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Prediction of pressure drop for flow of fine coal slurry

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Abstract: The flow behaviour of some high ash Indian coal-water slurry for long-distance transportation has been investigated. The non-Newtonian Bingham behaviour predicted from Rheological data obtained with -Haake Rotational RV 100 viscometer and pressure drop obtained from 50 mm diameter test loop have been taken into consideration to predict pressure drop .for flow of fine coal slurries .The Run- of- mine coal from Talcher,Odisha has been crushed,ground to make it Black Mesa type distribution..A non- dimensional parameter based on increase of volumetric concentration of solids in slurry has been incorporated in Durand-type correlation for predicting pressure drop. This modified Durand type correlation also incorporates SRC (Saskatechewan Research Council), data, for flow of low ash coal slurries showing good fit .

Keywords: Pressure drop, hydraulic transport, fine coal slurry, rheology.

1. INTRODUCTION

Considerable amount of studies have been reported on the prediction and estimation of pressure drop for homogeneous and heterogeneous flow of fine coal slurries. Durand [1953] through his extensive experimentation and analysis reported the following equation for calculating the pressure drop for close size range particles,

$\phi = K\,(\Psi)^{m}$ ------------------------------- (1)

Where $\phi = (i^{*} - i_w)/C_v i_w$ ----------------------------- (2)

$\Psi = v^2 \sqrt{C_D} / [gD\,(\rho_s - 1)]$ --------------------------- (3)

Where,

i^{*} = measured head loss of slurry [m]

i_w=head loss due to water [m]

C_D=Drag coefficient of particles [-]

D=Diameter of pipe [m]

ρ_s=specific gravity of solid [-]

g=acceleration due to gravity [m/s^2]

K, m are constants values of constants K and m have been reported to be 82 and 1.5 respectively by Durand while others have reported different values.

Zandi[1971],Turian and Yuan[1977],Wasp et al [1977], Hank[1981] have given equations,which are modifications of Durand equation for calculation of pressure drop for transporting slurries of sand,gravel and coal in horizontal pipes.

In actual practice,however,a slurry will consist of a wide range of particles.The fines in the mixture may give the characteristics of a homogeneous slurry while the coarser particles will try to segregate giving rise to heterogeneous flow regime.Wasp et al[1977]presented a method for calculating pressure drop for such hetero-homogeneous slurries using Durand equation.The pressure drop due to asymmetric suspension in heterogeneous regime is calculated by treating each size fraction as a separate entity & the pressure gradient due to rheological active part in the homogeneous regime separately.Finally ,the total pressure drop is obtained by adding the homogeneous & heterogeneous part which is rather cumbersome.

Wilson [1973,] presented a mechanistic model for the analysis of sliding bed flow.He has extended the analysis to mixed regime flow and presented nomographic charts.Roco and shook [1985] proposed a method which require several empirical coefficients and is rather complex.

Recently,Aziz & Mohammed[2013]deduced a non-dimensional approach for slurry flow in pipelines which is lengthy & cumbersome.Tanaji Mali[2014]suggested modified Wasp method for suspension flow which is rather complex.

In industrial practice,,however, method of Durand as modified by Wasp et.al[1977] is generally used. Since many authors have pointed out limitations in Durand type analysis., a different approach incorporating another dimensionless group in equation 1 has been proposed to predict pressure drop accurately for bingham slurries by modifying Durand equation.

2. MATERIALS AND METHODS

2.1Coal types and coal slurry preparation

Two types of coal, A and B obtained from Talcher, Odisha(India) have been selected for experiments. Their proximate analysis is shown in Table 1.The ash of these coals is more than 30 percent and their specific gravities are 1.64 and 1.78 respectively. A review of the literature suggests that for transportation of fine coal slurries, the size distribution of the particles should be below 1 mm and it should have particles of -325BS mesh to the extent of 20 percent by weight.(Wasp et.al. 1977).. The size range that have been used in the present study is close to particle size distribution of Black Mesa slurry pipeline,USA.This distribution has been achieved by crushing the coals of 20 mm size first in a jaw and then in a roll crusher and finally grinding it in a rod mill for 30 minutes..It may be noted that for both the coals the fraction below 325BS mesh is 19.7 & 20.3% respctively for A & B slurry[Table 2].Data for CN coal slurry has

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been taken from the report of SRC(Saskatechewan Research Council,Canada) for low ash coal.[Schriek et al.,1972]

2.2Slurry preparation

The fluid medium used in the preparation of slurry is water. The slurry for viscosity measurements was prepared by adding calculated amount of dried solid samples in 250 ml. beaker with required amount of water.The pH of the mixture was adjusted between 6 and 7 by adding small amount of lime. Since +52 mesh size particles cannot be used in the viscometer , they were scalped out and were replaced by solids of -52+72 mesh particles so that it does not significantly alter the rheology of the suspension..This scalping procedure is given by Ghalot et al [1982)] The volume percent of the solids used in the experiments were in the range of 8 to 40 percent.

2.3Rheological measurements:

Rheological measurements have been made by Haake RV 100 rotational viscometer .The MVII sensor system is used for measurement of viscosity which has a gap width of 0.9 mm and the volume of sample required is 40 ml. The temperature in the slurry is maintained at 30 ± 0.1^0c by circulating water from the constant temperature bath.

2.4Pipe loop experiments:

Experiments have been carried out in a 50 mm diameter pipeline loop described by one of the authors[Panda et al 1994].It is provided with a centrifugal rubber lined slurry pump having a throughput of 30 m^3/hr with a maximum discharge pressure of $4.5*10^3$ N/m^3 drive by a 30kw DC motor The motor is thyrister controlled with fully continuous speed variation.Control of pipeline velocity is obtained by use of variable speed drive on the pump 'The volumetric flow rate is measured with the help of magnetic flow meter which is mounted vertically. For measuring slurry pressure drop, a differential pressure measuring system provides accurate results under steady state flow. Pressure tappings are located at 10 m.length & connected to the settling traps to prevent air and slurry entering the main pipeline. Mercury manometers are connected in parallel to the pressure tappings through control valves.

The slurry was made by adding the required amount of solids in the slurry tank previously filled with water.1.5 percent solution of lime was also added to maintain pH between 6 to 7.Pressure drop was measured by mercury manometers and flow rate by magnetic flow meter .Experiments were conducted with 28.1, 33.3 and 37.9 percent by volume of solids of coal A and 33.3 and 45.2 percent by volume of coal B. The pressure drop-velocity data have been obtained for water and coal- water slurry at different volumetric concentrations . For CN slurries, data from SRC has been taken .The Drag coefficient C_D has been calculated utilizing individual particle drag-coefficient and taking the weighted mean for the distribution.The particle drag above 100 mesh is determined from terminal velocities of close size range particle in one meter water column and taking average of 50 readings, while $C_{D\ for}$ -100 mesh particles have been determined by Stoke's law.Durand parameters ϕ and Ψ from equation (2 &3) have been calculated .The pressure drop,i, is then calculated from equation 1. The head loss due to water only,$i_{w,}$and head loss for slurry, i_* was noted from experiment at a particular concentration.

3. RESULTS & DISCUSSIONS

The rheogram of coal A - water slurry is shown in fig 1.

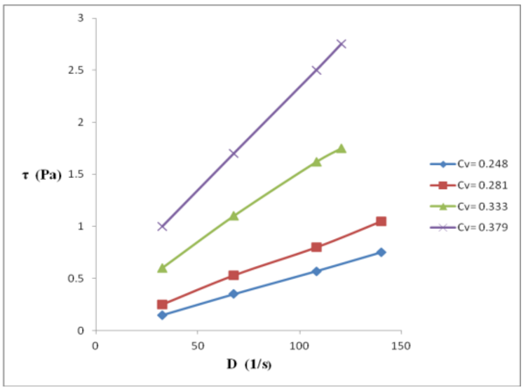

Fig. 1 - Rheogram for coal A-water slurry

The figure shows Newtonian behaviour at low concentrations which changes to non-Newtonian Bingham behaviour at higher concentrations. Coal B and CN slurries also show similar behaviour.The bingham or plastic viscosity value obtained from the above data (plastic viscosity=shear stress-yield stress/shear rate) when plotted against volume concentration,Cv ,gives a relation shown in figure 2.

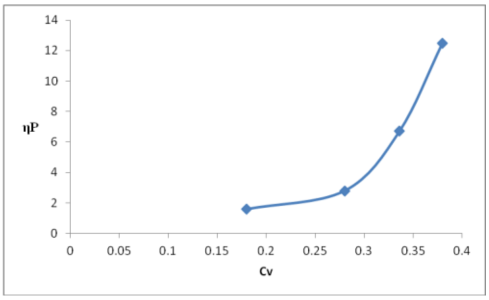

Fig. 2 - Plastic viscosity, η_p vs concentration for coal A-water slurry

For coal A -water slurry,.it may be seen that the change in viscosity with Cv is linear up to some concentration(AB in figure2) and then the rate of deviation increases with increase in volume concentration of solids in slurry.The point from which deviation from linearity starts approximately suggest the starting of non-Newtonian behaviour and it increases with increase in slurry concentration.Similar findings have also been found for coal B and CN coal- water slurries(Schrick et al ,1972).The deviation from linearity may be attributed to particle-particle interaction and can be quantitatively predicted by plotting logη* against Cv*ρ_s in a semilog plot as shown in figure 3.

$$\eta *= \eta_p/ \eta_0 \text{ and } C_v *=C_v/(C_v-C_{v0})$$

η_p= plastic viscosity at any C_v and
η_0= viscosity at C_{v0} [mPaS]

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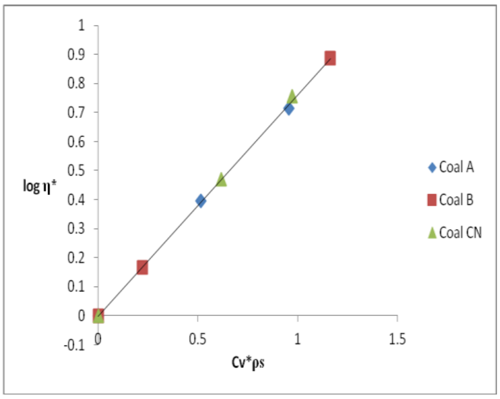

Fig. 3 – plot between Cv* ρ_s vrs log η_*

The relation obtained is represented by:

logη*=1.37 Cv* ρ_s ------------------ (4)

3.1Prediction of pressure drop in the non-linear zone.

It has already been stated that viscosity of slurry against Cv plot of both high ash and low ash fine coal slurries give a linear relation till the point it behaves as Newtonian fluid and then it deviates from linearity.In this case since our interest is in the non-Newtonian zone i.e. in the nonlinear portion,,an useful correlation has been developed between log η* and Cv* ρ_s as shown in equation .4...The experimental data in this zone when compared directly with the values of pressure drop,i calculated from the equation (1), shows deviation which ranges from a low value to high value.In other words, if i* is the pressure drop actually obtained through experiments at a particular Cv and if i is the value of pressure drop calculated from equation(1), then the ratio i*/i ranges from 1.1 and 1.6 for the coals A,B and CN. However, if i*/i is plotted against log η* in a plot as shown in figure 4,

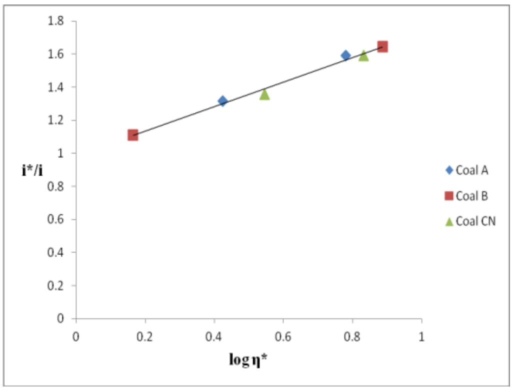

Fig.4 - Correlation Plot

it gives a linear relation which has been used gainfully in developing correlation in the nonlinear zone. The straight line relationship is represented by,

i*/i=1+0.73logη* ....(5)

Substituting for logη* from equation 4, one gets

i*/i=1+Cv* ρs --(6)

Comparing equation 1 & 5, a general equation of the form below can be shown to be valid which is modification of Durand type equation.

ϕ=f(C_vK(Ψ)^m,[Cv/(Cv-Cvo)/ρs] ....(7)

	Coal –A	Coal -B
Moisture%	**2.9**	**6.5**
Ash%	34	42.5
Volatile Matter%	24.1	25.5
Fixed carbon%	39	26.5

Table -1 Proximate analysis of coal

Sieve Size BS Mesh	Coal A	Coal B	Black Mesa
-14+16	4	----	1.2
-16+25	2	8	10.7
-25+52	23	21	27.3
-52+72	21	23	20.63
-72+200	12	17	16.5
-200+325	18.5	8	6.2
-325	19.5	23	17.5

Table-2 Particle size distribution of coals

4. CONCLUSION

a) Both high ash and low ash coal slurries shows non Newtonian Bingham behaviour .
b) Pressure drop can be accurately predicted by introducing a non dimensional parameter in Durand equation as shown in equation

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