Section TECH-E
Paper Stock

TECH-E-1 Paper Stock Discussion

Centrifugal pumps are used with complete success in handling paper stock and other fibrous suspensions. However, the nature of a stock suspension requires certain special considerations. All of the factors affecting pump operation discussed below must be carefully considered for a good installation.

SUCTION PIPING

The stock must be delivered freely to the impeller for the pump to operate. The suction pipe should be as short and direct as possible. The suction pipe and entrance from the stock chest should never be smaller than the pump suction connection, and should be level with no air pockets. Always keep the direction of flow in a straight line.

Inadequate suction design with undersize pipe and excessive fittings can prevent the pump from delivering rated capacity, or from operating at all on high consistency stocks.

SUCTION HEAD

Stock pumps will not operate when a vacuum is required to maintain flow into the pump. Thus, there must be a static suction head sufficient to overcome suction line friction losses.

PERCENT CONSISTENCY

The consistency of a pulp and water suspension is the percent by weight of pulp in the mixture. Oven Dry (O.D.) consistency is the amount of pulp left in a sample after drying in an oven at 212°F. Air Dry (A.D.) consistency is an arbitrary convention used by papermakers, and is the amount of pulp left in a sample after drying in atmosphere. Air Dry stock contains 10% more moisture than Bone Dry stock, i.e. 6% O.D. is 6.67% A.D.

Traditional paper stock pumps will handle stock up to approximately 6% O.D. consistency. The absolute maximum limit is a function of many factors including stock fiber length, pulping process, degree of refining, available suction head, etc. In certain situations, consistencies as high as 8% O.D. can be successfully handled with a standard paper stock pump.

Recent testing on various types of stock has indicated that pump performance is the same as on water for stock consistencies up to 6% O.D. In other words, water curves can be used to select stock pumps, as the capacity, head and efficiency are the same as for water.

Medium consistency paper stock is a term generally used to describe stock between 7% and 15% O.D. consistency. Pumping of medium consistency paper stock with a centrifugal pump is possible, but requires a special design due to the fiber network strength and the inherently high air content.

AIR IN STOCK

Entrained air is detrimental to good operation of any centrifugal pump, and can result in reduced capacity, increased erosion and shaft breakage. Obviously every effort must be made to prevent the over-entrainment of air throughout the process.

EXCESSIVE DISCHARGE THROTTLING

While it is realized that excess capacity is normally required over the paper machine output in tons per day, "over-selection" of pumps on the basis of capacity and head usually results in the necessity of throttling the pump at the valve in the discharge line. Since the valve is normally located adjacent to the pump, the restriction of the valve and the high velocity within the valve will result in some dehydration and cause vibration due to slugs of stock. Vibration at the valve due to throttling is transmitted to the pump and may reduce the normal life of the pump-rotating element.

Centrifugal pumps operating at greatly reduced capacity have more severe loading internally due to hydraulic radial thrust. Hence pumps selected too greatly oversize in both capacity and head have the combination of the vibration due to throttling plus the greater internal radial load acting to reduce the life of the rotating element. As a general rule, stock pumps should not be operated for extended periods at less than one quarter of their capacity at maximum efficiency. When excessive throttling is required, one of the two methods below should be employed.

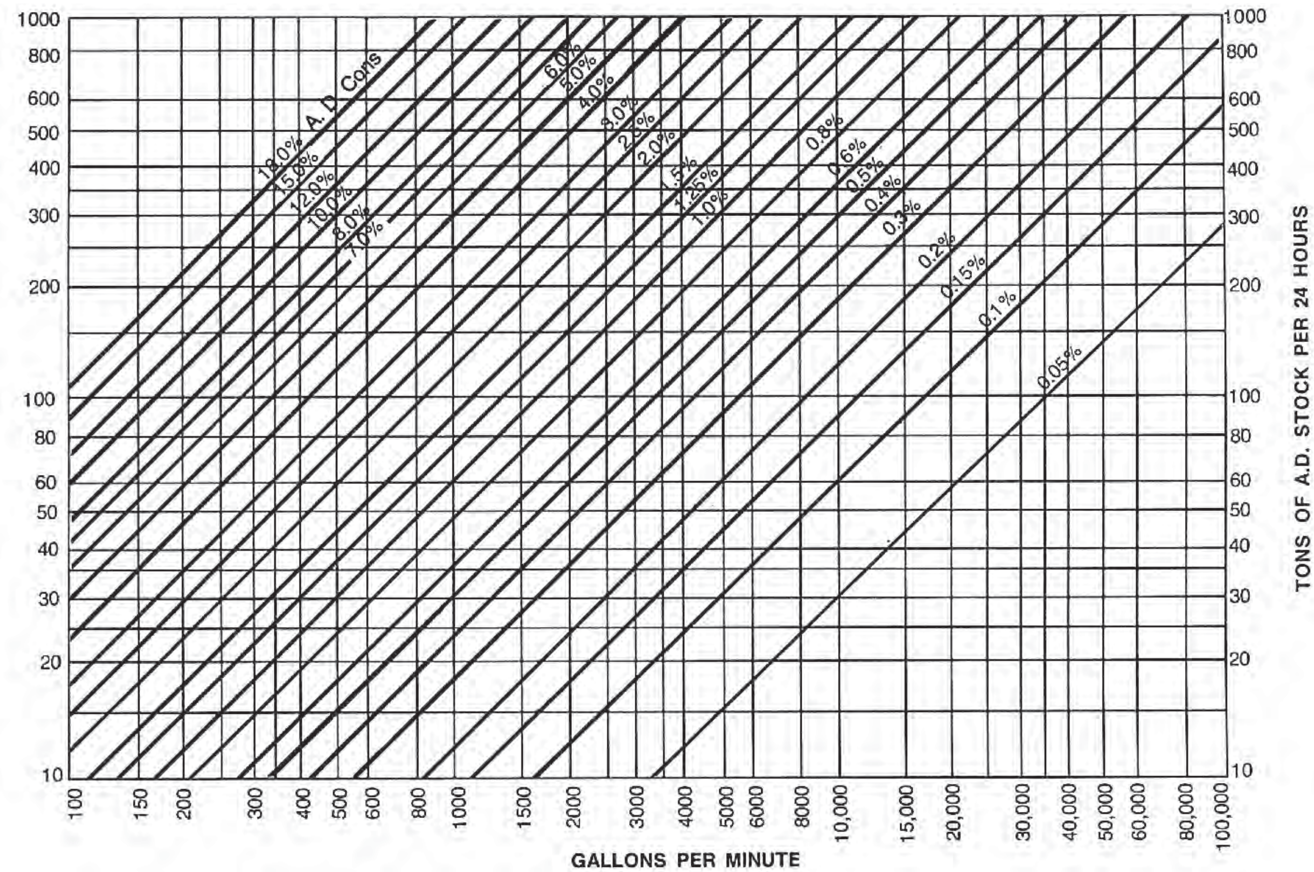
1. Review capacity requirements and check the static and friction head required for the capacity desired. Reduce the impeller diameter to meet the maximum operating conditions. This will also result in considerable power saving.
2. Install a by-pass line upstream from the discharge valve back to the suction chest below the minimum chest level, if possible, and at a point opposite the chest opening to the pump suction. This by-pass line should include a valve for flow regulation. This method is suggested where mill production includes variation in weight of sheet.

FILLERS AND ADDITIVES

The presence of fillers and chemical additives such as clay, size and caustics can materially increase the ability of paper stock to remain in suspension. However, overdosing with additives such as alum may cause gas formation on the stock fibers resulting in interruption of pumping.

TECH-E-2 Conversion Chart of Mill Output in Tons per 24 Hours

To U.S. Gallons per Minute of Paper Stock of Various Densities



EXAMPLE:

Find the capacity in gallons per minute of a pump handling 4% stock for a mill producing 200 tons per 24 hours.

Enter chart at 200 tons per day, read horizontally to 4% stock, then downward to find pump capacity of 840 GPM.

TECH-E-2.1 Definitions / Conversion Factors

A.D. = Air Dry stock (Contains 10% Water)

O.D. = Oven Dry stock (All Water Removed)
Also Called Bone Dry (B.D.)

A.D. = 1.11 x O.D.

O.D. = 0.90 x A.D.

A.D. = 1.11 O.D.T/D

O.D. = 0.90 x A.D. T/D

A.D. Consistency = 1.11 x O.D. Consistency

O.D. Consistency = 0.90 x A.D. Consistency

T/D or TPD or S. T/D = Short Tons Per Day

One Short Ton = 2000 lbs.

M. T/D = Metric Tons per Day

One Metric Ton = 2205 lbs.

A.D.S. T/D = Air Dry Short Tons/Day

A.D.M. T/D = Alr Dry Metric Tons/Day

S. T/D = 1.1025 x M. T/D

$$\frac{\textit{Production in A. D. S. T/D} \times 15}{\textit{\% O.D. Cons.}} = \text{Flow in GPM}$$

$$\frac{\textit{Production in A. D. S. T/D} \times 16.67}{\textit{\% A.D. Cons.}} = \text{Flow in GPM}$$

TECH-E-3 Friction Loss of Pulp Suspensions in Pipe

I. INTRODUCTION

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.

The following analytical method for determining pipe friction loss is based on the 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.

II. BACKGROUND

Fig. 1 and Fig. 2 show typical friction loss curves for two different consistencies ($C_2 > C_1$) of chemical pulp and mechanical pulp, respectively.

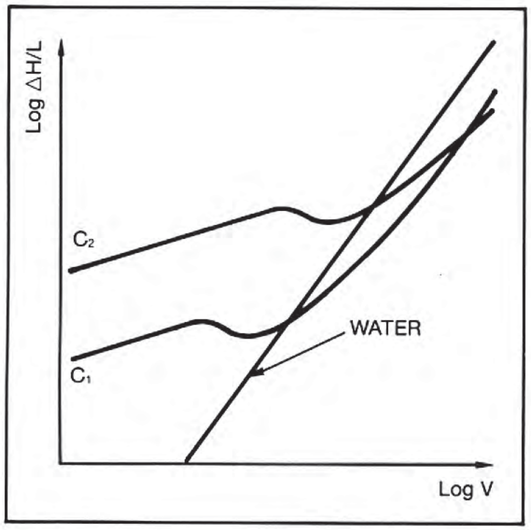


Fig. 1 – Friction loss curves for chemical pulp ($C_2 > C_1$).

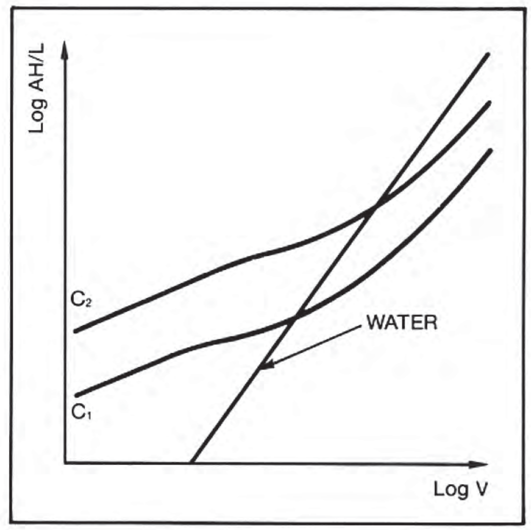


Fig. 2 – Friction loss curves for mechanical pulp ($C_2 > C_1$).

The friction loss curve for chemical pulp can be conveniently divided into three regions, as illustrated by the shaded areas of Fig. 3.

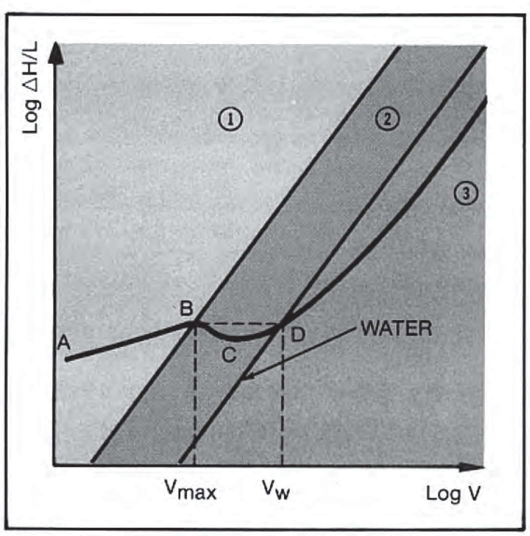


Fig. 3 – Friction loss curves for chemical pulp, shaded to show individual regions.

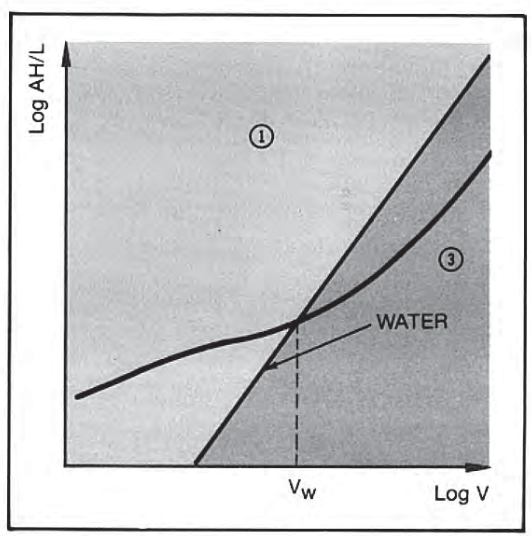


Fig. 4 – Friction loss curves for mechanical pulp, shaded to show individual regions.

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 at the upper limit of this linear region (Point B) is designated 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 Fig. 4, 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}.

III. DESIGN PARAMETERS

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

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.

IV. PIPE FRICTION ESTIMATION PROCEDURE

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 3 (Point B) is designated V_{max}. The value of V_{max} is determined using Equation $\boxed{1}$ and data given in Table I or IA.

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

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), and

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

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

$$H/L = F\, K\, V^{\alpha} C^{\beta} D^{y} \text{ (ft/100 ft)}, \qquad \boxed{2}$$

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

D = pipe inside diameter (in), and

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 (Equation $\boxed{2}$) is also given by Equation $\boxed{1}$. In this case, the upper velocity is actually V_w.

Region 2 The lower limit of Region 2 in Fig. 3 (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 Equation $\boxed{3}$

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

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

If V is between V_{max} and V_w, Equation 2 may be used to determine $\triangle$H/L at the maximum point (V_{max}). Because the system must cope with the worst flow condition, $\triangle$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. $(\triangle H/L)_w$ can be obtained from a Friction Factor vs. Reynolds Number plot (Reference 3, for example), or approximated from the following equation (based on the Blasius equation).

$$(\triangle H/L)_w = 0.58\ V^{1.75} D^{-1.25}\ \text{(ft/100 ft)}, \quad \boxed{4}$$

where V = bulk velocity (ft/s), and

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.

V. HEAD LOSSES IN BENDS AND FITTINGS

The friction head loss of pulp suspensions in bends and fittings may be determined from the basic equation for head loss, Equation $\boxed{5}$.

$$H = K\ V_1^2/2g\ \text{(ft)}, \quad \boxed{5}$$

where K = loss coefficient for a given fitting,

V_1 = inlet velocity (ft/s), and

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 (Reference 3, for example). 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 (SI) units are utilized, the following replace the corresponding equations in the main text.

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

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), and

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

$$\triangle H/L = F\ K\ V^{\alpha}\ C^{\beta}\ D^{y}\ \text{(m/100m)}, \quad \boxed{2M}$$

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), and

α, β, y = exponents (constant for a given pulp), obtained from Table II or IIA.

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

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

$$(\triangle H/L)_w = 264\ V^{1.75} D^{-1.25}\ \text{(m/100m)}, \quad \boxed{4M}$$

where V = bulk velocity (m/s), and

D = pipe inside diameter (mm).

$$H = K\ V_1^2/2g\ \text{(m)}, \quad \boxed{5M}$$

where K = loss coefficient for a given fitting,

V_1 = inlet velocity (m/s), and

g = acceleration due to gravity (9.81 m/s^2).

APPENDIX B

TABLE I

Data for use with Equation $\boxed{1}$ or Equation $\boxed{1M}$ 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 Stainless Steel	0.98 (0.3) 0.89 (0.27)	1.85 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 Stainless Steel	0.79 (0.24) 0.59 (0.18)	1.5 1.45
Long fibered kraft 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 judgement is required.
6. Wood is New Zealand Kraft pulp.

TABLE IA

Data (5, 6) for use with Equation $\boxed{1}$ or Equation $\boxed{1M}$ 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 other 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 millimeters (mm) and velocity (V) in meters per second (m/s)

APPENDIX C

TABLE II
Data for use with Equation $\boxed{2}$ or Equation $\boxed{2M}$ 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 reslurred (5)	8.80 (970)	0.31	1.81	-1.34
Long fibered kraft dried and reslurred (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 must be 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 IA
Data (5, 6) for use with Equation $\boxed{2}$ or Equation $\boxed{2M}$ 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	1140 (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 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 —

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

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

If SI units are used, the following would apply:

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

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

2. Bulk velocity, V —

$$V = \frac{0.321\ Q}{A} \quad \text{(ft/s), or} \qquad \text{(ii)}$$

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

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

The following would apply if SI units are used:

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

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

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

3.Multiplication Factor, F (.included in Equation 2) -

$$F = F_1 \bullet F_2 \bullet F_3 \bullet F_4 \bullet F_5, \qquad \text{(iv)}$$

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:

$$F_1 = 1.528 - 0.00556\,T, \qquad \text{(v)}$$

where T = pulp temperature (° F), or

$$F_1 = 1.35 - 0.01\,T, \qquad \text{(vM)}$$

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 above are typical values; experience and/or additional data may modify the above 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 judgement 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 3.

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 inch 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

$$V = \frac{0.4085\,Q}{D^2}, \qquad \text{(ii)}$$

and Q = flow = 1000 U.S. GPM.
D = pipe inside diameter = 7.981 in.

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

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}.

$$V_{max} = K'\,C^{\sigma}, \qquad \boxed{1}$$

and K' = numerical coefficient = 0.85 (from Appendix B, Table I),
C = consistency = 4.5%,
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, $\triangle H/L$, falls within the linear region, Region 1. The friction loss is given by the correlation:

$$\triangle H/L = F\,K\,V^{\alpha}\,C^{\beta}\,D^{y} \qquad \boxed{2}$$

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

F1 = 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),

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

V, C, D have been evaluated previously.

$\triangle H/L = (1.25)(5.30)(6.41^{0.36})(4.5^{2.14})(7.981^{-1.04})$

$= (1.25)(5.30)(1.952)(25.0)(0.1153)$

$= 37.28$ ft head loss/100 ft of pipe.

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 inch schedule 10 stainless steel pipe (pipe inside diameter = 12.39 in). Stock temperature is 1250°F.

Solution:

a) V, the bulk velocity, is

$$\mathbf{V = \frac{0.4085\ Q}{D^2},} \qquad \text{(ii)}$$

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

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

$$\mathbf{V_{max} = K'\ C^{\sigma},} \qquad \boxed{1}$$

and K' = 0.59 (from Appendix B, Table I),

= 1.45 (from Appendix B, Table I).

$V_{max} = 0.59\ (3.0^{1.45}) = 2.90$ ft/s.

c) Region 1 (the linear region) has been eliminated, since the bulk velocity, V, exceeds Vmax.

The next step requires calculation of V_w.

$$\mathbf{V_W = 4.00\ C^{1.40}} \qquad \boxed{3}$$

$= 4.00\ (3.0^{1.40}) = 18.62$ 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, Equation $\boxed{2}$.

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

$$\mathbf{and\ \ F_1 \bullet F_2 \bullet F_3 \bullet F_4 \bullet F_5;} \qquad \text{(iv)}$$

$$\mathbf{F_1 = 1.528 - 0.00556T,} \qquad \text{(v)}$$

and T = stock temperature = 125° F

$F_1 = 1.528 - 0.00556\ (125) = 0.833,$

$F_2 = 1.25$ (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.

$\triangle H/L = 1.041\ (8.80)\ (2.90^{0.31})\ (3.0^{1.81})\ (12.39^{-1.34})$

$= 1.041\ (8.80)\ (1.391)\ (7.304)\ (0.03430)$

$= 3.19$ 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 inch 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

$$\mathbf{V = \frac{0.4085\ Q}{D^2},} \qquad \text{(ii)}$$

$$= \frac{0.4085\ (1100)}{6.065^2} = 12.22 \text{ ft/s.}$$

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

$$\mathbf{V_{max} = K'\ C\,\sigma,} \qquad \boxed{1}$$

and K' = 0.59 (from Appendix B, Table I),

σ = 1.45 (from Appendix B, Table I).

$V_{max} = 0.59\ (20^{1.40}) = 1.61$ ft/s.

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.

$$\mathbf{V_W = 4.00\ C^{1.40}} \qquad \boxed{3}$$

$= 4.00\ (2.0^{1.40}) = 10.56$ ft/s.

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.

$$\mathbf{(\triangle H/L)_w = 0.579\ V^{1.75}\ D^{-1.25},} \qquad \boxed{4}$$

$= 0.579\ (12.22^{1.75})\ (6.065^{-1.25})$

$= 4.85$ ft head loss/100 ft of pipe.

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

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TECH-E-4 Pump Types Used in the Pulp & Paper Industry

Mill Area	Typical Services	Typical Pump Construction	Pump Type	Goulds Model
Woodyard	Log Flume Log/Chip Pile spray Chip Washer	Al/316SS Trim Al/316SS trim Al/316SS Trim	Mixed Flow Vertical Turbine Stock ANSI Double Suction	MF VIT 3175, 3180/85 3196 3410, 3415, 3420
Pulp Mill	Shower Supply Dilution Supply Screen Supply Cleaner Supply Decker Supply Hi/Med. Density Storage Transfer Medium Cons. Storage Chip Chute Circulation White Liquor Circulation Condensate Wash Liquor Circulation	Al/31SS Al316SS Al316SS 316SS 316SS/317SS 316SS/317SS Various 316SS/317SS CD4MCu CD4MCu Al/316SS 316SS	Stock ANSI Double Suction Medium Consistency Hi Temp/Press Stock	3175, 3180/85 3196 3410, 3415, 3420 3500 3181/86
Bleach Plant	Brown Stock Storage Bleach Tower Storage Bleach Chemical Mixing High Density Storage Chemical Feed Washer Supply Washer Shower Water Dilution Water Medium Consistency O_2 Reactor ClO_2 Generator Circulation	316SS 316SS 317SS, 254 SMO, Titanium 316SS/317SS 316SS 316SS 316SS 316SS 316SS Titanium	Stock ANSI Medium Consistency Axial Flow Non-metallic	3175, 3180/85 3196 3500 AF NM 3196
Stock Prep	Refiner Supply Deflaker Supply Machine Chest Supply	316SS 316SS 316SS	Stock ANSI	3175, 3180/85 3196
Paper Machine (Wet End)	Fan Pumps Couch Pit Saveall Sweetner Shower	Al/316SS Trim, All 316SS Al/316SS Trim, All 316SS Al/316SS Trim, All 316SS Al/316SS Trim, All 316SS A/316SS Trim, All 316SS	Double Suction Stock Low Flow High Pressure Two-Stage	3415, 3420 3175, 3180/85 LF3196 3310H 3316
Paper Machine (Dry End)	Dryer Drainage Condensate Trim Squirt Broke Chest	Al/316SS Trim, Al/316SS Trim Al/316SS Trim Al/316SS Trim	ANSI Low Flow Stock	3196 LF 3196 3175, 3180/85
Coater	Coating Slurries Kaolin Clay (Fillers)	316SS/CD4MCu 316SS/CD4MCu	ANSI Medium Duty Slurry	3196 JC
Kraft Recovery	Weak Black Liquor Evaporator Circulation Concentrated Black Liquor Condensate Injection Black Liquor Transfer Pumps Smelt Spout Cooling Water Collection Weak Wash Scrubber Green Liquor (Storage Transfer) Lime Mud Dregs	316SS 316SS 316SS 316SS 316SS CD4MCu Al/316SS Trim Al/316SS Trim 316SS/CD4MCu/28% Chrome 316SS/CD4MCu/28% Chrome 316SS/CD4MCu/28% Chrome 316SS/CD4MCu/28% Chrome	ANSI Stock Medium Duty Slurry High Temp/Pressure Stock High Pressure Multi Stage	3196 3175, 3180/85 JC 3181/86 3316
Utility (Power House)	Feedwater Condensate Deaerator Booster	CS/Chrome Trim/All Chrome 316SS 316SS	Multi-Stage ANSI High Pressure Vertical Can	3310H, 3600 3196 3700, VIC
Miscellaneous	Mill Water Supply Sump Pumps	Al/316SS Trim Al/316SS Trim	Double Suction Vertical Turbine Self-Priming Vertical Sumps Vertical Sump; Recessed Submersible	3410, 3415, 3420 VIT 3796 3171 VHS HSU
Recycle	Hole/Slot Screen Supply Rejects Float Cell Medium Consistency Storage Hydro Pulper Dilution Water	316SS/CD4MCu 316SS/CD4MCu 316SS 316SS/317SS 316SS/CD4MCu Al/316SS Trim	Stock Recessed ANSI Medium Consistency	3175, 3180/85 CV 3196,HS 3196 3500