet by calendaring to a uniform thickness via flattening the higher areas in the sheet, it can create areas that are more dense as well. These density variations are due to basis weight variations and can turn into variations in surface properties

- **Soft-Nip —** For this type, the loading roll is still hard but the opposing roll has a soft polymeric cover, usually some type of polyurethane. Since the side contacting the metal roll receives a much better finish than the side contacting the resilient roll, it is necessary to have two nips for equal finish.

Calendaring at high temperatures is desirable because the paper becomes more pliable and can be calendared at lower pressure.

Reel

After drying and calendaring, the paper product must be collected in a convenient form for subsequent process off-machine. This is typically done by a drum reel which collects the product to a specified diameter.

Most reels are motor-driven under sufficient load to ensure adequate tension on the sheet from the calendars. The web wraps around the reel drum and feeds into the nip formed between the drum and the collection reel, which is held by the secondary arms. While the reel builds up, an empty spool is positioned on the primary arms.

To transfer from a full roll to empty spool, the parent roll needs to be removed. An empty spool is held in the primary arms and is brought up to speed before contacting the paper on the reel drum. The paper is transferred to the new spool and the full parent reel is released from the reel drum. Once the parent roll is removed, the primary arms move the new roll down to the rails. The secondary arms are brought forward to take the spool and the primary arms return to their original position.

Winder

The purpose of the winder is to cut and wind the full-width, large diameter paper reels into suitable sized rolls. These rolls may then be wrapped and sent directly to the customer or may be processed through subsequent coating, calendaring, or sheeting operations. During winding, the two edges of the reel are trimmed off and conveyed back to the dry-end pulper, or broke pulper.

The full-width machine reel is transferred from the reel stand to the unwind stand by an overhead hoist. From the unwind stand, the paper is threaded through the web-tensioning rolls, the adjustable slitters, adjustable spreader bar and onto fiber or plastic cores. Typically, a steel shaft is inserted through the cores to provide a locking arrangement. However, some of the newer winders operate “shaftless” by providing a retaining surface on one side to prevent cross-machine wandering.

The winder drive must be capable of speeds of two and a half to three times faster than the paper machine in order to have time to change rolls, change reels, repair breaks, remove defective paper, set up the slitting arrangement, and adjust the spreader bar.

Roll Finishing

The steps in roll finishing are scaling, wrapping, crimping, heading, and labeling. Each of these is done manually at one time. Today, most wrapping operations are carried out semi-automatically, and the labeling function is handled by a data processing print unit.

Chapter 18

Boilers — Water/Steam Cycle

The efficient production of steam and electricity is an important function in the overall process of pulp and paper production. These items are basic raw materials required in large quantities for the manufacturing of pulp and paper.

In years past, the cost of operating the powerhouse may not have been a priority; however, with increasing prices of fuel and purchased electricity affecting bottom line profits, the industry has evolved to a more efficient and conservation conscious powerhouse. One key item in a more efficient powerhouse involves utilization of a reliable control system. The final element for many of these controls is the control valve.

Although design will vary from mill to mill, a generic water/steam cycle is shown in figure 18-1. This process is commonly referred to as cogeneration due to the simultaneous use of fuel energy for both process steam requirements and electrical power generation via steam driven turbines. Figure 18-2 details the upper, or convective, section of a boiler and indicates valves required for process control.

Condensate Return System

Water pumped to the boilers for production of steam is composed of condensate returned from process and demineralized make-up water. This mixture is commonly referred to as boiler feedwater (BFW).

The condensate returned from process is demineralized water, which was used to produce steam in the boiler and has condensed after giving up vaporization energy to process. In a typical mill, about 40-50% of the condensate is returned to the powerhouse. Most of this comes from indirect heating such as paper machine dryers and various heat exchangers. A large portion will also be returned from the condenser if a condensing turbine is used. Losses occur in direct heating or cleaning applications such as pulp cooking and sootblowers. Other losses occur in the transport system (pumps, valves, tanks, and piping) and condensate contaminated by leakage (mixing with process).

Serious operational problems may result if contaminated condensate (with black liquor, white liquor, etc.) enters the boilers. To prevent this, a condensate dump system is used. A conductivity element is used to sense contaminants and sends a signal to valves which dump the condensate to sewer until the problem is corrected. Automation of this system can save the time lost to a manual operated system.

Demineralized or deionized (DI) water involves treatment with ion exchange resins to remove hardness (minerals) and silica, which would deposit on boiler tubes. This process involves large equipment and operational expense. Most mills are equipped to supply only a portion of the feedwater required with demineralized water. Thus, the return of as much clean condensate as possible is critical from an economic and operational standpoint.

Condensate is usually brought to a single collection tank from various process users and the turbine condenser. It is then sent through a condensate polisher to remove any scale deposits picked up in the return system. From the collection tank the condensate is pumped to the deaerator (DA) heater. In some mills an indirect feedwater heater is used before the DA to raise temperature to near saturation. Low pressure (150 psig) steam is used for heating and the resulting condensate is returned to a lower pressure reservoir such as the condenser hotwell or DA.

Boiler Feedwater System

The BFW system begins at the DA and ends at the inlet to the economizer. The main components are the DA, the boiler feed pump, and the high pressure feedwater heaters. The main purpose of the BFW system is to condition the feedwater for entry into the boiler. The DA removes unwanted oxygen from the feedwater, which, in turn, prevents corrosion in the entire piping system. The boiler feed pump raises the pressure and the high pressure feedwater heaters raise the temperature of the feedwater. The critical valves within the boiler feedwater system are the boiler feedwater recirculation, feedwater startup, and feedwater regulator valves.

Feedwater Recirculation Valve

In order to protect the feed pump, there must be a recirculation system. The boiler feed pump recirculation valve takes feedwater from the boiler feed pump and recirculates it to the DA. It is there to protect the pump from cavitation and excess temperature rise. There are three basic methods of providing feed pump recirculation. Two older methods are continuous recirculation and on/off recirculation. The current method is modulating recirculation. This provides minimum recirculation flow to protect the pump and optimize efficiency. It requires a high technology recirculation valve. The recirculation valve typically experiences cavitation and if not properly taken into account with valve selection, cavitation damage will result. Because of the cavitation, tight shutoff is required. Any fluids leaking past the valve will cavitate and cause damage to the seat. A leaking recirculation valve can cause decreased unit capacity, reduced efficiency and repeated maintenance and repair cost. Plugging can occur if feedwater is not clean. A common issue with all feedwater applications is corrosion due to materials chosen. Amine or hydrazine treated feedwater is corrosive to the cobalt binding in alloy 6. If the feedwater is treated, use of this material should be avoided.

Design Considerations:

- Cavitation
- Tight shutoff (Class V)
- Typical process conditions are 800-1200 psig and 200-400 °F

Typical Specifications:

- easy-e, HP, EH, or Cavitrol IV trim
- Cavitrol III Trim
- HTS1 option with improved pressure balance seal
- FIELDVUE digital valve controller with low travel cutoff

Optional:

- NotchFlo or Dirty Service Trim
- Protected inside seat

Feedwater Startup and Regulating Valves

The feedwater startup valve is used to initially fill the boiler. Depending upon the design, this can be through the main feedwater pumps or the condensate pumps. The valve transitions operation to the feedwater regulator valve, or variable speed drive, once drum pressure has been built up. During drum fill operation, the boiler is under minimal pressure. This causes the entire pressure drop to be taken across the feedwater startup valve. Because of this, the formation of cavitation becomes a concern. Sizing of the startup valve must be done in combination with the feedwater regulator valve. This is to ensure that the feedwater regulator valve does not experience any service conditions that lead to damaging cavitation. The most common split is that 80% capacity in the startup valve is equal to 20% capacity in the regulator valve. Once the transition to the regulator valve has begun, the startup valve closes. Improper use is one of the main issues surrounding two valve feedwater systems. For example, the startup valve is not being used at all and the regulator valve is being used to perform both functions. This can be a major problem if the boiler feedwater regulator was not sized or selected to perform both functions. There can also be an issue if switching between the startup and the regulator valve is happening too quickly. Because of the cavitation concerns and taking the full pressure drop, the startup valve should utilize some form of anti-cavitation trim. Typically, in process plants, since the pressures are not as high as power plants, Cavitrol III trim is selected. 440C trim is recommended for the case of treated feedwater. For cases where one valve is performing the startup and regulator duties, characterized Cavitrol trim can be designed to handle the cavitating conditions at startup and then standard equal percentage or linear characteristic for steady-state conditions to maximize capacity. Another common issue in both the startup and regulator valves is to see them operated below the minimum operating point. This can cause “gear-toothing” damage on the plug.

Design Considerations:

- Cavitation
- Tight shutoff (Class V)
- Typical process conditions are 800-1200 psig and 200-400 °F

Typical Specifications:

- easy-e, HP, or EH
- Cavitrol III Trim
- HTS1 option with improved pressure balance seal
- FIELDVUE digital valve controller with low travel cutoff

Optional:

- NotchFlo or DST
- Protected inside seat

Steam Generation

The number and types of boilers used for steam production varies considerably from mill to mill. Figure 18-1 indicates a simple system consisting of one power boiler and one recovery boiler discharging into a common high pressure superheated steam header. For this system, the recovery boiler is base loaded at a constant flow of black liquor fuel with steam flow and pressure allowed to fluctuate. The steam header pressure (typically 1000-1500 psig) is controlled by varying the fuel input to the power boiler. Power boiler fuel is typically base loaded with bark or hog fuel and supplemented with coal, oil, or gas.

Figure 18-2 provides an enlarged view of the upper convective section of a boiler. BFW enters the economizer at 800-1200 psig and 200-400°F before flowing to the steam drum of the generating section. As mentioned earlier, demineralized water is used in boilers due to high operating pressures and temperatures. Even so, as saturated steam leaves the steam drum, trace amounts of solids are left behind. These solids must be removed via continuous bleed or blowdown of a small amount of water to prevent accumulation. The mud drum is also a low point for solids to settle and has provision for intermittent blowdown to prevent accumulation.

Saturated steam leaving the steam drum passes through the superheater section for further heating and moisture evaporation. Most superheaters consist of a primary and secondary section. Attemperation or desuperheating is used between the sections to control final temperature and prevent overheating of tubes. The source of water must be of demineralized quality to prevent accumulation of deposits on the inside of the tubes. A common source is boiler feedwater from the discharge of the boiler feedwater pump.

A vent is indicated on the superheated steam outlet before the high pressure steam header. This vent may serve multiple purposes. One use is to clear the superheater of any moisture during start-up. This is to assure no water droplets reach the steam turbine. A second function is pressure relief in case an alarm indicates a build-up of pressure. A final function may involve setting the valve to open on high pressure just before the spring operated safety valve would lift. Due to high flow and pressure drop creating excessive noise, the valve is often used in series with a diffuser and/or silencer. Also shown in figure 18-2 is a valve for controlling the flow of steam to the sootblowers.

Sootblower Valve

When firing fuels such as coal, oil, biomass, or other waste products, fouling of the boiler tubes becomes a concern. Deposits from the combustion process can collect on the heat exchanging tubes reducing thermal efficiency and can cause operational difficulties. In order to keep the unit operating, an online cleaning method must be used. This is usually accomplished by using what are called sootblowers. Sootblowers utilize flowing media such as water, air, or steam to remove deposits from boiler tubes. Widespread use of water has been limited due to the possibility of thermal shock on the tube banks so steam is the most common media. There are several different types of sootblowers used. Wall blowers are used for furnace walls and have a very short lance with a nozzle at the tip. The lance rotates as it moves into the furnace and cleans the deposits from the wall in a circular pattern. Retractable sootblowers are used in high flue gas temperature zones. These operate the same as the wall blower, but the lance is inserted into the boiler to clean the internal tubes and can be partially or fully retractable. Partially retractable sootblowers are used where sootblower materials can withstand the flue gas temperature.

Design Considerations:

- Noise and vibration
- Tight shutoff (Class V)
- High cycling operation
- Typical service conditions are 800-1200 psig at 300-500 °F

Typical Specifications:

- easy-e, HP, or EH
- Whisper Trim
- FIELDVUE digital valve controller with low travel cutoff

Optional:

- Oversized stem/VSC and/or welded stem connection

Steam Turbine Generators

The majority of steam from the high pressure header is used by large power generating steam turbines. Most mills use a backpressure turbine(s) (discharges to a lower pressure process header) and at least one condensing turbine (discharges to a condenser). Extraction steam from the turbines is used to supply the medium and low pressure process headers. These headers typically operate at 400-600 psig and 60-150 psig respectively. Pressure reducing valves are also used between headers to balance demand vs. extraction or to provide process steam during a turbine outage. If desuperheating is required, a steam conditioning valve is recommended for this service.

While electrical power produced by the turbines (typically 30-70 MW) is important to mill operations, supplying the process with steam is of primary concern. Most mills are connected to a local utility and purchase the balance of electrical power required. By nature, the back pressure turbine provides more than double the utilization of available fuel energy as the condensing turbine. The majority of steam discharged from the back pressure turbine is utilized by process, while the latent heat in the steam of the condensing turbine exhaust is wasted in the condenser.

Main Steam PRV and Turbine Bypass

Control of steam pressures and temperatures are likely the most critical applications in a pulp and paper mill. Steam is used for wood chip preparation, process heating, pulp and paper drying, boiler cleaning, energy production, and in many other applications. Without steam, a pulp and paper mill cannot operate. To accommodate a variety of steam pressure requirements most sites utilize three headers; high (1000-2000 psig), medium (500 psig), and low (100 psig) pressure. The power and recovery boilers supply high pressure, high temperature steam to the high pressure header. Much of the high pressure steam undergoes a pressure reduction and is directed to the medium and low pressure headers. When demand for low pressure steam is high, the medium pressure header also supplies steam to the low pressure header.

Main Steam PRV

Pressure reduction between headers can be achieved through the use of a pressure reducing valve (PRV) or a steam turbine (also called turbo generator). Main steam PRVs are often used to bridge the high (1000-2000 psig), medium (500 psig), and low (100 psig) pressure headers. Each PRV can perform only a single pressure reduction, so multiple PRVs are required.

Design Considerations:

- High pressure and temperature
- Noise and vibration
- Tight shutoff (Class V)

Typical Specifications:

- easy-e, EW, or HP
- Whisper Trim
- FIELDVUE digital valve controller with low travel cutoff

Optional:

- Inline diffuser (if extra noise attenuation is needed)

Turbine Bypass

Steam turbines generate electricity through pressure reduction and are becoming increasingly popular. Each turbine can have multiple take-off points so one unit can simultaneously feed the medium and low pressure headers. In order to minimize unplanned downtime, a bypass valve is installed in parallel with the turbine to ensure pressure reduction occurs even when the turbine is offline. Most of the steam produced in paper mills is not at the required conditions for all applications. Thus, some degree of steam conditioning is warranted in either control of pressure and/or temperature to protect downstream equipment. Steam conditioning valves represent state-of-the-art control of steam pressure and temperature by integrally combining both functions within one control element unit. These valves address the need for better control of steam conditions brought on by increased energy costs and more rigorous plant operation. These valves also provide better temperature control, improved noise abatement, and require fewer piping and installation restrictions than the equivalent desuperheater and PRV.

Design Considerations:

- High pressure and temperature
- Noise and vibration
- Large turndown
- Tight shutoff (Class V)
- High cycling operation
- Stroking speed

Typical Specifications:

- TBX
- Whisper Trim
- Bore-Seal
- FIELDVUE digital valve controller with low travel cutoff

Optional:

- Separate PRV (easy-e, HP or EH) with a Desuperheater
- WhisperFlo Trim
- 2625 booster(s)

Condensing and Cooling System

Even though it decreases cycle efficiency, a condenser is essential to provide a “cushion” or location to dump steam when a portion of the process is down and still benefit from electrical power production. The condenser is a shell and tube heat exchanger which operates at a vacuum. Cooling water passes through the tubes and condenses the steam on the outside of the tubes. The cooling water passes through a closed system back to a cooling tower where the heat is discharged to the atmosphere. Due to seasonal temperature variations, all cells of a cooling tower are not always in use. Butterfly valves are used to isolate cells or even bypass the cooling tower.

Condensed steam accumulates at the bottom of the condenser in the hotwell. The condensate is then pumped to the condensate collection tank to begin the cycle again. Since the condensate is near saturation, a minimum level must be maintained to prevent pump cavitation and a minimum flow is required to prevent overheating.

Condensate Recirculation Valve

The condensate recirculation valve is similar to the feed pump recirculation valve in that it also protects the pump from cavitation. Inlet pressure and temperature differ from the feedwater system. The dissimilarities from the feedwater system include the inlet pressure and temperature. Inlet sizing often indicates that flashing is occurring, however, experience shows this is always a cavitating application. The end user needs to ensure that there is not a sparger or diffuser downstream emitting back pressure on the valve. This will cause cavitation rather than flashing. Tight shutoff is needed on this application because it prevents loss of condenser vacuum, loss of condensate pressure and flow to the deaerator, and saves money in terms of wasted pump horsepower.

Design Considerations:

- Cavitation
- Tight shutoff (Class V)
- Typical service conditions are 300-500 psi at 100-150 °F

Typical Specifications:

- easy-e, HP, EH or Cavitrol IV trim
- Cavitrol III Trim
- HTS1 option with Improved Pressure Balance Seal
- FIELDVUE digital valve controller with low travel cutoff

Optional:

- NotchFlo or Dirty Service Trim
- Protected Inside Seat

Control Valve Selection

PROCESS			FISHER VALVE PRODUCT DESIGN							
Valve Tag #	Water/Steam Power Cycle		V150/ V300	V500	Control -Disk	E-Body	EH	HP	Steam Condi-tioning	Typical Valve Size
	Application Description	Control Function								
LV-1	M.P. Heater Drain	T	S	P						2″
LV-2	L.P. Heater Drain	T	S	P						2″
LV-3	Condensate Collection Tank Level	T		P	P					4″
LV-4	Demineralized Make-up Water	T	P			S				4″
FV-1	BFW Regulator	T					S	P		6″
FV-2	BFW Regulator Bypass	T					S	P		2″
FV-3	BFW Pump Recirculation	T					S	P		2″
FV-4	Deaerator Heating Steam	T	S		P					12″
FV-5	Condensate to Deaerator	T	P			S				4″
FV-6	Contaminated Condensate Dump	O/O		P		S				4″
FV-7	Condenser Hotwell Recirculation	T		P		S				2″
FV-8	Condenser/Cooling Tower Water	O/O			P					18″
FV-9	Sootblower Steam	O/O		P		S				4″
FV-10	High Pressure Steam Vent	T					S	P		4″
FV-11	Superheater Attemperation Water	T					S	P		1″
FV-12	Continuous Blowdown	T						P (HPA)		1″
FV-13	Intermittent Blowdown	O/O						P (HPA)		1″
PRV-1	High/Medium Steam Pressure Reducing	T					P		S (TBX)	8″
PRV-2	Medium/Low Steam Pressure Reducing	T					P		S (TBX)	8″

P=Primary Valve Choice
S=Secondary Valve Choice
T=Throttling Service
O/O=On/Off Service

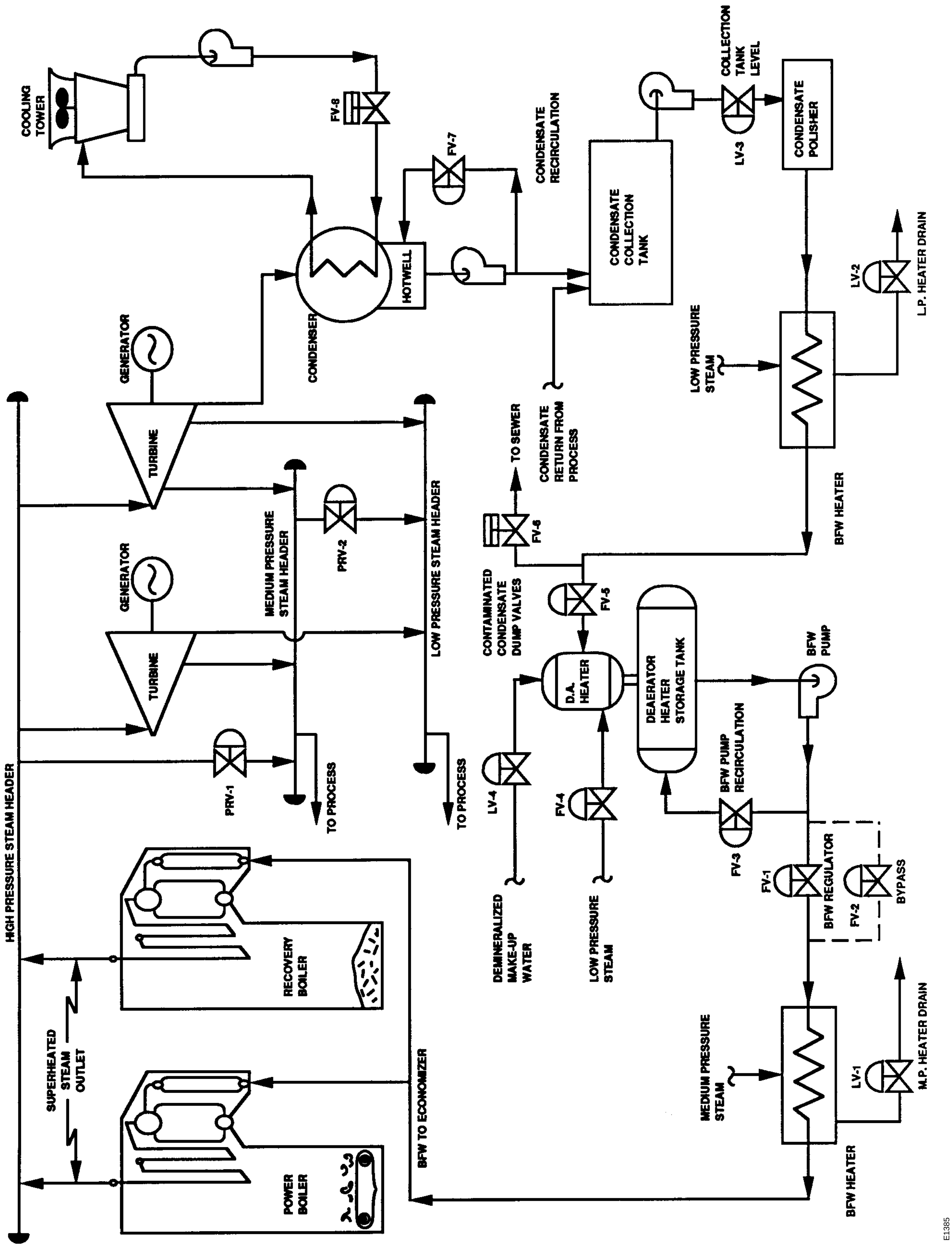

Figure 18-1. *Water/Steam Cycle Diagram*

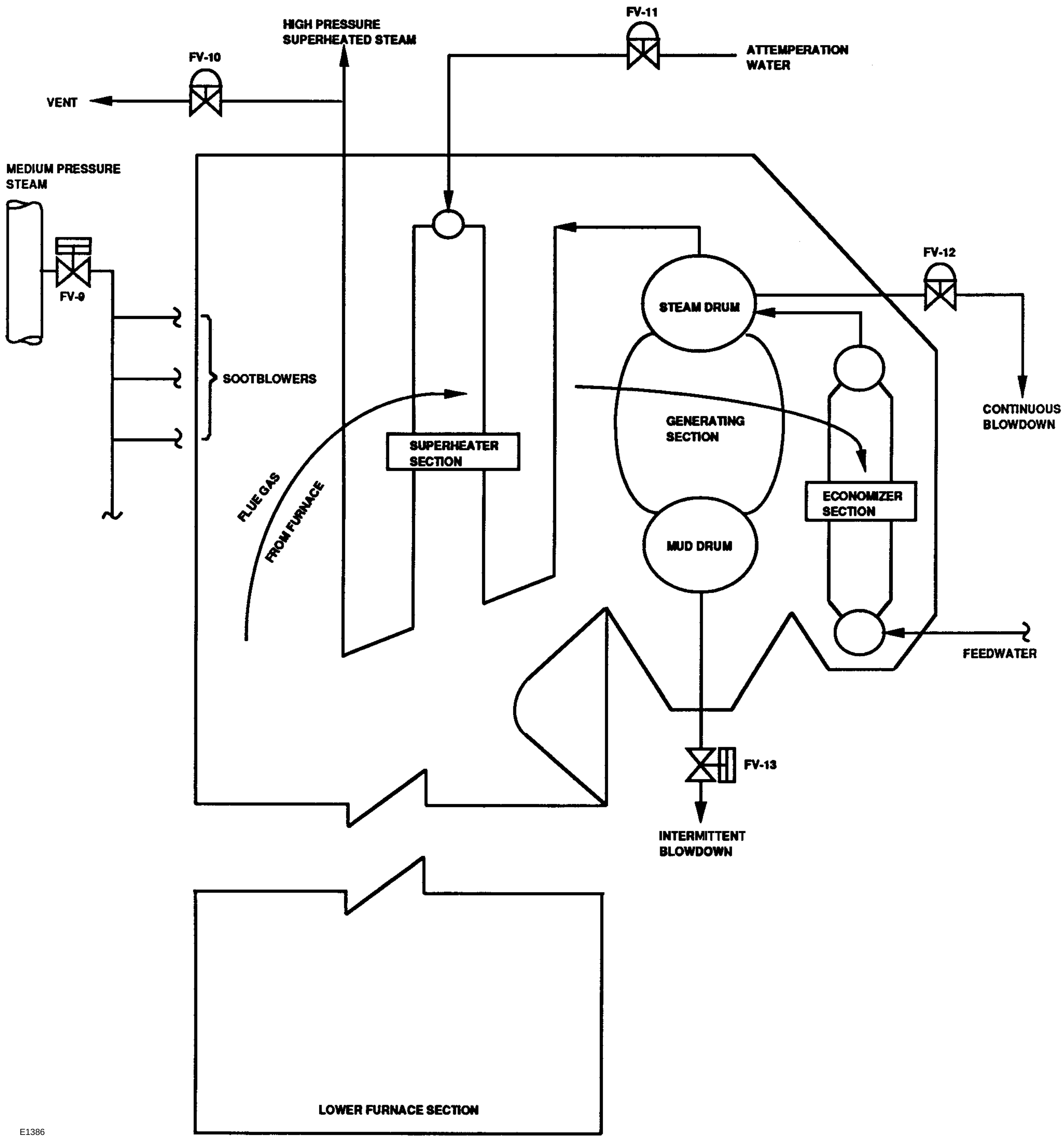

Figure 18-2. *Power or Recovery Boiler Upper Convective Section*

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