SECTION 9.8

PULP AND PAPER MILLS

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GLOSSARY

additive An additive is any material such as clay, filler, or color added to stock to contribute specific properties.

bleaching Bleach is the process of removing the lignin and other color-forming substances from the stock to render it white.

chest A chest is a vessel for storing pulp.

cellulose Cellulose is a carbohydrate that is the primary substance in plant fibers. It is extracted from the plant to make paper products.

consistency Consistency is the proportion by mass of fibers in a mixture of fibers and water.

cooking Cooking is the action of the chemical used to break down lignin bond between cellulose fiber in wood and other organic matter.

deinking Drinking is the process of removing ink particles from recycled paper such as newsprint or magazines.

digester A digester is a pressure vessel used to contain chemical action of cooking chemical and raw cellulose material. Digesters may be of the batch or continuous flow type.

evaporator In the recovery of chemicals from the cooking liquor in a chemical pulp mill, an evaporator is used to concentrate the liquor (remove water) so the concentrated liquor can be incinerated in the recovery furnace.

fiber Fibers are the vascular bundles found in plants that are extracted and used to make paper.

fourdrinier Fourdrinier is the continuous wire upon which pulp or paper sheet is produced.

freeness Freeness is a measure of degree of refinement of stock and, hence, of its ability to drain water.

groundwood Groundwood is a mechanical pulp formed by simple grinding to break down wood structure.

headbox A headbox is a specialized nozzle that takes flow from the fan pump and discharges a uniform layer of white water (stock) onto the forming wire of the paper machine.

kraft process The kraft process is a method of separating cellulose fiber from lignins by using caustic soda in presence of sulfur radical.

lignin Lignin is a generic term used to refer to the complex organic matter present in wood that acts as binding agent for cellulose fibers.

liquor *Black liquor:* Solution of water plus residual organic matter (or lignins) in the wood after washing of raw stock. *Green liquor:* solution of smelt from recovery furnace when dissolved in either water or weak washed liquor. *White liquor:* Solution of caustic soda (or other alkali), sometimes in the presence of a sulfur radical; this is the liquor charged to the digester for cooking.

neutral sulfite Neutral sulfite is made through a cooking process using a solution of about 10% sodium sulfite and 5% caustic soda mixed for cooking wood or agricultural fiber to produce high-yield pulp.

paper Paper is a sheet of cellulose or other fibers formed on a screen from a mixture of fibers in water. Thin absorbent paper is known as tissue; thicker grades of paper are called paperboard.

refining Refining is a mechanical process carried out on stock to improve the ability of the fiber to form paper sheet. Different techniques are employed—some designed to shorten the fiber, others to increase the amount of fibrils (or "whisker") on the fiber.

soda process A soda process is similar to kraft process but uses caustic soda without presence of sulfur.

stock Stock is a generic term for the suspension of cellulose fiber in water or chemicals. *Bleached stock:* The same after bleaching. *Brownstock:* The same before bleaching. *Raw stock:* The product discharged from digester(s) before any washing or other treatment. It is also referred to as pulp.

sulfite process A sulfite process is the method of separating cellulose fiber from lignin with acid. This method is becoming obsolete because of its inherent detrimental impact on the environment.

vat A vat is a semicylindrical mold or container for holding stock during washing or sheet formation.

yield Yield is the percentage of cellulose fiber in the form of pulp produced from a given weight of wood or other raw material. *High yield:* The same when some lignins are allowed to remain in the finished product.

GENERAL

Apart from the petrochemical industry, there are few continuous-process plants with pumps as much in evidence and with reliability as essential as in the pulp and paper industry.

Before paper leaves the machine room, 100 to 200 tons of water will have been pumped to the mill for every ton of paper produced. These figures represent only the basic amount of water taken from a river and rejected as effluent; the amount of liquid circulated is several times greater.

Although many attempts have been made to utilize a dry process for papermaking, both pulping (the separating of crude fibers from the raw material) and papermaking (actual treatment of the fiber and mechanical formation of the sheet) still require water as the medium to convey fiber. Throughout the mill, pumps are used to transfer or circulate fibers suspended in water (stock), chemicals or solids in solution (liquors), or residues and waste matter as slurries, as well as to supply water for general services.

There are at least 150 pumps installed in a modern pulp mill and another 50 or so in a paper mill. About 1000 kW · h is required for the production of one ton of pulp, and a further 500kW · h for the finished paper. Of this total, about 25% is used in pumping. This means that even in a medium-size mill, the installed power required for pumps alone is approximately 10,000 hp (7457 kW), and often it is much higher.

PULPING PROCESS

Raw Materials In the past, the traditional fibrous raw materials for the manufacture of paper were cloth and agricultural residues; today the vast bulk of cellulose pulp is made from wood. Although over half of this is produced from softwoods (long-fibered), an increasing amount is being now produced from hardwoods (short-fibered). Traditional raw materials such as linen, cotton waste, straw, and agricultural residues are still used in small quantities, particularly where the paper sheet requires special properties. These distinctions are important in the selection of pumps, for the liquors have different characteristics. For example, straw black liquor is much more viscous than wood black liquor, and the proper corrections must be made in calculating the pump performance and pipe frictional losses.

Many grades of paper include fiber recovered from waste paper—both pre- and post-consumer. Recently, because of environmental concerns, much emphasis has been placed on recycling post-consumer paper products. Specialized plants exist for the recovery and processing of recycled fiber before it is used for papermaking. Some of the different types of recycled fiber are ONP (old newsprint), OCC (old corrugated containers), and MOW (mixed office waste). Special care is needed in the selection of pumps to handle recycled stock because of the large amount of foreign matter present—rope, string, metal, synthetic fibers and adhesive materials—all of which can cause problems in the process and pumping. Deinking is also widely used in the processing of recycled fibers. Flotation cell deinking, a popular method, uses large amounts of entrained air, which has a dramatic effect on centrifugal pump performance and must be accounted for.

Groundwood Pulp This type of pulp is produced by simply grinding away wood by mechanical action. Almost all of the wood is used in the pulp, including many of the resins and other complex organic compounds. The fibers are bruised so the pulp has inferior strength.

Large amounts of water are required for cooling and for carrying away the groundwood pulp; the latter is usually acidic (pH 4 to 5), and so corrosion-resistant materials must be used. The pulp is used primarily for newsprint and magazines. Depending on the end use, some mechanical treatment (refining) may be required to alter the characteristics of the pulp, particularly the viscosity. In some cases, a mild bleach may be used to improve the color.

Refiner Mechanical Pulp The refiner mechanical pulping process utilizes a disc refiner to reduce wood chips to fibers. It produces a longer fibered pulp than conventional groundwood, but not as long as the chemical pulps. The pulp is therefore somewhat stronger and freer than SGW, but not nearly as strong as kraft pulp. RMP is actually the first of many processes utilizing the disc refiner to produce pulp, The processes vary as to the number of refining stages, refining pressure, temperature, and pre-treatment of the chips (steaming, chemical pre-treatment and so on). Two of the more popular versions are TMP (thermomechanical pulp), in which chips are pre-softened with steam, and CTMP (chemithermomechanical pulp), in which they receive an additional chemical pre-treatment. RMP pulps do not require a rigorous bleaching process in contrast to chemical pulps.

Chemical Pulping Wood is a complex, nonuniform material containing about 50% by weight cellulose fiber, 30% lignins, and 18 to 20% carbohydrate. The remainder is proteins, resin, and other complex organic compounds that vary from one species to another. Cellulose resists attack from most chemicals, whereas the carbohydrates and other organic materials generally form compounds with the chemical cooking liquor. Some paper products can use the carbohydrate fraction to contribute bulk to the sheet, and for such papers groundwood and RMP and other mechanical pulps are used. Where high strength is required, cooking is necessary to separate the fibers completely from the remainder of the wood.

Most cooking of wood is done in a pressure vessel at high temperature and pressure in the presence of an acid or alkali.

There is considerable tradition in chemical pulping, and a number of different processes are used. For many years the traditional method of producing pulp for high-grade papers was the acid sulfite process. This has been largely superseded in recent years by an alkaline process using sodium-based liquors in the presence of a sulfur radical; this is known as the sulfate or kraft process. The main reasons for the change to the sulfate process have been lower corrosion rates, ease of chemical recovery, and a stronger pulp. The properties of the liquids pumped in the two processes are different, and the pumps require different materials of construction.

Typical Sulfate Process Pulpwood logs are first chipped to about $\frac{3}{4}$ by $\frac{1}{8}$ in (19 by 3 mm) and then charged into either a continuous digester or a series of batch digesters. Digester capacities range from approximately 100 air-dried tons per day to over 2000 air-dried tons per day, necessitating a wide range of hydraulic coverage for digester pumps. Cooking liquor (NaOH plus up to 30% Na_2S) is then allowed to react with the wood chips for 2 to $2\frac{1}{2}$ h at a temperature up to 350°F (177°C) and a pressure in the digester of 80 to 100 lb/in^2 (551 to 689 kPa). In many mills, the heating of the chips and cooking liquor is by direct steam injection to the digester. In others, some form of indirect heating is used with a closed liquor recirculation system. In the latter case, the digester circulating pumps are a critical item because they must handle hot caustic solutions and entrained solid matter in a closed, pressurized circuit. After cooking, the contents of the digester are discharged to atmospheric pressure into a vessel called the blow tank, where the sudden expansion causes the fibers to separate from the liquid, which is now known as black liquor.

At this point, the process splits into two streams—one for fiber processing and the other for chemical recovery. The fiber is washed and screened and then formed into a pulp or paper sheet. The black liquor is washed from the pulp and treated for chemical recovery. Because the most troublesome liquors are to be found in the recovery process and bleach plant, the selection of these pumps is critical for the successful operation of the process.

The chemistry of the recovery process is as follows: After concentration of the black liquor in multiple-effect evaporators to about 50% total solids, the final concentration to 60 to 65% is done by direct contact with hot flue gas from the waste heat or recovery boiler. The 65% concentration black liquor is mixed with salt cake (Na_2SO_4) before being sprayed into the furnace under pressure generated by high-pressure pumps. The furnace atmosphere is maintained with a minimum of excess air so the Na_2SO_4 is reduced to Na_2S, and sodium carbonate (Na_2CO_3) is formed in the process. These molten chemicals run out as a smelt and are dissolved in a tank to form green liquor. This liquor is then causticized with lime to form caustic soda (NaOH), with the Na_2S still present along with other residual chemicals, thus forming the regenerated cooking liquor known as white liquor. The calcium carbonate ($CaCO_3$) formed is burned in a lime kiln for reuse in causticizing. Various lime slurries and residues are formed during this process. The white liquor it then clarified and reused in the digesters, completing the cycle, as shown in Figure 1.

There are a variety of other pulping processes in use, but the sulfate process offers so many advantages that almost all recent installations have been of this type.

Bleaching Bleaching may be considered an extension of the cooking process, the object being to remove the coloring matter, carbohydrate, and lignins to that the remaining pulp

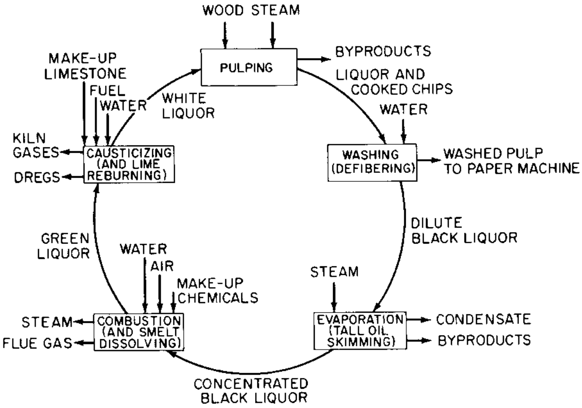

FIGURE 1 The recovery cycle in the sulfate process.

contains a maximum percentage of alpha cellulose, which is the purest cellulose form and the one most resistant to attack from normal chemicals. Bleaching is carried out to reach a degree of reflectance of monochromatic light and called pulp brightness. Because of resistance to attack, special highly reactive chemicals must be used for bleaching. The traditional chemical used for bleaching is chlorine, which is highly selective at attacking the lignin while resisting attack of the cellulose. Chlorine has a tendency, however, to form pollutants in the bleach plant effluent and is therefore being replaced with other chemicals such as chlorine dioxide, hydrogen peroxide, and gaseous oxygen and ozone. Chlorine dioxide produces highly corrosive liquors in the bleach plant.

LIQUIDS PUMPED IN A MILL

There are, broadly, three categories of liquids to be pumped in a paper mill:

1. Water and similar fluids
2. *Liquors* and *slurries*—mainly chemicals and solids in solution or suspension
3. *Stock*—suspension of cellulose fibers in water

Water Apart from the quantities involved, there are no special requirements concerning the water in pulp and paper mills because operating conditions are well within normal limits. However, iron and carbon steel piping should not be used in bleach pulp mills because of iron pickup.

Process water treatment is frequently used to purify process water for the mill and to remove undesirable elements such as iron. Higher-quality water is required for chemical reparation in the bleach plant and for boiler feedwater where demineralizer plants are used. Rubber- or epoxy-resin-lined pumps are used for those components in contact with the demineralized water.

PUMPS FOR MILL WATER For the majority of pumps, standard cast iron or stainless steel fittings are used except as noted for demineralized water. In many mills, however, stainless-steel-fitted pumps are standard because this permits a minimum number of spares to be held in stock for other duties.

In the paper mill, water used to form the sheet on the paper machine has a very low fiber content—$\frac{1}{2}$ to 1% consistency—and is known as white water. Fiber contents this low usually do not cause any pumping problems except in wear ring areas where flashing or slotting is used to keep leakage paths open and free from binding.

Much of this water is recirculated, and where bleached products are produced, pumps must be constructed an austenitic stainless steel.

Liquors and Slurries Depending on the process and the particular point in that process, the liquor characteristics may require special pumps or special materials. Although the liquor cycle is a difficult one as far as the pumps are concerned, standard designs should be used whenever possible because this reduces the number of different types of pumps in the mill. In some cases, it may be necessary to use a higher material specification than necessary to achieve interchangeability.

Liquor and slurry pumps may be grouped as follows:

Group A—Standard designs suitable for most process uses where corrosion or erosion is not a major factor. Impellers are typically stainless steel with casings of cast iron.

Group B—Standard end-suction designs suitable for corrosive liquors. All liquid end components are typically 316 stainless steel. Duplex stainless steels may be used where erosion may be a factor.

Group C—Standard or nonstandard designs suitable for special services. Pumps are similar to group B for most applications but are of 317 or 317L stainless steel. For most corrosive services, glass-reinforced epoxy, resin, titanium, super austenitic stainless steels are used for both impeller and casing. Mechanical seals in place of packed boxes or dynamic seals are usually fitted to these pumps.

Recommendations for liquor and slurry pumps are

1. All liquor pumps should be classified as slurry type with open nonshrouded impellers of the end-suction and back pull-out type. Simply supported, double suction pumps are also used for fibrous slurries (stock)—particularly $\frac{1}{2}$% to 3% consistency stock on the paper machine. This includes most fan and cleaner pump applications.
2. On group A and B pumps, sealing is accomplished with dynamic seals, mechanical seals, or packed stuffing boxes.
3. For group C pumps, in particular, it may be necessary to depart from a standard design or type of centrifugal pump. For example, if a positive displacement characteristic is required, a screw-type pump may be used with confidence. In addition, all pumps handling stock with consistency above 6% must be regarded as nonstandard types.

After the pumps are grouped, it becomes necessary to decide which pump may be used for specific liquors. Requirements for individual mills will differ in detail, but the following may be taken as an indication of current practice, particularly in modern sulfate (kraft) mills. In every case, manufacturers should be made aware of the liquor characteristics and of the location of the pump in the process.

COOKING LIQUOR (WHITE LIQUOR—SULFATE PROCESS) This is essentially an alkaline solution made by causticizing green liquor. The liquor is prepared at concentrations over the range of 50 to 100 g/liter depending on the wood species, and the amount of active alkali (expressed as Na_2O) may be from 14 to 30% of the dry wood weight. White liquor is mainly sodium hydroxide, with a small percentage of sodium sulfide which depends on the mill sulfidity. Higher values of active chemical are used in bleached pulp mills. The term *sulfidity* is used to denote the ratio of chemicals present; it is frequently expressed as Na_2O and calculated from the expression

$$\frac{Na_2S}{NaOH + Na_2S}$$

The sulfidity value commonly used is from 20 to 30%; the higher values usually denote better chemical recovery. The specific gravity of the liquor will be approximately 1.2, and after clarification only small quantities of grit should be present. The liquor must be considered an abrasive that produces a high rate of wear on pump rotating elements. White liquor has a tendency to crystallize on internal surfaces of pipes and pumps, but there are no special viscosity problems and a pump head loss allowance of about 10% above that of water should be adequate. Group B pumps are recommended.

BLOW TANK DISCHARGE As the liquor introduced with the chips into the digester combines with the noncellulose and hemicellulose fractions of the wood, it changes from white liquor to black liquor before reaching the blow tank. In addition, the sudden release of pressure frees the cellulose fibers from the other matter, so the blow tank contains both raw stock (pulp) and black liquor. Pulp from the blow tank is often entrained with air, sand, and other contaminants. A stock pump, therefore, is required for this duty because the stock concentration is quite high.

BLACK LIQUOR For convenience these pumps are divided into three groups.

Weak Black Liquor (Total Solids Up to 20%) During washing, hot water is used to dissolve away the surplus organic matter from the pulp, and the liquor produced is termed *black liquor.* This liquor is a mixture of the lignins and carbohydrates in the original wood plus the cooking chemicals: it is alkaline with a solids content of 14 to 16% in a sulfate mill. The temperature will be about 180 to 190°F (82 to 87°C), and the specific gravity about 1.08. Washing is usually carried out with a minimum of three countercurrent stages, and the solids content given previously is representative of the liquor leaving the stages nearest the inlet; that is, where it is most concentrated. The quantity of recirculated liquor is quite high, and many mills have found group A pumps with stainless trim to be satisfactory and economical. With the low solids content, there are no special viscosity problems. This may be seen from Figure 2.

Black Liquor with Total Solids of 20 to 50% This liquor is formed by the evaporation of water from weak black liquor. The concentration is accomplished in multiple-effect evaporators, which usually discharge liquor with about 50% total solids at close to 200°F (93°C). In some odor-free installations, the solids concentration is much higher. Because of the nature of the evaporation, special pumps are usually required.

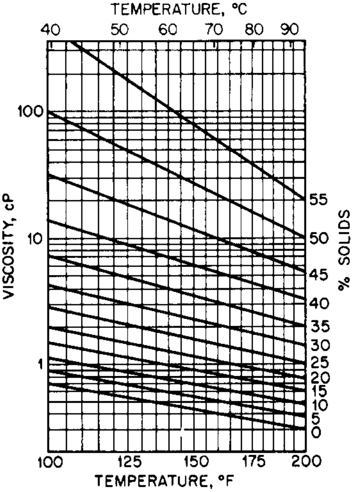

FIGURE 2 Black liquor viscosity

Liquor containing up to 50% solids is reasonably easy to pump, but allowance must be made for viscosity effects. In noting the values in Figure 2, it should be remembered that the plant must often start up cold, so cold liquor with a higher viscosity may have to be pumped. The liquor-specific gravity rises during evaporation from about 1.1 to 1.25. Group B pumps are recommended.

Black Liquor with Total Solids of 50 to 65% This is often referred to as heavy black liquor because the specific gravity rises to 1.35. The liquor is formed by further evaporation, either in the multiple-effect units or by contact evaporators using hot flue gas.

From a pumping standpoint, this liquor is probably the most difficult of all liquids to pump satisfactorily in pulp and paper mills. Continuous operation requires careful attention to pump sealing and maintenance. Steaming out at regular intervals of the evaporator and piping is particularly important to prevent solids buildup affecting *NPSHA* to the pumps.

No accurate figures are available for the viscosity of liquids with a solids concentration above 55% because there is wide variation in the liquors produced from different wood species and also in the liquors from the same wood of different ages. Hardwood species produce a more viscous liquor, especially eucalyptus, as well as more liquor per ton of pulp produced. Black liquor produced from straw pulping is even more viscous and, in addition, causes the deposition of silica on the walls of pumps and piping. An approximation of the viscosity of straw mill heavy black liquor may be determined from published figures, which give viscosities up to 2000 centistokes. This is probably at least 50% higher than liquor from normal long-fibered softwood.

During recovery, liquor is sprayed into the furnace for evaporation to dryness and burning. Prior to this, the make-up chemical (sodium sulfate or salt cake) is added and reduced to Na_2S in the reducing atmosphere of the furnace.

Little is known with certainty about heavy black liquor, but it does not seem to be very corrosive, and carbon steel is often used for pipework, although stainless steel pumps are fairly common. The pumps are subjected to severe duties—notably high heads, lumpy material, high temperature and pressure, and continuous service. Group B pumps are almost universally specified, often with casings of more wear-resistant material such as Alloy 20 or duplex stainless steels. In some cases, mills making straw pulp have not found suitable centrifugal pumps and have had to resort to gear pumps because of the very high viscosity of the liquor.

GREEN LIQUOR Green liquor is a solution of sodium carbonate and sodium sulfide plus other elements and compounds. One of these other compounds is iron sulfide in a colloidal form, which produces a greenish color. The liquor is formed by dissolving smelt from the causticizing process. Severe erosion takes place in green-liquor pumps, primarily because of the violent action inside the dissolving tank but also because of the gritty matter always present. Green liquor also builds up on the walls of pumps and piping, causing high frictional losses. The specific gravity is usually about 1.2, and an allowance of about 20% should be made for viscosity. Group B pumps are recommended for this service.

LIME SLURRIES In causticizing, various solutions and slurries are present that, apart from causing excessive wear in standard pumps, do not cause any problems. Thus, any normal slurry pump should prove satisfactory. In sulfate mills, the lime mud formed during green liquor causticizing presents the most serious problem, for approximately 1000 lb (500 kg) of mud may be formed for each ton (1000 kg) of pulp produced. Solid loads above 35% can occur, and frequent blockages are likely unless pumps are selected for minimizing downtime. For mild slurry duty, group B pumps with duplex stainless steel construction are satisfactory. For harsher applications, hard iron pumps like those used in the mining industry are employed.

BLEACH PLANT LIQUOR Most bleached pulp mills today use at least four stages of bleaching, and often six or more. Bleaching is used to remove residual lignins or to convert them to compounds that are stable regarding color and heat. The stages used include chlorination, either by hypochlorite, gaseous chlorine, (both becoming obsolete) or chlorine dioxide (usually two stages), with an alkali extraction washing stage between. On occasions oxygen is also used. Bleach plant chemicals are usually prepared in the mill so solutions such as chlorine water, sulfuric acid, sodium chlorate, sodium chloride, sodium hydroxide, calcium hypochlorite, and chlorine dioxide all have to be pumped.

It cannot be emphasized too strongly that materials of construction are of vital importance in the chemical preparation area of the bleach plant.

In addition to the standard chemicals, some of the common pulp mill bleach substances, together with some chemical preparation systems, are as follows.

CHLORINE This is usually delivered to the mill in tank cars but is always vaporized to a gas before use.

CHLORINE WATER (HYPOCHLOROUS AND HYDROCHLORIC ACID) Concentrations cover the range from pH 2 to 10 for bleaching pulp. In some cases, the gas is mixed directly with pulp in special mixers. Group C lined pumps are essential.

SODIUM HYPOCHLORITE AND CALCIUM HYPOCHLORITE This mixture is made in the mill by permitting chlorine to react with either sodium or calcium hydroxide concentrated caustic (70%) diluted to 5 to 6% before chlorination. Calcium hypochlorite is made from a 10% solution of slaked lime at temperatures up to 150°F (66°C), but not normally exceeding 70°F (21°C). These liquors are corrosive to steel, and group C or lined pumps are necessary when handling solutions *to* the bleach plant; *after* bleaching the filtrate may still have residual hydrochloric acid.

CHLORINE DIOXIDE This is the most common bleach solution used because it gives an excellent brightness to the pulp and, despite corrosion problems, is usually cheaper than other bleach solutions.

After generation of the gas, during which absolute cleanliness is vital, the gas is stripped in a packed tower as an aqueous solution and stored in plastic tanks made of special resins that resist chemical attack. In modern plants, increasing use is made of glass-reinforced plastic with selected resins for piping, valves, and pump linings. This is sometimes a cheaper alternative than the use of exotic metals, such as titanium, for pumps. Pumps must be group C, and stainless steel is not satisfactory. Solution strengths of up to 8 g/liter are used.

SODIUM PEROXIDE AND HYDROGEN PEROXIDE These are used for bleaching groundwood pulp. Typical solutions contain sodium silicate (5%), sodium peroxide (2%), and sulfuric acid (1.5%). The latter controls the pH of the liquor. Concentrations of bleach liquors are up to 15%. Temperatures are usually less than 90°F (32°C). Group C pumps are necessary.

WASH LIQUORS In general, the filtrate from bleach washing stages will exhibit at least some of the properties of the stage immediately before washing, owing to slight excesses of chemical present. Filtrates are collected in corrosion-resistant pipes and vessels, usually made from glass-reinforced plastic, and the pumps used will be either group B or C, depending on the stage in question. The filtrate from the chlorine dioxide stages should be pumped with a super austenitic stainless steel case and trim pump because the filtrate is not as corrosive as the bleach solution.

Spent acid from chemical preparation plants is also highly corrosive, and usually stainless steel is not satisfactory for use with it.

Effluent from the bleach plant, on the other hand, is usually a mixture of several liquors, and experience has shown that 317 stainless steel is a suitable material for pumps that handle it.

CHLORINE DIOXIDE PREPARATION; SODIUM CHLORATE Chlorine dioxide is produced by permitting sodium chlorate to react with sulfuric acid and hydrochloric acid in a vessel into which a reducing agent such as NaCl, SO_2, or methanol is introduced in controlled quantities. Sodium chlorate solutions are usually from 43 to 46%, at which strength the specific gravity is about 1.38. Stainless steel pumps may be used, but epoxy-resin-lined pumps are superior.

FOUL CONDENSATE This arises from the evaporation of water from black liquor at the multiple-effect evaporators, as these units flash vapor from the liquor in one stage and use this to evaporate the liquid in the next stage. The vapor when condensed contains some carry-over from the black liquor, and thus the condensate is contaminated and corrosive. When a nickel cast iron casing and stainless trim are used, group A pumps should be satisfactory. Some liquors produce very corrosive vapors, and a stainless casing pump may prove necessary. Group B pumps are recommended.

Stock Stock is the term applied to the suspension of cellulose fiber in water. It first appears either after grinding (in the case of mechanical pulp) or after the blow tank (in the case of chemical pulp). Stock production rates may be converted to pump flow rates with the following formula:

$$\text{Flow (USGPM)} = \frac{\text{Production (air dried short tons per day)} \times 15}{\text{Consistency (\% oven dried)}}$$

After the separation of chemicals or impurities by washing and screening, the stock is given a mechanical treatment known as either beating or refining, depending on the nature of the treatment. This enhances the sheet properties. Additives such as starch, clay fillers, alum, and size are introduced to impart special characteristics, depending on the end use of the product.

Over the range of stock in normal use, the specific gravity may be considered constant for all practical purposes, with a value equal to that of water at the appropriate temperature.

Cellulose fibers have a specific gravity slightly greater than water, and constant agitation is required to ensure that stratification does not occur in storage. Agitation, however, can also introduce air, to the detriment of the stock.

The pH of stock varies over a wide range—from as low as 1.0 during some bleaching processes to 11.0 with others. In the paper machine room, the pH of the stock will usually range from 4 to 8. Thus from a corrosion viewpoint washed stock does not usually present special problems except when high-grade bleached products are produced. Stains will be caused by iron sulfides or oxides, and therefore stainless steel must be used—frequently 304 for washed stock, but 316 or 317 within the bleach plant before washing or where bleach liquor is likely to be present with the stock.

Unbleached paper mills generally do not experience corrosion with washed stock, except in the case of groundwood mills, where the pH is usually lower than in chemical pulp mills.

FIBER CHARACTERISTICS Stock made from softwoods will have a predominance of fibers 2.8 to 3.5 mm long and 0.25 to 0.3 mm wide; fibers from hardwoods will be about 1.0 to 1.3 mm long and 0.1 mm wide. Straw fiber will be still shorter—0.75 mm on the average—but flax can have fibers up to 9.0 mm long. These figures are typical and are of interest because of their effect on pump performance.

CONSISTENCY This is the amount of dry fiber content in the stock, expressed as a percentage by mass. Typical values will vary from about 0.1% for the feed to the headbox of a special paper machine to 16% for stock between some bleaching stages or in high-density towers. The critical stock consistency in the selection of pumps is 6%. Up to the 6% level, pumps may be selected on the basis of their water performance.

FREENESS When stock is beaten, or refined, it acquires an affinity for water, and the longer the stock is beaten, the longer the water retention period. The retention of water by the stock increases the friction factor of the flow of stock.

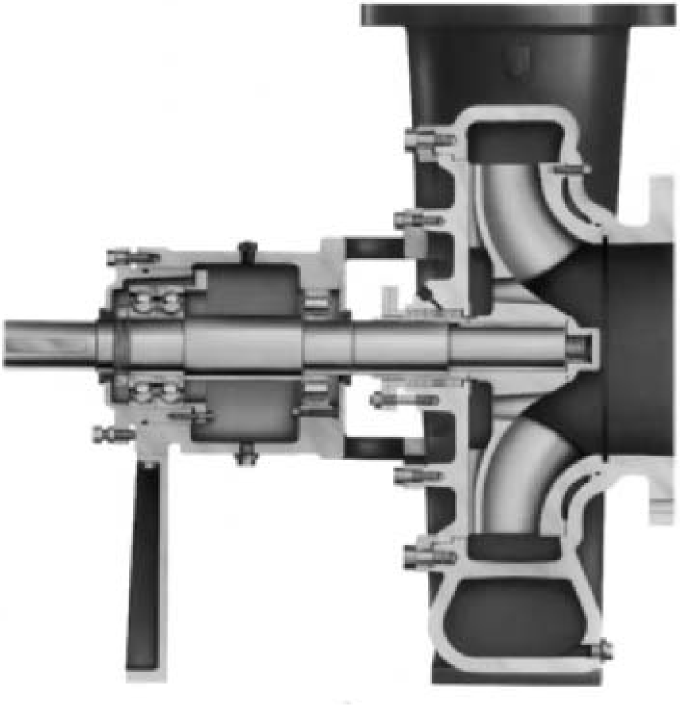

FIGURE 3 End suction stock pump. (Courtesy ITT / Goulds Pumps, Inc.)

Freeness is often measured by an instrument called the Canadian standard freeness tester. The range of values covers a scale from 0 to 900, with a higher freeness value indicating a less refined stock and thus a lesser affinity for water. This instrument measures the amount of water drained from a sample of stock under a regularly decreasing head. Its use is recommended by the Technical Association of the Pulp and Paper Industry (TAPPI), and it is commonly employed in North American mills.

STOCK PUMPS In stock pumps, consistency is not a major problem until a value of about 6% is reached. The essential requirement is to get the stock to the pump impeller, and every effort should be made to keep the piping as large and straight as possible. A typical open impeller, end suction stock pump is shown in Figure 3.

Above 6% consistency, special pumps are required, and they can be of the positive displacement screw type or centrifugal type. Air entrainment in the stock will reduce pump output. Air entrainment occurs from agitation in the chests, from flow over weirs, and from flow through restricted openings. How air entrained in water and in stock affects pump performance is shown in Figure 6.

PIPING ARRANGEMENT Piping should be as straight and short as possible. This is particularly important on the suction side of the pump to prevent dewatering of the stock. The diameter of the suction piping should be at least one pipe size larger than the diameter of the pump suction and should project into the stock chest. The inlet end of the suction pipe should be cut at an angle, and the bottom of the pipe should be at least $1\frac{1}{2}$ pipe diameters from the bottom of the chest. With the long side of the pipe on top, the probability

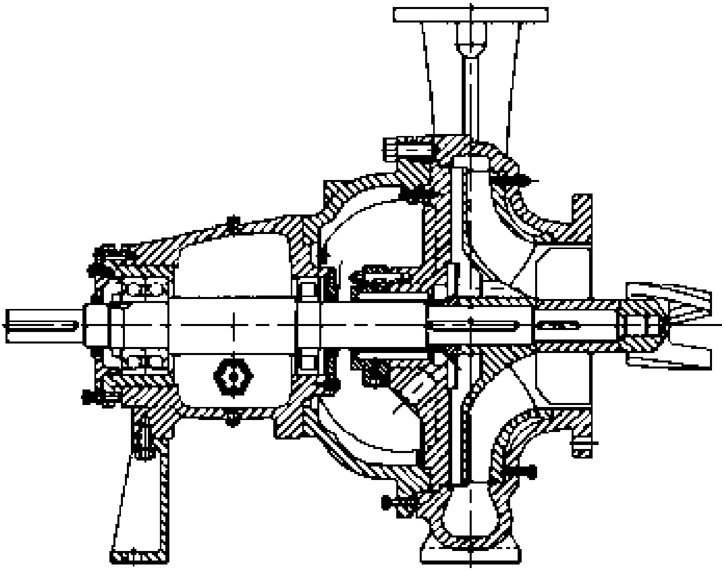

FIGURE 4 Medium consistency stock pump. (Courtesy ITT / Goulds Pumps, Inc.)

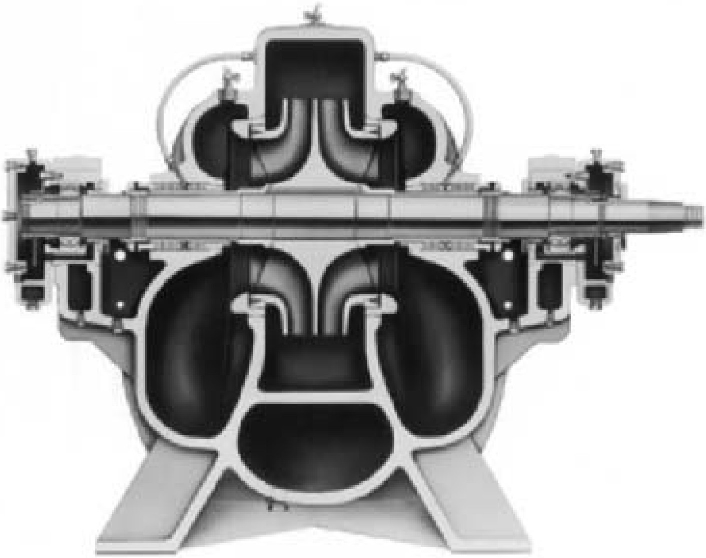

FIGURE 5 Fan pump. (Courtesy ITT / Goulds Pumps, Inc.)

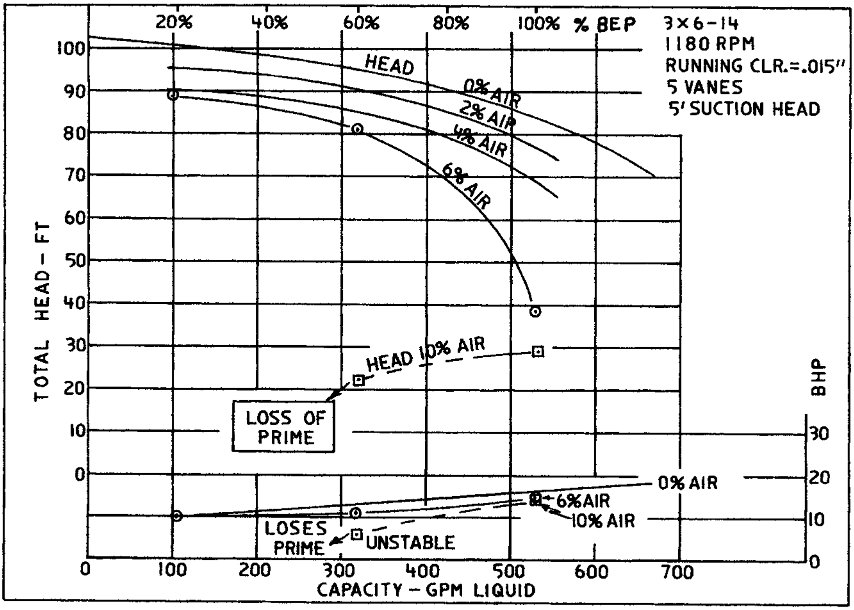

FIGURE 6 General effect of entrained gas on pump performance. (Courtesy ITT / Goulds Pumps, Inc.)

of drawing air into the suction of the pump through vortices is reduced. Some manufacturers provide a lump breaker or screw feeder at the suction side of the pump for pumping stock above from 6% to 8% consistency.

SIZE OF PUMPS It is important to estimate the performance requirements of stock pumps as accurately as possible. Oversizing of centrifugal pumps will cause an unbalanced radial thrust on the impeller resulting in excessive shaft deflection and reduced bearing and seal life. Oversizing can also result in impeller recirculation and the accompanying cavitation-like noise and damage to pump components.

*FRICTION LOSS OF PULP SUSPENSIONS IN PIPE**

In any stock piping system, the pump provides flow and develops hydraulic pressure (head) to overcome the differential in head between two points. This total head differential consists of pressure head, static head, velocity head and total friction head produced by friction between the pulp suspension and the pipe, bends, and fittings. The total friction head is the most difficult to determine because of the complex, nonlinear nature of the friction loss curve. This curve can be affected by many factors.

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*Courtesy ITT/Goulds Pumps, Inc.

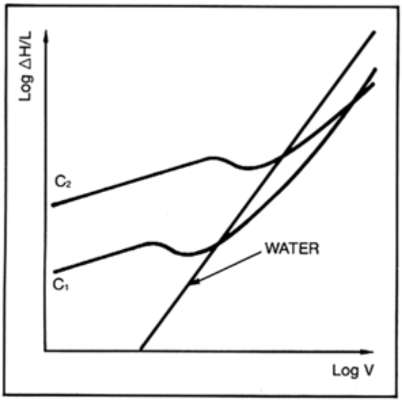

FIGURE 7 Friction loss curves for chemical pulp ($C_2 > C_1$). (Courtesy ITT / Goulds Pumps, Inc.)

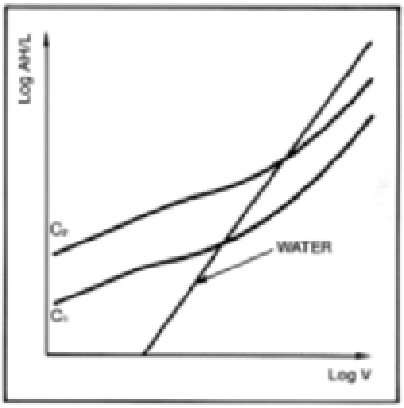

FIGURE 8 Friction loss curves for mechanical pulp ($C_2 > C_1$). (Courtesy ITT / Goulds Pumps, Inc.)

The following analytical method for determining pipe friction loss is based on the recently published TAPPI Technical Information Sheet (TIS) 408-4 (Reference 1), and is applicable to stock consistencies (oven-dried) from 2 to 6 percent. Normally, stock consistencies of less than 2% (oven-dried) are considered to have the same friction loss characteristic as water.

The friction loss of pulp suspensions in pipe, as presented here, is intended to supersede the various methods previously issued.

Figure 7 and Figure 8 show typical friction loss curves for two different consistencies ($C_2 > C_1$) of chemical pulp and mechanical pulp, respectively.

The friction loss curve for chemical pulp can be conveniently divided into three regions, as illustrated by the shaded areas of Figure 9.

These regions may be described as follows:

Region 1 (Curve AB) is a linear region where friction loss for a given pulp is a function of consistency, velocity, and pipe diameter. The velocity of the upper limit of this linear region (Point B) is designed $V_{\max}$.

Region 2 (Curve BCD) shows an initial decrease in friction loss (to Point C) after which the friction loss again increases. The intersection of the pulp friction loss curve and the water friction loss curve (Point D) is termed the onset of drag reduction. The velocity at this point is designated V_W.

Region 3 (Curve DE) shows the friction loss curve for pulp fiber suspensions below the water curve. This is due to a phenomenon called drag reduction. Reference 2 describes the mechanisms which occur in this region.

Regions 2 and 3 are separated by the friction loss curve for water, which is a straight line with a slope approximately equal to 2.

The friction loss curve for mechanical pulp, as illustrated in Figure 10, is divided into only two regions:

Regions 1 and 3. For this pulp type, the friction loss curve crosses the water curve at V_W and there is no true $V_{\max}$.

To determine the pipe friction loss component for a specified design basis (usually daily mass flow rate), the following parameters must be defined:

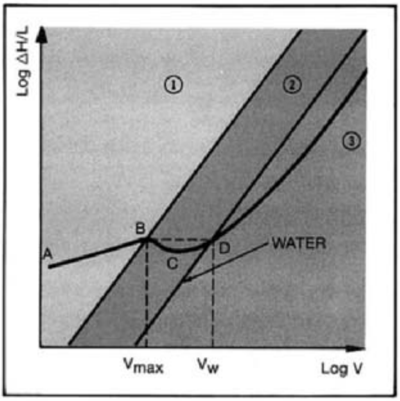

FIGURE 9 Friction loss curves for chemical pulp, shaded to show individual regions. (Courtesy ITT / Goulds Pumps, Inc.)

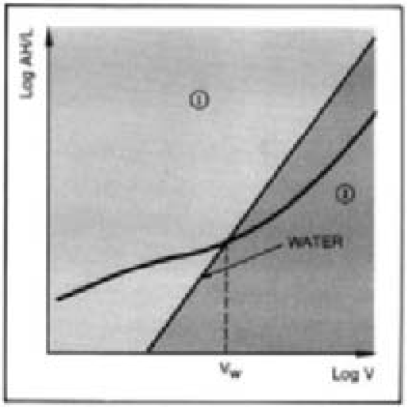

FIGURE 10 Friction loss curves for mechanical pulp, shaded to show individual regions. (Courtesy ITT / Goulds Pumps, Inc.)

a) **Pulp Type** Chemical or mechanical pulp, long or short fibered, never dried or dried and reslurried, etc. This is required to choose the proper coefficients which define the pulp friction curve.

b) **Consistency, *C* (oven-dried)** Often a design constraint in an existing system. *Note*: If air-dried consistency is known, multiply by 0.9 to convert to oven-dried consistency.

c) **Internal pipe diameter*, D*** Lowering *D* reduces initial capital investment, but increases pump operating costs. Once the pipe diameter is selected, it fixes the velocity for a prespecified mass flow rate.

d) **Bulk velocity, *V*** Usually based on a prespecified daily mass flow rate. Note that both *V* and *D* are interdependent for a constant mass flow rate.

e) **Stock temperature*, T*** Required to adjust for the effect of changes in viscosity of water (the suspending medium) on pipe friction loss

f) **Freeness** Used to indicate the degree of refining or to define the pulp for comparison purposes

g) **Pipe material** Important to specify design correlations and compare design values

The bulk velocity (*V*) will depend on the daily mass flow rate and the pipe diameter (*D*) selected. The final value of *V* can be optimized to give the lowest capital investment and operating cost with due consideration of future demands or possible system expansion.

The bulk velocity will fall into one of the regions previously discussed. Once it has been determined in which region the design velocity will occur, the appropriate correlations for determining pipe friction loss value(s) may be selected. The following describes the procedure to be used for estimating pipe friction loss in each of the regions.

Region 1 The upper limit of Region 1 in Figure 9 (Point B) is designated $V_{\max}$. The value of $V_{\max}$ is determined using Eq. 1 and data given in Table I or IA.

$$V_{max} = K'C^{\sigma}(\text{ft/s}), \tag{1}$$

where K' = numerical coefficient (constant for a given pulp is attained from Table I or IA)

C = consistency (oven-dried, expressed as a percentage, not decimally)

σ = exponent (constant for a given pulp), obtained from Table I or IA

If the proposed design velocity (V) is less than $V_{\max}$, the value of flow resistance ($\Delta H/L$) may be calculated using Eq. 2 and data given in Table II or IIA, and the appendices.

$$H/L = FKV^{\alpha}C^{\beta}D^{y} \text{ (ft/100 ft)} \tag{2}$$

where F = factor to correct for temperature, pipe roughness, pulp type, freeness, or safety factor (refer to Appendix D)
K = numerical coefficient (constant for a given pulp), obtained from Table II or IIA
V = bulk velocity (ft/s)
C = consistency (ven-dried, expressed as a percentage, not decimally)
D = pipe inside diameter (in)
α, β, y = exponents (constant for a given pulp), obtained from Table II or IIA

For mechanical pumps, there is no true $V_{\max}$. The upper limit of the correlation equation (Eq. 2) is also given by Eq. 1. In this case, the upper velocity is actually V_W.

Region 2 The lower limit of Region 2 in Figure 9 (Point B) is $V_{\max}$ and the upper limit (Point D) is V_W. The velocity of the stock at the onset of drag reduction is determined using Eq. 3.

$$V_W = 4.00C^{1.40} \text{ (ft/s)} \tag{3}$$

where C = consistency (oven-dried, expressed as a percentage, not decimally).

If V is between $V_{\max}$ and V_W, Eq. 2 may be used to determine $\Delta H/L$ at the maximum point ($V_{\max}$). Because the system must cope with the worst flow condition, $\Delta H/L$ at the maximum point ($V_{\max}$) can be used for all design velocities between $V_{\max}$ and V_W.

Region 3 A conservative estimate of friction loss is obtained by using the water curve. $(\Delta H/L)_W$ can be obtained from a Friction Factor vs. Reynolds Number plot (for example, Hydraulic Institute ANSI/HI 2000 Edition Pump Standards, Reference 3), or approximated from the following equation (based on the Blasius equation.)

$$(\Delta H/L)_W = 0.58V^{1.75}D^{-1.25} \text{ (f/100 ft)} \tag{4}$$

where V = bulk velocity (ft/s)
D = pipe diameter (in)

Previously published methods for calculating pipe friction loss of pulp suspensions gave a very conservative estimate of head loss. The method just described gives a more accurate estimate of head loss due to friction, and has been used successfully in systems in North America and world-wide.

Please refer to Appendix A for equivalent equations for use with metric (SI) units. Tables I and IA are located in Appendix B; Tables II and IIA are located in Appendix C. Pertinent equations, in addition to those herein presented, are located in Appendix D. Example problems are located in Appendix E.

The friction head loss of pulp suspensions in bands and fittings may be determined from the basic equation for head loss, Eq. 5.

$$H = KV_1^2/2g \text{ (ft)} \tag{5}$$

where K = loss coefficient for a given fitting
V_1 = inlet velocity (ft/s)
g = acceleration due to gravity (32.2 ft/s^2)

Values of K for the flow of water through various types of bends and fittings are tabulated in numerous reference sources (for example, Hydraulic Institute ANSI/HI 2000 Edition Pump Standards, Reference 3). The loss coefficient for valves may be obtained from the valve manufacturer.

The loss coefficient for pulp suspensions in a given bend or fitting generally exceeds the loss coefficient for water in the same bend or fitting. As an approximate rule, the loss coefficient (K) increases 20 percent for each 1 percent increase in oven-dried stock consistency. Please note that this is an approximation; actual values of K may differ, depending on the type of bend or fitting under consideration (4).

Appendix A When metric (S/I) units are utilized, the following replace the corresponding equations in the main text.

$$V_{\max} = K'C^{\sigma} \text{ (m/s)} \tag{1M}$$

where K = numerical coefficient (constant for a given pulp), obtained from table I or IA
C = consistency (oven-dried, expressed as a percentage, not decimally)
σ = exponent (constant for a given pulp), obtained from Table I or IA

$$\Delta H/L = FKV^{\alpha}C^{\beta}D^{y} \text{ (m/100 m)} \tag{2M}$$

where F = factor to correct for temperature, pipe roughness, pulp type, freeness, or safety factor (refer to Appendix D)
K = numerical coefficient (constant for a given pulp), obtained from Table II or IIA
V = bulk velocity (m/s)
C = consistency (oven-dried, expressed as a percentage, not decimally)
D = pipe inside diameter (mm)
α, β, y = exponents (constant for a given pulp), obtained from Table II or IIA

$$V_W = 1.22C^{1.40} \text{ (m/s)} \tag{3M}$$

where C = consistency (oven-dried, expressed as a percentage, not decimally).

$$(\Delta H/L)_w = 264V^{1.75}D^{-1.25} \text{ (m/100m)} \tag{4M}$$

where V = bulk velocity (m/s)
D = pipe inside diameter (mm)

$$H - KV_1{}^2/2\,g \text{ (m)} \tag{5M}$$

where K = loss coefficient for a given fitting
V_1 = inlet velocity (m/s)
g = acceleration due to gravity (9.81 m/s^2)

Appendix B

TABLE I Data for use with Eq. 1 or Eq. 1M to determine velocity limit, $V_{\max}$$^{(1)}$

Pulp Type	Pipe Material	K'	σ
Unbeaten aspen sulfite never dried	Stainless Steel	0.85 (0.26)	1.6
Long fibered kraft never dried CSF = 725$^{(6)}$	PVC	0.98 (0.3)	1.85
	Stainless Steel	0.89 (0.27)	1.5
Long fibered kraft never dried CSF = 650$^{(6)}$	PVC	0.85 (0.26)	1.9
Long fibered kraft never dried CSF = 550$^{(6)}$	PVC	0.75 (0.23)	1.65
Long fibered kraft never dried CSF = 260$^{(6)}$	PVC	0.75 (0.23)	1.8
Bleached kraft never dried and reslurried$^{(6)}$	PVC	0.79 (0.24)	1.5
	Stainless Steel	0.59 (0.18)	1.45
Long fibered kraft never dried and reslurried$^{(6)}$	PVC	0.49 (0.15)	1.8
Kraft birch dried and reslurried$^{(6(}$	PVC	0.69 (0.21)	1.3
Stone groundwood CSF = 114	PVC	4.0 (1.22)	1.40
Refiner groundwood CSF = 150	PVC	4.0 (1.22)	1.40
Newsprint broke CSF = 75	PVC	4.0 (1.22)	1.40
Refiner groundwood (hardboard)	PVC	4.0 (1.22)	1.40
Refiner groundwood (insulating board)	PVC	4.0 (1.22)	1.40
Hardwood NSSC CSF = 620	PVC	0.59 (0.18)	1.8

Notes:

1. When metric (SI) units are utilized, use the value of K' given in parentheses. When the metric values are used, diameter (D) must be in millimeters (mm) and velocity (V) in meters per second (m/s).
2. Original data obtained in stainless steel and PVC pipe. PVC is taken to be hydraulically smooth pipe.
3. Stainless steel may be hydraulically smooth although some manufacturing processes may destroy the surface and hydraulic smoothness is lost.
4. For cast iron and galvanized pipe, the K' values will be reduced. No systematic data are available for the effects of surface roughness.
5. If pulps are not identical to those shown, some engineering judgment is required.
6. Wood is New Zealand Kraft pulp.

TABLE IA Data (5, 6) for use with Eq. 1 or Eq. 1M to determine velocity limit, $V_{\max}$

Pulp Type$^{(5)}$	Pipe Material	K'	σ
Unbleached sulphite	Copper	0.98 (0.3)	1.2
Bleached sulphite	Copper	0.98 (0.3)	1.2
Kraft	Copper	0.98 (0.3)	1.2
Bleached straw	Copper	0.98 (0.3)	1.2
Unbleached straw	Copper	0.98 (0.3)	1.2

Estimates for othe pulps based on published literature.

Pulp Type$^{(5, 6)}$	Pipe Material	K'	σ
Cooked groundwood	Copper	0.75 (0.23)	1.8
Soda	Steel	4.0 (1.22)	1.4

Note: When metric (SI) units are utilized, use the value of K' given in parentheses. When the metric values are used, diameter (D) must be in millimeters (mm) and velocity (V) in meters per second (m/s).

Appendix C

TABLE II Data for use with Eq. 2 or Eq. 2M to determine head loss, $\Delta H/L^{(1)}$

Pulp Type	K	α	β	y
Unbeaten aspen sulfite never dried	5.30 (235)	0.36	2.14	−1.04
Long fibered kraft never dried CSF = 725⁽⁵⁾	11.80 (1301)	0.31	1.81	−1.34
Long fibered kraft never dried CSF = 650⁽⁵⁾	11.30 (1246)	0.31	1.81	−1.34
Long fibered kraft never dried CSF = 550⁽⁵⁾	12.10 (1334)	0.31	1.81	−1.34
Long fibered kraft never dried CSF = 260⁽⁵⁾	17.00 (1874)	0.31	1.81	−1.34
Bleached kraft bleached and reslurried⁽⁵⁾	8.80 (970)	0.31	1.81	−1.34
Long fibered kraft dried and reslurried⁽⁵⁾	9.40 (1036)	0.31	1.81	−1.34
Kraft birch dried and reslurred⁽⁵⁾	5.20 (236)	0.27	1.78	−1.08
Stone groundwood CSF = 114	3.81 (82)	0.27	2.37	−0.85
Refiner groundwood CSF = 150	3.40 (143)	0.18	2.34	−1.09
Newspaper broke CSF = 75	5.19 (113)	0.36	1.91	−0.82
Refiner groundwood CSF (hardboard)	2.30 (196)	0.23	2.21	−1.29
Refiner groundwood CSF (insulating board)	1.40 (87)	0.32	2.19	−1.16
Hardwood NSSF CSF = 620	4.56 (369)	0.43	2.31	−1.20

Notes:

1. When metric (SI) units are utilized, use the value of K' given in parentheses. When the metric values are used, diameter (D) must be in millimeters (mm) and velocity (V) in meters per second (m/s).
2. Original data obtained in stainless steel and PVC pipe (7, 8, 9).
3. No safety factors are included in the above correlations.
4. The friction loss depends considerably on the condition of the inside of the pipe surface (10).
5. Wood is New Zealand Kraft pulp.

TABLE IIA Data⁽⁵, ⁶⁾ for use with Eq. 2 or Eq. 2M to determine head loss, $\Delta H/L$

Pulp Type⁽⁵⁾	K	α	β	y
Unbleached sulfite	12.69 (1438)	0.36	1.89	−1.33
Bleached sulfite	11.40 (1291)	0.36	1.89	−1.33
Kraft	11.40 (1291)	0.36	1.89	−1.33
Bleached straw	11.40 (1291)	0.36	1.89	−1.33
Unbleached straw	5.70 (646)	0.36	1.89	−1.33

Estimates for other pulps based on published literature.

Pulp Type⁽⁵, ⁶⁾	K	α	β	y
Cooked groundwood	6.20 (501)	0.43	2.13	−1.20
Soda	6.50 (288)	0.36	1.85	−1.04

Note: When metric (SI) units are utilized, use the value of K' given in parentheses. When the metric values are used, diameter (D) must be in millimeters (mm) and velocity (V) in meters per second (m/s).

Appendix D

The following gives supplemental information to that where I.P.D. mill capacity (metric tons per day), provided in the main text.

1. Capacity (flow), Q—

$$Q = \frac{16.65(\text{T.P.D.})}{C} \text{ (U.S. GPM)}, \tag{i}$$

where T.P.D. = mill capacity (short tons per day)
C = consistency (oven-dried, expressed as a percentage, *not* decimally)

If SI units are used, the following would apply:

$$Q = \frac{1.157(10^{-3})(\text{T.P.D.})}{C} \text{ (m}^3\text{/s)} \tag{iM}$$

where T.P.D. = mill capacity (metric tons per day)
C = consistency (oven-dried, expressed as a percentage, *not* decimally)

2. Bulk velocity, V—

$$V = \frac{0.321Q}{A} \text{ (ft/s)} \tag{ii}$$

or

$$V = \frac{0.4085Q}{D^2} \text{ (ft/s)} \tag{ii}$$

where Q = capacity (U.S. GPM)
A = inside area of pipe (in^2)
D = inside diameter of pipe (in)

The following would apply if SI units are used:

$$V = \frac{1(10^6)Q}{A} \text{ (m/s)} \tag{iiM}$$

or

$$V = \frac{1.273(10^6)Q}{D^2} \text{ (m/s)} \tag{iiM}$$

where Q = capacity (m^3/s)
A = inside area of pipe (mm^2)
D = inside diameter of pipe (mm)

3. Multiplication Factor, F (included in Eq. 2)—

$$F = F_1 \cdot F_2 \cdot F_3 \cdot F_4 \cdot F_5 \tag{iv}$$

where F_1 = correction factor for temperature. Friction loss calculations are normally based on a reference pulp temperature of 95°F (35°C). The flow resistance may be increased or decreased by 1 percent for each 1.8°F (1°C) below or above 95°F (35°C), respectively. This may be expressed as follows:

$$F_1 = 1.528 - 0.00556T_1 \tag{v}$$

where T = pulp temperature (°F), or

$$F_1 = 1.35 - 0.01T_1 \tag{vM}$$

where T = pulp temperature (°C)

F_2 = correction factor for pipe roughness. This factor may vary due to manufacturing processes of the piping, surface roughness, age, etc. Typical values for PVC and stainless steel piping are listed below:

F_2 = 1.0 for PVC piping

F_2 = 1.25 for stainless steel piping

Please note that the previous values are typical values; experience and/or additional data may modify the factors.

F_3 = correction factor for pulp type. Typical values are listed below:

F_3 = 1.0 for pulps that have never been dried and reslurried

F_3 = 0.8 for pulps that have been dried and reslurried

Note: This factor has been incorporated in the numerical coefficient, *K,* for the pulps listed in Table II. When using Table II, F_3 should *not* be used.

F_4 = correction factor for beating. Data have shown that progressive beating causes, initially, a small decrease in friction loss, followed by a substantial increase. For a kraft pine pulp initially at 725 CSF and $F_4 = 1.0$, beating caused the freeness to decrease to 636 CSF and F_4 to decrease to 0.96. Progressive beating decreased the freeness to 300 CSF and increased F_4 to 1.37 (see *K* values in Table II). Some engineering jugment may be required.

F_5 = design safety factor. This is usually specified by company policy with consideration given to future requirements.

Appendix E

The following are three examples which illustrate the method for determination of pipe friction loss in each of the three regions shown in Figure 9.

EXAMPLE 1 Determine the friction loss (per 100 ft of pipe) for 1000 U.S. GPM of 4.5% oven-dried unbeaten aspen sulfite stock, never dried, in 8 in schedule 40 stainless steel pipe (pipe inside diameter = 7.981 in). Assume the pulp temperature to be 95°F.

Solution:

a. The bulk velocity, *V,* is

$$V = \frac{0.4085\, Q}{D^2} \tag{ii}$$

and Q = flow = 1000 U.S. GPM

D = pipe inside diameter = 7.981 in

$$V = \frac{0.4085\,(1000)}{7.981^2} = 6.41 \text{ ft/s} \qquad ()$$

b. It must be determined in which region (1, 2, or 3) this velocity falls. Therefore, the next step is to determine the velocity at the upper limit of the linear region, $V_{\max}$.

$$V_{max} = K'C\sigma \tag{1}$$

and K' = numerical coefficient = 0.85 (from Appendix B, Table I)

C = consistency = 45%

σ = exponent = 1.6 (from Appendix B, Table I)

$V_{\max} = 0.85(4.5^{1.6}) = 9.43$ ft/s

c. Since $V_{\max}$ exceeds *V,* the friction loss, $\Delta H/L$, falls within the linear region, Region 1. The friction loss is given by the correlation:

$$\Delta H/L = FKV^{\alpha}C^{\beta}D^{y} \tag{2}$$

and F = correction factor = $F_1 \cdot F_2 \cdot F_3 \cdot F_4 \cdot F_5$

F_1 = correction factor for pulp temperature. Since the pulp temperature is 95°F

$F_1 = 1.0$

F_2 = correction factor for pipe roughness. For stainless steel pipe,

$F_2 = 1.25$ (from Appendix D)

F_3 = correction factor for pulp type. Numerical coefficients for this pulp are contained in Appendix C, Table II, and have already incorporated this factor.

F_4 = correction factor for beating. No additional beating has taken place, therefore

$F_4 = 1.0$ (from Appendix D)

F_5 = design safety factor. This has been assumed to be unity.

$F_5 = 1.0.$

$F = (1.0)(1.25)(1.0)(1.0)(1.0) = 1.25$

K = numerical coefficient = 5.30 (from Appendix C, Table II)

σ, β, y = exponents = 0.36, 2.14, and −1.04, respectively (from Appendix C, Table II)

V, C, D have been evaluated previously.

$$\begin{aligned}\Delta H/L &= (1.25)(5.30)(6.41^{0.36})(4.5^{2.14})(7.981^{-1.04})\\ &= (1.25)(5.30)(1.952)(25.0)(0.1153)\\ &= 37.28 \text{ ft head loss}/100 \text{ ft of pipe}\end{aligned}$$

This is a rather substantial head loss, but may be acceptable for short piping runs. In a large system, the economics of initial piping costs versus power costs should be weighed, however, before using piping which gives a friction loss of this magnitude.

EXAMPLE 2 Determine the friction loss (per 100 ft of pipe) of 2500 U.S. GPM of 3% oven-dried bleached kraft pine, dried and reslurried, in 12 in schedule 10 stainless steel pipe (pipe inside diameter = 12.39 in). Stock temperature is 1250°F.

Solution:

a. *V,* the bulk velocity, is

$$V = \frac{0.4085\,Q}{D^2} \tag{ii}$$

$$= \frac{0.4085(2500)}{12.39^2} = 6.65 \text{ ft/s}$$

b. The velocity at the upper limit of the linear region, $V_{\max}$, is

$$V_{max} = K'C^{\sigma} \tag{1}$$

and $K' = 0.59$ (from Appendix B, Table I)
$C = 3.0$ (from Appendix B, Table I)
$\sigma = 1.45$ (from Appendix B, Table 1)
$V_{\max} = 0.59\,(3.0^{1.45}) = 2.90$ ft/s

c. Region 1 (the linear region) has been eliminated, since the bulk velocity, V, exceeds $V_{\max}$. The next step requires calculation of V_W.

$$V_W = 4.00\,C^{1.40} \tag{3}$$
$$= 4.00(3.0^{1.40}) = 18.62 \text{ ft/s}$$

d. V exceeds $V_{\max}$, but is less than V_W, indicating that it falls in Region 2. The friction loss in this region is calculated by substituting $V_{\max}$ into the equation for head loss, Eq. 2.

$$\Delta H/L = F\,K\,(V_{max})^{\propto}\,C^{\beta}\,D^{y}$$

and
$$F_1 \cdot F_2 \cdot F_3 \cdot F_4 \cdot F_5 \tag{iv}$$
$$F_1 = 1.528 - 0.00556T \tag{v}$$

and T = stock temperature = 125°F
$F_1 = 1.58 - 0.00556(125) = 0.833$
$F_2 = 1.25$ (from Appendix D)
$F_3 = F_4 = F_5 = 1.0$
$F = 0.833(1.25)(1.0) = 1.041$
$K = 8.80$ (from Appendix C, Table II)
$\alpha, \beta, y = 0.31, 1.81$, and -1.34, respectively (from Appendix C, Table II)

$V_{\max}$, C, and D have been defined previously.

$$\Delta H/L = 1.041(8.80)(2.90^{0.31})(3.0^{1.81})(12.39^{-1.34})$$
$$= 1.041(8.80)(1.391)(7.304)(0.03430)$$
$$= 3.19 \text{ ft head loss/100 ft of pipe}$$

EXAMPLE 3 Determine the friction loss (per 100 ft of pipe) for 2% oven-dried bleached kraft pine, dried and reslurried, through 6 in schedule 40 stainless steel pipe (inside diameter = 6.065 in). The pulp temperature is 90°F; the flow rate 1100 U.S. GPM.

Solution:

a. The bulk velocity is

$$V = \frac{0.4085\,Q}{D^2}$$
$$= \frac{0.4085(1100)}{6.065^2} = 12.22 \text{ ft/s} \tag{ii}$$

b. It must be determined in which region (1, 2, or 3) this velocity falls. To obtain an initial indication, determine $V_{\max}$.

$$V_{max} = K'C\sigma \tag{1}$$

$$
\begin{aligned}
\text{and} \quad K' &= 0.59 \text{ (from Appendix B, Table I)} \\
\sigma &= 1.45 \text{ (from Appendix B, Table I} \\
V_{\max} &= 0.59(2.0^{1.40}) = 1.61 \text{ ft/s}
\end{aligned}
$$

c. Since V exceeds $V_{\max}$, Region 1 (the linear region) is eliminated. To determine whether V lies in Region 2 or 3, the velocity at the onset of drag reduction, V_W, must be calculated.

$$
\begin{aligned}
V_W &= 4.00\ C^{1.40} \\
&= 4.00(2.0^{1.40}) = 10.56 \text{ ft/s}
\end{aligned}
$$

d. V exceeds V_W, indicating that it falls in Region 3. The friction loss is calculated as that of water flowing at the same velocity.

$$
\begin{aligned}
(\Delta H/L)_w &= 0.579\ V^{1.75}\ D^{1.25} \\
&= 0.579(12.22^{1.75})(6.065^{-1.25}) \\
&= 4.85 \text{ ft head loss/100 ft of pipe} \qquad (4)
\end{aligned}
$$

This will be a conservative estimate, as the actual friction loss curve for pulp suspensions under these conditions will be below the water curve.

ECONOMICS AND PUMP SELECTION

The normal economic considerations of any continuous process apply equally well to pulp and paper mills, with a few points of difference. In pump installations, the improved cost figures that are possible from larger units are limited to some extent by the manufacturer's standard size units. Because the industry is capital intensive, the overriding factor in any pump installation is reliability. To achieve this, it does not necessarily follow that it is better to have two pumps installed, with one as a standby. One properly designed and serviced unit may well be better than two unknown units; this is especially true where the pump is in a portion of the process that cannot be interrupted without serious losses, either in raw materials or in quality of the finished product.

A duplication of pumps means complications in extra valves, pipework, connections for steam and viscous liquids, electric motors, cables, and starters. The result is that, in modern mills with good machinery and materials of construction, there is a strong tendency away from the duplication of pumps because of increased costs and questionable reliability. It follows that the important thing is to select the right pump and the right duty point in a particular range.

There may be several hundred pumps in a modern pulp and paper mill, but the cost of these pumps is probably less than 5% of the total equipment cost. It is unwise, therefore, to jeopardize mill reliability by compromising pump quality. Corrosion and erosion are major factors in pump life, and even with the best materials, the life of some components in severe service may be 12 months or less. Moreover, the power used by pumps is usually less than one-third of the mill demand. If one remembers that the cost of total power absorbed in a mill is only around 4%, even a 50% reduction in pump power will still be less than 1% net.

Efficiency The best point at which to operate a pump is, of course, its maximum efficiency, but this is not always possible, particularly in the case of stock pumps because of the wide range of process variables in most pulp and paper mills. Open impellers and excess clearances also reduce the efficiency, yet these factors are much more important in stock pumps than efficiency. Another important consideration is speed. Stock pumps should be chosen to run at as low a speed as possible to achieve stable operation, and this speed may not produce an efficient pump. The shape of the pump performance curve is much more important than the best efficiency quoted by a manufacturer. A flat or unstable head curve may produce surging or instability in the pump output. Good pump selection, therefore, must emphasize reliability as the first consideration and efficiency and costs as secondary considerations.

Pump Speeds Most of the pump duties in a mill can be accomplished by single-stage pumps and four-pole motor speeds. For liquids other than water, two-pole motor speeds should be avoided if possible. For special duties, including stock pumping, six- or eight-pole motors may be required unless some indirect or variable speed is used. Although it is true that lower speeds mean larger pumps and more expensive electric motors, lower speeds are justified because of reduced maintenance and greater reliability. Some deviation from these speeds may be necessary for pumps generating heads in excess of 150 ft (46 m), but this can often be taken care of by a larger impeller rather than a higher shaft speed.

Although not an option in every circumstance, the use of variable speed drive systems for pumps to replace control valves should also be considered. Reliable alternating current variable frequency drives are now readily available up to 2300 volts and are easily justifiable based on normal power costs at the 440 volt level. The commensurate speed reduction seen by the pump when replacing a control valve and avoiding its necessary pressure drop will also add to the reliability and life of the pump.

Multistage Pumps Except with boiler feedwater, the use of multistage pumps should be avoided. This is particularly true for stock and viscous liquors. The complicated pump design makes such units unacceptable for these services.

Pipeline Systems With black liquor, green liquor, and similar high-viscosity liquors, adequate provision must be made for steaming out and subsequent liquor drainage. The pumps must also be included in this system. Although the liquor pumps should be designed to pass some solid matter, motorized strainers should be used on the pumps for cyclone evaporators and recovery boiler-fuel pumps because both pumps discharge to spray nozzles. Dead pockets and other areas where liquor can collect should be avoided because solids from the liquor will build up in these areas and possibly break away to block pipelines or pump impellers. For protection at shutdowns, even for short periods, steaming out is essential.

Positive Displacement Pumps The principal use of the positive displacement pump is for consistency control of stocks above 5%. The normal measuring device used is quite satisfactory at low consistencies but is less reliable at the higher values. More satisfactory control may be achieved by using a screw pump, where the power is proportional to the pulp consistency at constant flow. Such pumps have been very reliable on consistency control.

Digester Circulating Pumps Digester circulating pumps are used with indirectly heated batch digesters to circulate the liquor at the digester pressure and temperature. Maintenance problems are common on these pumps because heads can be as high as 150 lb/in^2 (1034 kPa) and temperatures as high as 350°F (177°C). In addition, the circulating liquor contains some raw pulp even though screens are fitted to the digester outlets. Pumps for this service, therefore, should be centerline mounted, of very heavy construction, have closed impellers, and mechanical seals. In addition, there is often considerable pipework involved, for a digester may easily be 60 ft (18 m) high and pipe loads are often imposed on the pumps. Expansion joints and long-radius bends are used, but it is desirable to support the pumps on springs or slide bases.

Pumps for Heavy Black Liquor Above 60% Solids A typical pump for this service is shown in Figure 11. An open impeller in a 316 stainless steel casing is recommended. A heavy sleeved shaft of 316 stainless steel with ample clearance between the rotating parts is also required for satisfactory operation. These pumps may be required to handle black liquor up to 2000 centistokes viscosity and should be provided with water cooling. Steam

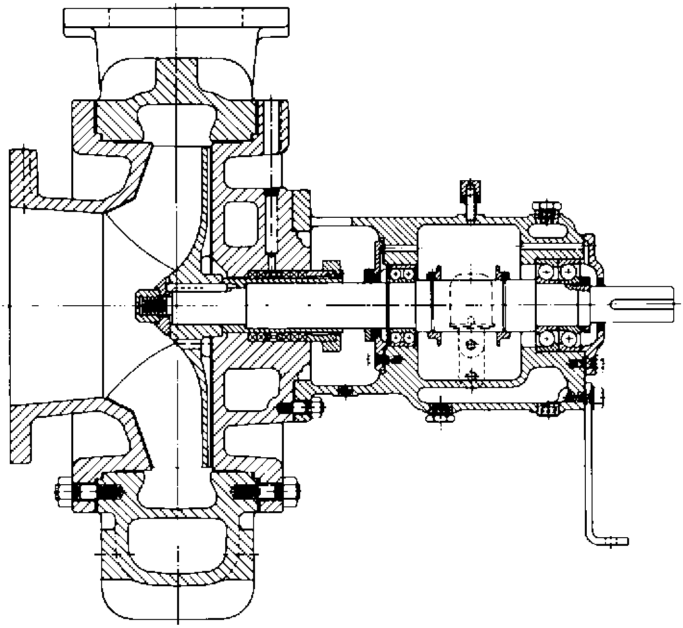

FIGURE 11 Black liquor pump (Courtesy ITT/Goulds Pumps, Inc.)

jacketing is not always satisfactory because the liquor may tend to bake on the walls of the casing. Pump speeds should be below 1800 rpm, if possible.

Multiple-Effect Evaporator Pumps Pumps in this service often operate in cavitation owing to problems in regulating the flow between evaporation stages. Level control valves in the suction line to the pump can alleviate this problem, but cavitation can still be expected in the pump. A self-priming pump may give longer life of the rotating elements than the condensate pump usually used on this service.

Diaphragm Pumps Diaphragm pumps are used in pumping lime mud slurries of high concentration. They consist of a rubber or neoprene diaphragm with a pulsating air supply on one side, controlled by a timer, and the slurry on the other.

Medium Consistency Stock Pumps Pumping of medium consistency stock (from about 8% to about 16% consistency) can be accomplished with positive displacement screw pumps or centrifugal pumps that have been specially adapted. Medium consistency stock is a thick viscoelastic material made up of strong networks of fibers called flocs. A high shear rate is necessary to render the stock capable of flow. Therefore all centrifugal medium consistency pumps are equipped with an inducer or feeder vane device in front of the pump suction to provide the shear necessary for the stock to flow into the impeller eye. There are also large amounts of entrained air in medium consistency stock and most centrifugal medium consistency pumps are equipped as well with an auxiliary vacuum pump to remove the air allowing for stable pump operation and high efficiencies. An example of a medium consistency centrifugal pump is shown in Figure 4.

Fan Pump Another specialized pump application in the paper mill is the pump that feeds the headbox or nozzle that spreads white paper onto the moving wire sheet that

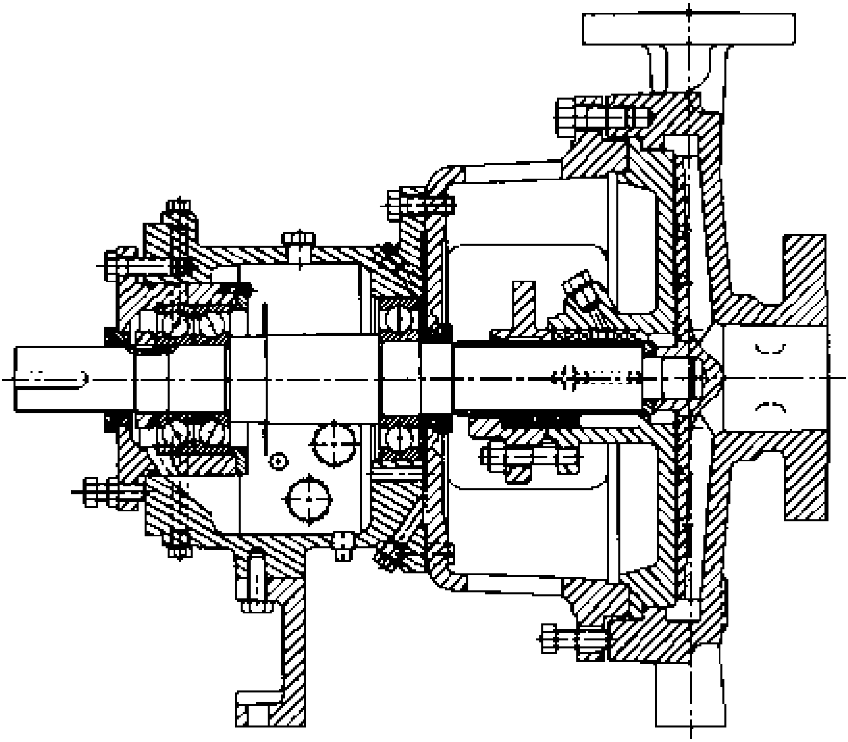

FIGURE 12 A typical low flow pump used for shower services. (new) (Courtesy ITT / Goulds Pumps, Inc.)

forms the paper. The *fan pump* is usually a large horizontally split double suction pump in austenitic (AISI 316) trim or all austenitic (AISI 316) stainless steel construction. To form an evenly distributed sheet, the headbox must be provided with flow that is free of pressure pulsations and flow disturbances. The fan pump rotating element (impeller, shaft, sleeves, and so on) is designed and built to special tolerances to guarantee a typical maximum pressure pulse of 0.5% of pump total dynamic head, peak-to-peak, at any frequency. A typical fan pump is shown in Figure 5.

Shower Services Shower services require pumps to operate at low flows and high pressures. Operation at low flows requires special pump designs to ensure good pump reliability. These pumps are usually of single stage design with special, circular volute construction to minimize radial loads on the rotor and bearings. A typical low flow pump is shown in Figure 12. Some high pressure shower services require multistage or high speed (greater than 3600 rpm) pumps to reach the desired pressure. Generally, multistage and high speed pumps require more maintenance than single stage units because of mechanical complexity.

Solid Handling Services There are many pump applications that require handling of various size solids, particularly in recycle services. Recycle services may contain tramp metal and plastics that can clog stock pumps. Recessed impeller pumps, sometimes referred to as vortex pumps, are particularly useful for these types of services because the impeller is recessed from the main flow allowing large solids to pass through the pump.

Sealless Pump Services In recent years, some of the severely corrosive chemical applications have been served well by sealless pumps. Magnetic drive pumps are particularly useful for tank car unloading or sodium hydroxide and other chemicals where mechanical seals have required high levels of maintenance (See Section 2.7).

Vacuum Pumps These are used to extract water from the sheet on the fourdrinier wire and at the suction presses by means of a vacuum up to a maximum of about 25 inHg (635 mmHg). Approximately 40,000 lb (18,100 kg) of water is extracted by this means for every ton (1000 kg) of paper produced, and this water is removed by entrainment with the air handled by the vacuum pumps. Frequently water separators are used to remove water; their use is a matter of economics, as a reduction of up to 10% in power may be achieved.

Vacuum pumps are of three basic types:

1. Water ring
2. Positive displacement
3. Centrifugal or axial-flow

Many engineers prefer the water-ring type, probably because of its simplicity. In general, however, this type uses more power, mainly because of the heating of the circulating water, which is then discharged to a drain.

Centrifugal and axial-flow machines must be provided with water separators, but they are more efficient overall, particularly when the heat of compression is used in the machine room ventilating system. The machines run at high speed and are usually driven by a steam turbine.

The paper machine system requires vacuums at different levels, from a few inches (millimeters) of mercury to the maximum possible. Often pumps are connected to a common header, and orifice plates are used to divide the flow to ensure some measure of standby capacity. This involves throttling, however, and may create flow problems unless quantities are carefully estimated. The axial-flow machine permits extraction at any point along the rotor within fairly close limits and requires an accurate estimation of the quantities and specific vacuum required. A standby for axial-flow machines cannot usually be justified.

Stock and Liquor Pump Standardization Throughout the mill the duties of many pumps are similar, but different materials of construction may be used. If, at a slightly extra initial cost, the rotating elements of the pump can be standardized, this will reduce spare-parts inventories. This is also an advantage when purchasing pumps for a new mill. For example, if a standard arrangement consists of a complete rotating element, including bearings, only the impeller size and material need be different. Standardization is an additional reason for recommending that all pumps be stainless-fitted. Obviously, large pumps need individual evaluation. Standardization of stock pumps is less feasible, but up to about 6% stock, similar pumps can usually be specified.

Pump Selection Guidelines In many cases, an excess margin on head and capacity is specified. Where margins are excessive, mechanical troubles and cavitation often occur. The following guidelines will help to properly size a pump and motor in order to avoid these problems:

1. Carefully calculate the pump duty, using the TAPPI technical information sheet (TIS 408-4) for stock friction and the proper viscosity corrections for liquor friction. Always use a schematic of the actual piping system to be installed.
2. Properly size control valves to minimize the required pressure drop. Consider the use of variable speed drives.
3. Make the proper corrections to head and power for the presence of entrained gas in the fluid being pumped, per pump manufacturers recommendations.

4. Select a pump from the manufacturer's curve and note the impeller diameter and range for the pump. If the duty point falls near the end of the curve or if the impeller diameter is greater than 95% of the maximum impeller diameter, it is advisable to select the next size larger pump. For maximum reliability, select an impeller diameter equal to or nearly equal to: {(maximum impeller diameter—minimum impeller diameter) × 0.75} + minimum impeller diameter.

5. Allow 10% or 3 ft (whichever is larger) between *NPSH*A and *NPSHR*. Systems should be designed for a maximum available *S* value (suction specific speed) of 8,000.

6. Motors should be sized to be non-overloading for 105% of the impeller diameter chosen. Baseplates should allow for the installation of the next larger frame size.

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