TIS 0410-14

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Generalized method for determining the pipe friction loss of flowing pulp suspensions

Purpose

The purpose of this Technical Information Sheet (TIS) is to provide up-to-date correlations for basic pipe friction data obtained from laboratory flow loops and pulp mill piping systems and to propose a method for estimating pipe friction over a wide range of flow rates. Because of the complex nature of the friction loss curve, it is not possible to recommend a single equation or a simple method for all pulps under various flow conditions. Hence, this TIS provides a means of determining the *minimum* value of pipe friction loss that can be expected based directly on all available published data. Consequently, it does not necessarily provide directly the actual design value of friction loss, and some judgment must be made by the designer. Each designer will have to determine and apply his own safety factor depending on company policy, projected expansions, possible flow system alterations, effects of other pipe fittings, and effects of other variables such as temperature, fiber aging, and past history. This TIS simply provides a strong basis from which to develop the design estimate.

The method has resulted from a review of published data, design correlations, and procedures for obtaining the pipe friction loss as explained in TIS 0410-12 "Pipe Friction Pressure Loss of Pulp Suspensions — Literature Review and Evaluation of Data and Design Methods" (*1*). The approximate consistency range is 2% to 6% oven-dried.

The basis for the proposed method is a review and research work done by Duffy and coworkers, University of Auckland, New Zealand (*2, 3, 4, 5*).

Introduction

As indicated by the friction loss curves for pulp suspensions in Figure 1, the frictional pressure drop or friction loss is not a simple function of velocity. At low bulk velocities, there is a flow regime in which the flow resistance increases as a power function of bulk velocity and stock consistency. Flow resistances in this regime have been correlated for a wide range of pulps (*1*). For most chemical pulps, the friction loss curves go through maxima as bulk velocity increases. Beyond the maxima there is a regime characterized by flow resistance which decreases as bulk velocity increases. Gross over-design can result if the correlations derived to predict flow resistances before the maxima in the friction loss curves are misapplied to predict flow resistances in the regime beyond the maxima. At higher bulk velocities the friction loss curves for most chemical pulps pass through local minima, and flow resistance again increases as bulk velocity increases.

For most mechanical pulps the friction loss curves have inflection points rather than maxima and minima, and at no velocity does flow resistance decrease as bulk velocity increases.

At very high bulk velocities in smooth pipes the flow resistances for both chemical and mechanical pulps are lower than those for water flowing alone at the same rate. The point at which a pulp curve crosses the water curve is termed the onset of drage reduction.

This TIS presents specific correlation equations in the "Equations and data" section for the region before the maximum in the friction loss curve and presents a method for calculating realistic but conservative values of the pipe friction component over other ranges of flow rate. Application of this method should avoid gross overdesign.

It must also be pointed out that all methods of determining pipe friction loss are based on steady-state flow where adequate upstream and downstream calming sections have been provided. In practice this is sometimes not the case. The friction loss per unit length of pipe immediately following a flow disturbance (bends, valves, contractions, etc.) can actually be higher than for calmed flow (see Reference 8).

Determination of pipe friction loss

The following pertinent design data are required: pulp type, over-dried consistency, stock temperature, pipe material, pipe diameter, and bulk velocity based on design daily mass flow rate.

Approved by the Fluid Mechanics Committee of the Engineering Division
TAPPI

Step 1

Calculate the velocity, V_{max}, at the upper limit of the linear region in the friction loss curve using equation (1) and the appropriate parameters from Table 1. If the design bulk velocity V is less than V_{max}, go to Step 2. If the design bulk velocity V is greater than V_{max}, go to Step 3.

Step 2

Calculate the value of flow resistance ΔH/L by substituting the appropriate values for stock parameters K, α, β, and γ from Table 2, design values for bulk velocity V, pipe diameter D, and oven dried stock consistency C into equation (2). Use this value of flow resistance for design and proceed no further.

Step 3

Determine the bulk velocity at the onset of drag reduction V_w where the pulp pressure loss curve intersects the water pressure loss curve from equation 3. If the design bulk velocity V is greater than V_w, go to Step 4. If the design velocity is less than V_w (but greater than V_{max}), go to Step 5.

Step 4

Calculate the friction loss for water flowing alone under the same conditions of bulk velocity, pipe diameter, and temperature using accepted correlations. For smooth pipes use equation (4). For rough pipes and pipe fittings, use accepted correlations for water (e.g., Ref. 6). Use this value of flow resistance for design and proceed no further.

Step 5

Calculate the flow resistance at the upper limit of the linear region in the friction loss curve $(\Delta H/L)_{max}$ by substituting the value for V_{max} (Step 1) and the appropriate value of oven-dried consistency C, pipe diameter D, and stock parameters K, α, β, and γ from Table 2 into equation (2). Use the value of friction loss $(\Delta H/L)_{max}$ calculated at V_{max} for all values of bulk velocity V between V_{max} and the point where this value intersects the water curve (near V_w).

The value of pipe friction loss ΔH/L calculated from Steps 1 to 5 forms the *basis* for design. If ΔH/L is calculated for the region before the maximum in the curve (Step 2), it will be an accurate estimate of the friction loss component. At velocities greater than V_{max} the friction loss estimate using Steps 3 to 5 will usually be a conservative approximation (see Fig. 1.) The design engineer can then apply the safety factor F appropriate to the system in question.

Equations and data

Equation (1)

To calculate the approximate value of the bulk velocity at the upper limit of the linear region in the friction loss curve

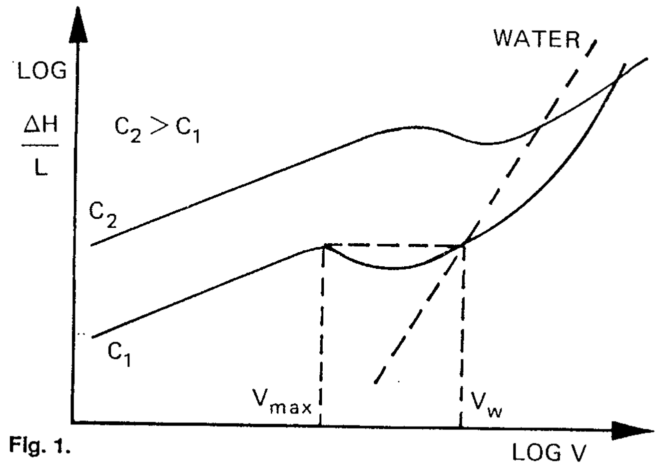

Fig. 1.

V_{max} use equation (1).

$$V_{max} = K'C^{\sigma} \quad (1)$$

where

V_{max} = bulk velocity at the maximum in the friction loss curve (m/s)

C = consistency (% oven-dried)

K′ = numerical coefficient, constant for a given pulp (see Table 1.)

σ = exponent, constant for a given pulp (see Table 1.)

Equation (2)

The correlation equation for the linear region in the friction loss curve is of the general form:

$$\Delta H/L = FKV^{\alpha}C^{\beta}D^{\gamma} \quad (2)$$

where

ΔH/L = friction loss (m water/100 m pipe)

V = bulk velocity (m/s)

C = pulp consistency (% oven-dried)

D = internal pipe diameter (mm)

K = numerical coefficient, constant for a given pulp (see Table 2)

α, β, γ = indices, constant for a given pulp (see Table 2)

F = factor to correct for temperature and pipe roughness; may also include safety factor. Explanation at the bottom of Table 2.

Equation (3)

To calculate the bulk velocity at the onset of drag reduction V_w in m/s use the following general correlation:

$$V_w = 1.22\,C^{1.40} \quad (3)$$

where

C = Pulp oven-dried consistency, %

Actual data for a range of different pulps may be obtained from Fig. 3 in Reference 7.

Equation (4)

The friction loss for water flowing in hydraulically smooth pipes $\Delta H_w/L$ can be calculated from the Blasius equation, which is presented here in rewritten form, for water at 35°C:

$$(\Delta H/L)_w = 264\ V^{1.75}\ D^{1.25} \quad (4)$$

where

$(\Delta H/L)_w$ = flow resistance in m water/100 m pipe
V = bulk velocity in m/s
D = pipe diameter in mm

Equation (4) is suitable for turbulent flow conditions when Reynolds numbers are less than 10^5. A more accurate estimate of the friction loss for water (including compensation for temperature and pipe roughness) may be obtained from the Nikuradse equation or the graphical procedure (friction factor, Reynolds number plot) in Reference 6.

Literature cited

1. TAPPI TIS 0410-12, "Pipe Friction Pressure Loss of Pulp Suspensions — Literature Review and Evaluation of Data and Design Methods," Technical Association of the Pulp and Paper Industry, Atlanta.
2. K. Moller, G.G. Duffy, and A.L. Titchener, *Appita*, 26(**4**): 278 (1973).
3. G.G. Duffy and A.L. Titchener, *Tappi*, 57(**5**): 162 (1974).
4. G.G. Duffy, K. Moller, P.F.W. Lee, and S.W.A. Milne, *Appita*, 27(**5**): 327 (1974).
5. G.G. Duffy, *Tappi*, 59(**8**): 124 (1976).
6. R.H. Perry and C.H. Chilton, Eds., "Chemical Engineers' Handbook," 5th ed., McGraw-Hill, New York. 1973.
7. G.G. Duffy and P.F.W. Lee, *Appita*, 31(**4**): 280 (1978).
8. K. Moller and B. Norman, *Sven. Papperstidn.*, 78(**16**): 582 (1975).
9. W. Brecht and H. Heller, *Tappi*, 33(**9**): 14A (1950).

Table 1. Data for calculation of the velocity limit V_{max} of equation (1)

Origin of data	*Pulp type*	*Pipe material*	*K'*	*σ*
1	Unbleached sulfite	Copper	0.3	1.2
	Bleached sulfite	Copper	0.3	1.2
	Kraft	Copper	0.3	1.2
	Bleached straw	Copper	0.3	1.2
	Unbleached straw	Copper	0.3	1.2
2	Unbeaten aspen, sulfite never dried	Stainless steel	0.26	1.6
	Long-fibered kraft, never dried CSF = 725	PVC	0.3	1.85
		Stainless steel	0.27	1.5
	Long-fibered kraft, never dried CSF = 650	PVC	0.26	1.9
	Long-fibered kraft, never dried CSF = 550	PVC	0.23	1.65
	Long-fibered kraft, never dried CSF = 260	PVC	0.23	1.80
	Bleached kraft pine, dried and reslurried	PVC	0.24	1.5
		Stainless steel	0.18	1.45
	Long-fibered kraft, dried and reslurried	PVC	0.15	1.8
	Kraft birch, dried and reslurried	PVC	0.21	1.3
	Stone groundwood, CSF = 114	PVC	1.22	1.40
	Refiner groundwood, CSF = 150	PVC	1.22	1.40
	Newsprint broke, CSF = 75	PVC	1.22	1.40
	Refiner groundwood (hardboard)	PVC	1.22	1.40
	Refiner groundwood (insulating board)	PVC	1.22	1.40
	Hardwood NSSC, CSF = 620	PVC	0.18	1.8

1. Original data obtained in copper pipes by Brecht and Heller (*9*).
2. Original data obtained in stainless steel and PVC pipes (*2, 3, 4*).

Table 2. Data for design correlation, equation (2)

Origin of Data	*Pulp type*	*K*	*α*	*β*	*γ*
Original data obtained in copper pipes by Brecht and Heller (*9*).	Unbleached sulfite	1438	0.36	1.89	–1.33
	Bleached sulfite	1291	0.36	1.89	–1.33
	Kraft	1291	0.36	1.89	–1.33
	Bleached straw	1291	0.36	1.89	–1.33
	Unbleached straw	646	0.36	1.89	–1.33
Original data obtained in stainless steel and PVC pipes (*2, 3, 4*).	Unbeaten aspen sulfite never dried	235	0.36	2.14	–1.04
	Long-fibered kraft never dried CSF = 725	1301	0.31	1.81	–1.34
	Long-fibered kraft never dried CSF = 650	1246	0.31	1.81	1.34
	Long-fibered kraft never dried CSF = 550	1334	0.31	1.81	–1.34
	Long-fibered kraft never dried CSF = 260	1874	0.31	1.81	–1.34
	Bleached kraft pine dried and reslurried	970	0.31	1.81	–1.34
	Long-fibered kraft dried and reslurried	1036	0.31	1.81	–1.34
	Kraft birch dried and reslurried	236	0.27	1.78	–1.08
	Stone groundwood CSF = 114	82	0127	2.37	–0.85
	Refiner groundwood CSF = 150	143	0.18	2.34	–1.09
	Newsprint broke CSF = 75	113	0.36	1.91	–0.82
	Refiner groundwood (hardboard)	196	0.23	2.21	–1.29
	Refiner groundwood (insulating board)	87	0.32	2.19	–1.16
	Hardwood NSSC CSF = 620	369	0.43	2.31	–1.20

NOTES

1. No safety factors are included in above data for design correlations.
2. The above values apply to a pulp temperature of 35°C. Increase or decrease the flow resistance by 1% for each Celsius degree below or above 35°C, respectively.
3. The friction loss depends considerably on the morphology of the inside pipe surface (*4*).