FRICTION LOSSES IN MASSECUITE PIPELINES

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Abstract

Friction losses were measured in massecuite pipelines. Although the results were scattered they show that the losses can be predicted using Fanning friction factors for laminar flow. The friction losses in bends seem to increase with decreasing Reynolds numbers.

Introduction

A degree of uncertainty seems to exist in the sugar industry as regards the estimation of friction losses in massecuite pipelines both in straight pipes and in bends.

The estimation of friction loss in straight pipes has been discussed previously by Brooks and Nicklin.[1] They suggested three methods of calculation, but favoured viscosity measurements using the pipeline viscometer.

Data for the friction loss for laminar flow in bends are meager. They are reported by different sources to be either constant or increase with decreasing Reynolds numbers.

This study was undertaken to find out if viscosity measurements using a rotating cylinder viscometer would, in conjunction with available equations, predict the losses in straight pipes with a reasonable degree of accuracy and to obtain an estimation of the magnitude of the losses through pipe bends.

Theory

The energy balance for isothermal incompressible flow through a pipe of uniform diameter can be written (see nomenclature for meaning of symbols).

$$\Delta H = \frac{gc}{pg}(P_1 - P_2) + (x_1 - x_2) \qquad (1)$$

The friction loss, ΔH, represents the head loss resulting from the flow of massecuite through the pipeline. It is correlated as the Fanning friction factor f versus the Reynolds number N_{Re}, where

$$f = \frac{\Delta Hg\,D}{2\,L\,V^2} \qquad (2)$$

and for non-Newtonian fluids

$$N_{Re} = \frac{D^n\,V^{2-n}\,P}{K}.8.\left[\frac{n}{6n+2}\right]^n \qquad (3)$$

Massecuites have a relatively high viscosity, and thus massecuite flow is generally laminar.

For laminar flow the relation between f and N_{Re} is

$$f = \frac{16}{N_{Re}} \qquad (4)$$

The friction loss of non-Newtonian pseudoplastic fluids flowing through 90° bends has been shown[2] to be very similar to that obtained with Newtonian fluids. The expression for this loss is

$$\Delta H = \frac{k\,V^2}{2g} \qquad (5)$$

The value of the factor k is given in reference (3) as a function of the relative radius r/D for smooth bends, and as a function of the deflection angle for mitered bends. The value of k based on this data is independent of the Reynolds number. A more recent method of calculation[4] gives k as a function of the Reynolds number and pipe diameter.

$$k = k_1/N_{re} + k_2\,(1 + 0{,}0254/D) \qquad (6)$$

At the low Reynolds numbers occurring for massecuite flows the effect of pipe diameter can be neglected. For mitred bends with two welds (45° angles) $k_1 = 800$.

Thus

$$k = 800/N_{re} \qquad (7)$$

Experimental Procedure

All the measurements reported in this study were done on pipes carrying B or C-massecuite at DL, EM and GH. The pressures were measured by means of Bourdon type gauges filled with light machine oil. The flowrates were obtained from the sectional areas and differences in level in the crystallizers and massecuite receivers at DL and EM and from the daily C-massecuite production at GH. The rheological properties of the massecuite were measured using a Brookfield HBT viscometer with spindle No. 7. The density was calculated from the brix of the massecuite.

Results and Discussion

The results of the pressure drop measurements are given in Table 1 and shown in Figure 1 as a plot of the Fanning friction factors versus the Reynolds numbers. Although the values obtained generally follow the line $16/N_{Re}$ the scatter is great and the correlation coefficient is only 0,59.

TABLE 1
Results of Friction Loss Measurements in Straight Pipes

Temp (°C)	K	n	D	V	N_{re}	f
51,5	99,8	0,871	0,31	0,071	0,334	181
42	223	0,857	0,31	0,023	0,0419	1 863
51	195	0,945	0,31	0,064	0,146	290
47,5	75,3	0,986	0,26	0,080	0,454	46,3
39	67,4	0,993	0,26	0,069	0,430	78,3
43,5	388	0,833	0,26	0,067	0,0808	147
66,5	479	0,948	0,31	0,060	0,0572	147
64	246	1,00	0,31	0,087	0,160	22,6
56	483	0,904	0,31	0,028	0,0250	613
62	419	0,913	0,31	0,041	0,0438	415
61,5	435	0,891	0,31	0,033	0,0326	755

It is believed that this scatter results from the following causes:

(*a*) Massecuite is pumped intermittently at DL and EM. Therefore steady conditions are not attained in the pipelines.

(*b*) The measurements on C-massecuite at EM were done on a vertical pipe, and any inclusion of air in the massecuite would have affected the density and caused an error in the estimation of the hydrostatic head.

(*c*) Massecuite volumetric flow rates were estimated from the change in the level in the C-massecuite receiver at EM. The sectional area being large, a small error in level measurement would have resulted in a large volumetric error.

The velocity head loss, k, which was measured in pipe bends is shown in Table 2 together with the values given by references (3) and (4). The friction loss across the pipe bend was obtained by first measuring the friction loss per unit length of straight pipe, and subtracting the loss equivalent to the length of the test section from the total friction loss. The loss in the bend was thus obtained by difference and reflects the errors in straight pipes measurements which, as we have seen, are appreciable. It seems, however, that the estimation of the friction loss in bends is more accurate when the values of reference (4) are used rather than those of reference (3).

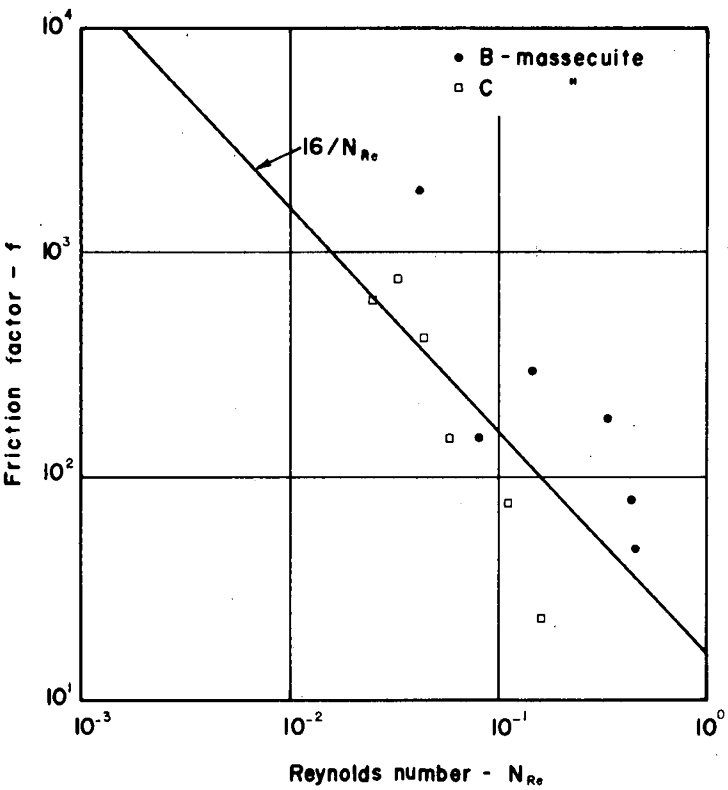

FIGURE I Fanning friction factors for laminar flow in pipes.

TABLE 2
Results of Friction Loss Measurements in Pipe Bends

Factory	Masse-cuite	N_{re}	Excess ΔP (kPa)	Factor K Measured	From Ref (4)	From Ref (3)
DL	B	0,0419	10	2 8000	19 000	1,9
	B	0,334	5,5	1 600	2 400	1,9
	B	0,146	23	8 400	5 500	1,9
EM	B	0,453	−2,8	−500	1 700	1,9
	C	0,572	−10	−3 900	14 000	1,9
	B	0,430	5,9	1 400	1 900	1,9
	C	0,159	0,5	92	5 000	1,9
	B	0,0808	13	3 200	9 900	1,9
GH	C	0,0250	−2,6	−4 600	32 000	1,9
	C	0,0438	−13	−11 000	18 000	1,9
	C	0,0326	36	63 000	25 000	1,9

Conclusions

This study shows that the friction loss of massecuite flowing in straight pipes can be estimated using the Hagan-Poiseuille equation

$$\Delta H = \frac{32\ L\ V^2}{g\ D\ N_{Re}} \qquad (8)$$

Here N_{Re} is the generalised Reynolds number calculated from equation (3), the rheological properties being obtained using a Brookfield viscometer with cylindrical spindles.

The friction loss in bends can be obtained from equation (5) with the value of k read from Equation (7).

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Nomenclature

D	=	diameter of pipe	m
f	=	Fanning friction factor	—
g	=	acceleration of gravity	$m.s^{-2}$
gc	=	gravitational conversion factor	9,807
ΔH	=	head loss	m
K	=	power law consistency index	$kg.m^{-1}.s^{n-2}$
k	=	velocity heads	—
L	=	length of pipe	m
n	=	power low flow behaviour index	—
N_{Re}	=	Reynolds number	—
P	=	pressure	kPa
r	=	radius of curvature	m
V	=	velocity	$m.s^{-1}$
x	=	elevation	m
p	=	density	$kg.m^{-3}$

Subscripts

1 level 1
2 level 2

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