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BRIEF COMMUNICATION

PRESSURE DROP IN A LONG RADIUS 90° HORIZONTAL BEND FOR THE FLOW OF MULTISIZED HETEROGENEOUS SLURRIES

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INTRODUCTION

The flow characteristics in a bend for a single-phase fluid are reasonably well understood and critically reviewed by Ito (1987). Investigators have established the effect of secondary flows on bend flow characteristics through measurement of velocity field, Reynold's stresses and bend loss coefficient at various radius ratios (Hwang & Hita 1987). Studies in bends for a two-phase fluid are relatively few in number. Ayukawa (1968) derived a theoretical relationship for calculating the pressure drop across a bend in a vertical plane in slurry using energy considerations. However, the validity of this relationship is questionable due to the paucity of the experimental data. Toda *et al.* (1972) investigated the flow through horizontal and vertical pipe bends using suspensions of equisized glass and polystyrene bends. Their observation was that the flow behavior is complicated due to the presence of secondary flows and that the pressure drop in a horizontal or vertical bend increased with increasing concentration. Kalayanaraman *et al.* (1973) also investigated through a 90° horizontal bend for larger particles at different radii of curvature and established an optimum radius of curvature for minimum pressure loss.

Das *et al.* (1988) obtained data for pressure drop for different types of horizontal bends for non-Newtonian slurries at low concentrations to predict pressure loss. Nasr-El-Din & Shook (1987) suggested that pressure drop and wear are adversely affected by flow disturbances such as those generated in bends. Mukhtar *et al.* (1993), in their study with multisized particulate slurries, have shown that there is a redistribution of particles belonging to different size fractions, with larger particles being more affected. This phenomenon is more prominent at higher velocities.

The pressure loss in a bend is a strong function of the concentration of solid particles, the pipe diameter, the mean flow velocity, radius of curvature of bend, bend angle, specific gravity and PSD of the solid as well as the geometrical configuration of the bend. The data on the pressure drop in bends for a two-phase flow, particularly for multisized particulate slurries, is very limited. Hence in the present work, effort has been made to generate data on bend pressure drop on two materials, namely slurries of iron ore and zinc tailings. These two materials have been chosen because they differed widely in specific gravity as well as particle size distribution.

EXPERIMENTAL SET-UP AND INSTRUMENTATION

Experiments were conducted in the pilot plant loop existing in the Fluid Mechanics Laboratory of Indian Institute of Technology, Delhi. It consists of a mixing tank, a measuring tank and a closed circuit pipe test loop of 100 mm NB having a 60 m length incorporating the bend under test. The operation of the loop has been described in detail by Mukhtar *et al.* (1993). The flow rate of the slurry in the pipe loop was varied over a wide range by suitable adjustment of a plug valve and/or by the operation of the valve in the bypass line. On the return circuit, a magnetic flow meter for continuous monitoring of the flow rate was incorporated in the vertical section of the pipeline and a sampling point was also provided in the pipe line to collect efflux samples in order to monitor the solid concentration during experimentation. The pipe loop also has facilities for the measurement of various parameters like the pressure drop in a straight pipe section, a sampling tube for the concentration profile across the diametrical plane of pipe cross section and deposition velocity through the transparent observation chamber.

A commercially available 90° mild steel bend with 100 mm NB having a radius of curvature of 21 cm and a radius ratio of 4 was incorporated in the pilot plant test loop to carry out the studies of pressure drop across the bend (figure 1). One pressure tap with a separation chamber was provided one diameter upstream of the bend on the inner side and two pressure taps with separation chambers, one on the inner side and the other on the outside were provided two diameters downstream of the bend for measuring the pressure drop across the bend. The difference in pressure indicated by the upstream tap and the average pressure of the two downstream taps is designated as the pressure drop across the bend. The straight length of the pipe available on the upstream of the pipe bend was approximately 15 m (150 pipe diameters) which ensured fully developed conditions at the inlet to the bend.

RANGE OF PARAMETERS INVESTIGATED

In the present study, two materials, namely iron ore slimes and zinc tailings have been used as solid materials. The specific gravity of the iron ore slimes was 4.2 whereas for the zinc tailings it was 2.60. In the iron ore slimes approximately 96% of the particles were finer than 75 microns whereas the corresponding figure for the zinc tailings was 50%. Thus the zinc tailings had a much coarser and wider size distribution of particles. The physical properties and particle size distribution of the two materials are tabulated in tables 1and 2 respectively. The rheological characteristics of the slurries were measured in a Weissenberg rheogoniometer using concentric cylinder platens (6). Measurement of pressure drop on both slurries has been done at four efflux concentrations (by weight) and at different velocities. The range of velocities covered is such that the flow conditions are in an unsymmetric suspension regime.

RESULTS AND DISCUSSION

In order to quantify the effect of pipe bend, the relative pressure (R_{pb}) is calculated as follows:

$$R_{pb} = \frac{\Delta P_b}{\Delta P_{st}}$$

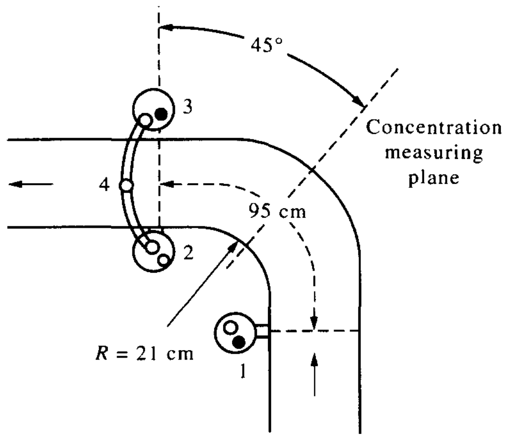

Figure 1. 90° bend in a horizontal plane with a pressure measuring arrangement across the bend.

Table 1. Properties of iron ore slimes

(i) Overall specific gravity of the solids = 4.20

(ii) Particle size distribution in the fresh sample (wet sieving over B.S. 200 mesh + hydrometer analysis)

Particle diameter (microns)	% Finer (by wt)
1180	100.0
600	99.0
300	98.2
150	97.2
106	96.4
75	95.8
45	57.0
28	45.8
16	33.3
8	18.2
4	9.4

(iii) Rheological data of iron ore slimes

Sample No.	Concentration by weight (%)	Temperature (°C)	Yield stress (dynes/cm^2)	Slurry viscosity (cP)	Remarks
1	10	33.5	0	0.884	Newtonian
2	20	33.5	0	1.065	Newtonian
3	30	33.5	0	1.700	Newtonian
4	40	32.5	1.65	3.460	Bingham

where

ΔP_b = pressure drop in the bend
ΔP_{st} = pressure drop in the straight pipeline of equal length.

Both ΔP_b and ΔP_{st} are measured at the same velocity for the same slurry. The ratio R_{pb} represents the increase in the pressure drop due to the bend. Figure 2 shows the variation of R_{pb} with flow

Table 2. Properties of zinc tailings

(i) Overall specific gravity of the solids = 2.6

(ii) Particle size distribution in fresh sample (wet sieving over B.S. 200 mesh + hydrometer analysis)

Particle diameter (microns)	% Finer (by wt)
1180	100.0
297	91.7
150	76.0
106	61.1
75	50.1
53	40.5
48	37.6
38	35.3
21	26.8
12	5.0
8	4.1
6	3.7

(iii) Rheological data of zinc tailings

Sample No.	Concentration by weight (%)	Temperature (°C)	Yield stress (dynes/cm^2)	Slurry viscosity (cP)	Remarks
1	30	28.0	0	1.262	Newtonian
2	35	28.0	0	1.363	Newtonian
3	40	27.5	0	1.540	Newtonian
4	45	28.0	0.28	2.224	Bingham

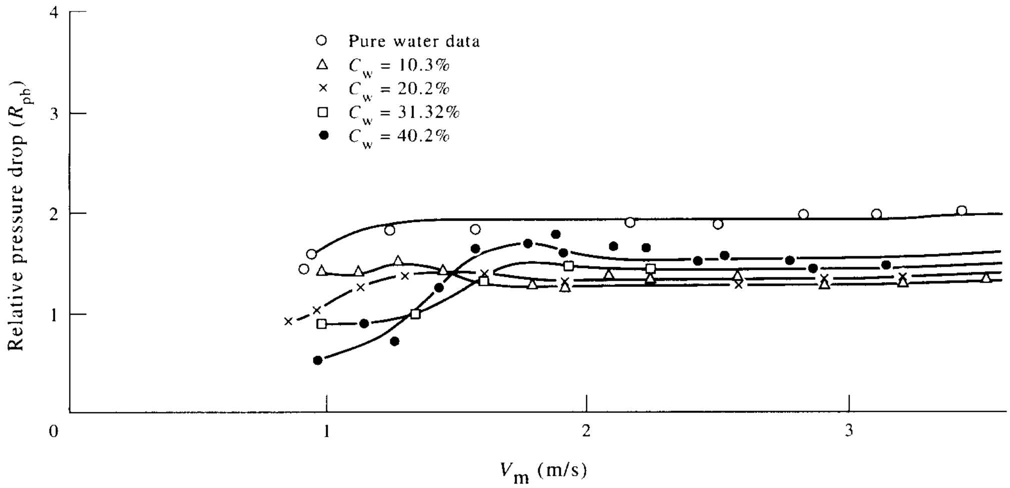

Figure 2. Variation of relative pressure drop in a bend at different concentrations with flow velocity for the iron ore slimes slurry.

velocity for the iron ore slimes slurry at various concentrations. It is seen that in the case of water, the value of R_{pb} is almost constant ($=1.8$) except at the lowest velocity tested. The figure also shows that for the slurries at all concentrations, the values of R_{pb} are lower than those for water. This can be attributed to the fact that the secondary flows inside the bend tend to be inhibited by the presence of solid particles which also causes redistribution of the solid particles making the suspension more homogeneous compared to the conditions in the straight pipe. Further, at any given slurry concentration, R_{pb} appears to reach a constant value for velocities larger than approximately 1.75 m/s. In this velocity range, the relative pressure drop appears to be a very weak function of solid concentration showing a slight increase with increase in concentration. This may be attributed to the fact that as the solids concentration is increased, the redistribution of solids due to secondary flows is inhibited due to strong interaction effects. Thus the solids will not become more homogeneously distributed in the bend. However, this effect does not seem very pronounced. As the velocity of the slurry reduces, the relative pressure drop also reduces and falls below the value of unity. The deposition velocity for this slurry in a straight pipe at different concentrations was in the range of 1.0–1.2 m/s. As the flow velocity approaches the deposition velocity, the particles in the straight pipe tend to settle to the bottom of the pipe and drag along the lower pipe surface. This asymmetry in the concentration profile tends to increase the pressure drop in a straight pipe considerably. However, in the bend, due to secondary flows, this deposition is delayed and the flow is still in a fully suspended state. This explains the reduction of R_{pb} as the deposition velocity is approached.

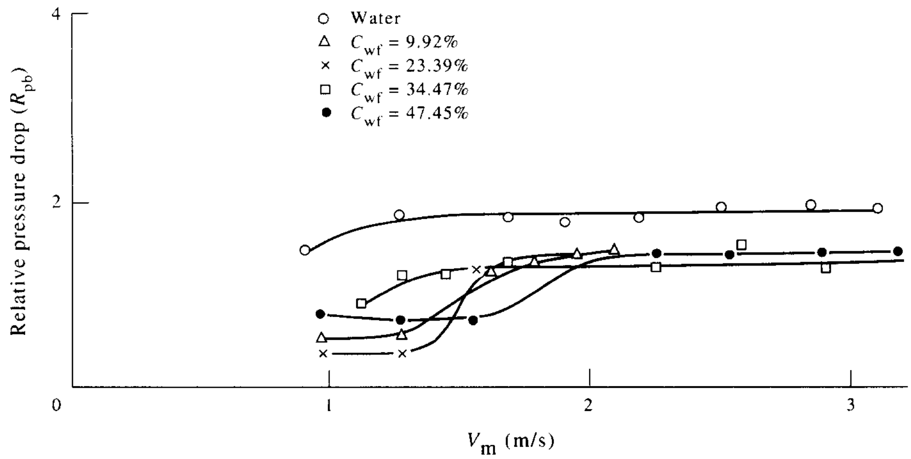

Figure 3. Variation of relative pressure drop in a bend at different concentrations with flow velocity for the zinc tailing slurry.

Table 3. Values of bend loss coefficient (K_b) for slurry flows (mixture velocities exceed the deposition velocity by at least 0.5 m/s)

Sample No.	Concentration of solids (by wt)	Values of K_b	
		Iron ore slurry	Zinc tailing slurry
1	0	0.46	0.46
2	10	0.30	0.35
3	20	0.32	0.35
4	30	0.32	0.35
5	40	0.32	0.35

Figure 3 shows the variation of R_{pb} with flow velocities for the tailings slurry at various concentrations. It is seen from the figure that for the slurry at all concentrations the values of R_{pb} are lower than those for water just as they were for the iron ore slimes slurries. The ratio of R_{pb} appears to reach a constant value for velocities larger than approximately 1.8 m/s. In this velocity range the relative pressure drop does not appear to be very dependent on the concentration of the slurry up to 35% concentration and has a value of approximately 1.4. However, at the highest concentration ($C_W = 47.45\%$), the value of R_{pb} is somewhat lower. The zinc tailings material has a lower specific gravity compared to iron ore slimes and possesses a much wider particle size distribution. This results in relatively more homogeneous distribution of particles in the bend. As the flow velocity reduces, the relative pressure drop decreases as in the case of the iron ore slimes slurries. The deposition velocities in the straight pipe for the zinc tailing slurries are in the range of 1.2–1.4 m/s. It is seen from the figure that as the flow velocity approaches the deposition velocity in a straight pipe, a significant reduction in the value of R_{pb} takes place due to reasons already explained.

The loss coefficient (K_b) for slurry flows can be defined as:

$$\frac{\Delta P_b}{\rho_m g} = H_b = K_b \frac{V_m^2}{2g}$$

where

ΔP_b = pressure drop in bend (N/m^2)
ρ_m = density of slurry (kg/m^3)
H_b = pressure drop in bend in meters of column of slurry
V_m = the mean flow velocity of slurry (m/s).

The values of K_b in water flow for various types of bends are tabulated in standard literature (Perry 1984). Values of K_b have been calculated for various velocities in the range where R_{pb} remains almost constant. The values of K_b for slurry were not very sensitive to slurry concentration and the effect of velocity was also not significant if the flow velocity is about 0.5 m/s above the deposition velocity in the pipe. It is seen from the values in table 3 that the values of K_b for both slurries are relatively unaffected by the solids concentration. For this bend, the value of K_b for water was 0.46, however, for a two-phase fluid it was approximately in the range of 0.32–0.35.

CONCLUDING REMARKS

The bend loss coefficient for a long radius 90° bend in the flow of a multisized particulate slurry is less than that for water. It is relatively independent of solids concentration and specific gravity. As long as the mixture velocities exceed the deposition velocity by at least 0.5 m/s, the value of bend coefficient can be assumed to be independent of flow velocities. As the deposition velocity is approached, the additional loss in the bend decreases. This can be attributed to the redistribution of solid particles in the bend due to secondary flows.

REFERENCES

AYUKAWA, K. 1968 Pressure drop in hydraulic conveyance of solid materials through a bend in vertical plane *Bull. JSME* **12,** 1388–1396.

DAS, S. K., BISWAS, M. N. & MITRA, A. K. 1988 Flow of non-Newtonian fluids through bends In *Proc. Int. Symposium on Hydraulic Transportation of Coal and other Materials*, Bhubneshwar, pp. 199–204.

HWANG, N. H. C. & HITA, C. E. 1987 *Fundamentals of Hydraulic Engineering Systems*, 2nd Edn. Prentice–Hall, New York.

ITO, H. 1987 Flow in curved pipes *JSME Int. J.* **30,** 543–552.

KALYANARAMAN, K., GHOSH, D. P. & RAO, A. J. 1993 Characteristics of sand–water slurry in 90° horizontal pipe bends *Inst. Eng. (I)-ME* **54,** 73–79.

NASR-EL-DIN, H. & SHOOK, C. A. 1987 Effect of a 90° bend on slurry velocity and concentration distributions *J. Pipelines* **6,** 239–252.

PERRY, J. H. (Ed.) 1984 *Chemical Engineers Hand Book*. McGraw–Hill, New York.

SINGH, S. N. SESHADRI, V. 1993 Distribution of solid particles in the flow of multisized particulate slurries through a 90° pipe bend located in the horizontal pipe *Bulk Solids Handling* **13,** 379–386.

TODA, M., KOMORI, N., SAITO, S. & MAEDA, S. Hydraulic conveying of solids through bends. *J. Chem. Engng Jap.* **5,** 4–13.