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References

- (1) K. Fujie: Bulletin of JSME, Vol. 1, No. 1 (1958), p. 42.
- (2) H. Tahara: Trans. Japan Soc. Mech. Engrs., Vol. 18, No. 66 (1952), p. 122.

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A Study of Flow Properties of Paper Stock Suspension*

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The authors measured the pipe friction losses up to consistency of about 6 %, using groundwood pulp suspensions which have comparatively stable properties for flow, with brass pipes 23.3, 36.6, and 48.8 mm in diameter and galvanized gas pipes 1", 1½", and 2".

As the results, the pipe friction coefficients λ vs. a new dimensionless number : $N = 8 \frac{\rho v^2}{\tau_w}$ (N is flow number, ρ : density, v : mean velocity in pipe and τ_w : shearing stress on pipe wall) which corresponds to Reynolds number in the case of water, coinciding well on the line of $\lambda = 64/N$.

Moreover, the authors gave the calculation formulas of pipe friction losses which are more accurate than previous ones.

1. Introduction

In spite of a necessity of finding flow properties of paper stock suspension in pulp manufacture, reports of the experimental results on this item are very few⁽¹⁾, especially on high consistency one. The authors measured the pipe friction losses up to consistency of about 6 %, changing pipe diameter, roughness of pipe wall, pulp consistency and velocity. Moreover, authors gave a calculation method of pipe friction losses of groundwood pulp suspensions***** which is easier and more accurate than previous ones.

2. Experimental apparatus, method and results

Pipe friction losses were measured using pulp suspensions of 0~5.8 % consistency (by weight percentage) under a constant temperature, with three brass pipes and three gas pipes as shown in Table 1. The experimental apparatus is as shown

Table 1. Dimensions of pipes for measurement

Kinds of pipe	Diameters Dmm ϕ	L_1 cm	L_1/D	L_2 cm	L_3 cm
Brass pipe	23.3	35	15	150	20
	36.6	73	20	"	"
	48.8	92.5	19	"	"
Gas pipe	(1") 27.6	89.5	32.5	150	48
	(1½") 41.6	100	24	"	"
	(2") 52.9	100	19	"	"

in Fig. 1. The measurement was carried out after the freeness became constant*****. A little vessel which was divided into 2 parts by a diaphragm, shown in Fig. 2, was set between a pipe and manometer, and the opposite part of the diaphragm from the pipe was filled with water and connected to manometer, and the pressure of pulp suspensions was led to the manometer.

Fig. 3 and 4 show the relations between the

***** According to the literature (2), by continuous operation for several hours, freeness and pipe friction losses become constant.

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***** This pulp consists of pine timber. By the view of microscope, length of simple fibre is about 0.7 mm and the thickness about 30 μ .

Fig. 1 The experimental apparatus

Fig. 2 Details of pressure hole

Fig. 3 $v \text{ m/s} \sim \Delta H \text{ mAq/1m}$ Fig. 4 $v \text{ m/s} \sim \Delta H \text{ mAq/1m}$

pipe friction losses ΔH m per 1 m of pipe length and the mean velocity v m/s of pulp suspension in pipe as parameter of pulp consistency.

The flow state of pulp suspensions is seen as being divided into following three: first, in the case the consistency is 1 to 2 % and velocity is small, the pipe friction loss ΔH is constant, regardless the fluids velocity, and is larger than that of water, but when the velocity exceeds a certain value, ΔH becomes smaller than that of water, and suspensions which flow from pipe end is seen as a Newtonian liquid. Secondly, in the case the consistency is 2.5 to 4.2 %, ΔH is almost constant, and the suspensions seem to be plastic fluid. Thirdly, in the case of above 5.8 % consistency, ΔH increases with velocity, the suspensions indicating brittle solid.

Fig. 5 and 6 show the relations between shearing stresses

$$\tau_w = \Delta p \cdot R / 2L \quad (\text{kg/cm}^2) \quad \dots\dots (1)$$

at pipe wall and the velocity v m/s, where Δp is the pressure drop due to the pipe friction for L cm kg/cm^2 and R the pipe radius. Nearly same oblique lines are drawn, except high consistency (5.8 %), having connection with the roughness of wall and the consistency, regardless the pipe diameter. These straight lines are generally expressed by a formula,

$$\tau_w = A \cdot v^\alpha \quad \dots\dots (2)$$

When the consistency is under 4.2 % index number α is decided chiefly with the roughness of wall, but in the case of consistency more than 4.2 %, α is surmisable to be effected by both consistency and roughness of wall. Constant A is a function of roughness of wall and pulp consistency*, as shown in Fig. 7.

* Minutely it would be effected moreover by freeness and fibre length, etc.

Fig. 5 v m/s $\sim \tau_w$ kg/cm² Fig. 6 v m/s $\sim \tau_w$ kg/cm² Fig. 7 c % $\sim A$

From Figs. 5 and 6, τ_w for brass pipes are formulated as follows :

($c=2.1 \sim 4.2$ %)

$$\tau_w = 0.46 \times c^{2.8} \times v^{0.2} \times 10^{-5} \text{ kg/cm}^2 \quad \dots (3)$$

$$A = 0.46 \times c^{2.8}, \quad \alpha = 0.2$$

($c=5.8$ %)

Fig. 8 $N \sim \lambda$

$$\tau_w = 0.46 \times c^{2.8} \times v^{0.3} \times 10^{-5} \text{ kg/cm}^2 \quad \dots (4)$$

$$A = 0.46 \times c^{2.8}, \quad \alpha = 0.3$$

And for gas pipes,

($c=1.75 \sim 3.7$ %)

$$\tau_w = 0.365 \times c^{3.5} \times v^{0.12} \times 10^{-5} \text{ kg/cm}^2 \quad \dots (5)$$

$$A = 0.365 \times c^{3.5}, \quad \alpha = 0.12$$

Fig. 9 $N \sim \lambda$

in which c is pulp consistency.

3. Method to arrange experimental values

In the case of Newtonian fluid, pipe friction coefficient λ is $64/R_e$ ($R_e = vd/\nu$) in the laminar flow, but in the case of pulp suspensions, the value of kinematic coefficient ν is unknown. And so, in the authors' experiments a new dimensionless number which corresponded to Reynolds Number was used calling "flow number N ", which is denoted as follows:

$$N = \text{const.} \times \frac{\text{force of inertia per unit volume}}{\text{shearing stress on the wall}} = k \times \rho v^2 / \tau_w \quad (6)$$

where ρ is density of pulp suspension $\text{kg}\cdot\text{s}^2/\text{m}^4$, v mean velocity in pipe m/s and τ_w shearing stress on the wall kg/m^2 .

The pipe friction coefficient λ and τ_w [from Eq. (1)] are

$$\lambda = \frac{\Delta H \cdot D}{L} \cdot \frac{2g}{v^2} \quad (7)$$

$$\tau_w = \Delta p \cdot R / 2L = (\Delta H \cdot D \cdot \gamma) / 4L \quad (8)$$

where L is pipe length in m , D diameter in m , g gravity acceleration in m/s^2 and γ weight of fluids per unit volume kg/m^3 .

Eliminating τ_w from the Formulas (6), (7), and (8) and putting $\lambda = 64/R_e$, the relation between

λ and N was gained as follows:

$$\lambda = 64/N \quad \text{and} \quad k = 8 \quad (9)$$

And from Eq. (2)

$$N = 8 \cdot \frac{\rho v^2}{\tau_w} = (8 \times \rho v^2) / (A \cdot v^\alpha) \quad (10)$$

Figs. 8 and 9 show the relation between N and λ which were obtained by the authors' experiment. And they coincide well on the line of $\lambda = 64/N$, except the range of turbulent flow. According to a literature⁽³⁾, the values of pipe friction losses of pulp suspensions change with treatment, etc., but their tendencies resemble. Therefore, it is necessary, in practical use, to know the values of A and α in every material of pulp and pipe, and it is a problem yet to be studied in the future.

4. Calculation methods of pipe friction losses

With the experimental values of A and α of Eqs. (2), (3), (4), and (5), and using Eq. (11) reduced from Eq. (1), or using Eqs. (10) and (12) which is used customarily as an equation of pipe friction losses, the pipe friction losses Δp are calculated as follows:

$$\Delta p = 2L \cdot \tau_w / R = 4(L/D) \tau_w \quad (11)$$

$$\Delta p = \lambda \cdot \frac{L}{D} \cdot \gamma \frac{v^2}{2g} = \frac{64}{N} \cdot \frac{L}{D} \cdot \gamma \frac{v^2}{2g} \quad (12)$$

where D is pipe diameter. Thus by giving pipe length L , diameter D , consistency c and velocity v , the pipe friction losses Δp can be easily calculated.

5. Conclusion

Through the flow tests of pulp suspensions of consistency below 5.8%, the value of friction coefficient λ can be expressed as a function of a new dimensionless number N , in the same manner as in case of Newtonian fluid, and pipe friction loss Δp of groundwood pulp suspensions becomes calculable more easily and accurately than previous ones.

References

- (1) Robert J. Richardson: Depart. Chem. Eng. M.I.T.
- (2) Richard E. Durst and L.C. Jenness: TAPPI, Vol. 38, No. 4 (1955), p. 193.
- (3) Richard E. Durst: Pulp & Paper Mag. of Canada, No. 3 (1956).