The Use of Computers for Heterogeneous Slurry Pumping Analysis

J. R. G. Williamson, South Africa

1. Introduction

The pipeline transportation of solids by heterogeneous suspension in a carrying fluid is a complex phenomenon. The well researched, documented and reliable hydraulic theory applicable to the flow of a truly homogeneous fluid with measurable properties such as water is not applicable to slurry flow analysis. The design engineer is now faced with a multi-phase flow situation having indeterminate and variable properties and, unless a reliable mathematical method of analysis can be used, expensive pilot plant studies are necessary before a system can be engineered.

The mathematical solutions to slurry flow determination are further complicated when the flow is broken into two components for analysis, namely a pseudo homogeneous amended carrying fluid consisting of the actual carrying fluid together with the finer particles, with the larger particles being carried in this amended fluid in heterogeneous suspension.

The use of a computer to solve the resulting complex equations by iterative means, and the subsequent automatic plotting of results is described in this paper.

The conclusion reached in the paper is that meaningful results, utilising extensions of existing slurry pumping theory can be obtained by using computerised iterative analysis. Thereby the analyses of specific or ranges of slurry pumping duties become a relatively simple affair.

2. Development of Existing Theory to Obtain Practical Results by Computer Analysis

Thorough research into published literature reveals that there is no easy solution to the problem of determining critical velocity and friction gradient for the pipeline flow of solids in heterogeneous suspension. It is, therefore, understandable that designers turn either to simple nomograph type solutions as published by various pump manufacturers, which have been based on many years of practical experience, or to costly and time consuming laboratory loop test procedures.

In 1970, after studying existing literature, Uhlmann (1) outlined a different type of approach to slurry pumping analysis whereby the fine particles form a homogeneous part of the carrying fluid in which the coarse particles are then transported in heterogeneous suspension.

The method uses as its basis, well reasoned extensions of existing published theory in order to determine the friction gradient of a complex slurry, and to find its critical velocity. Emphasis is placed on the determination of the average drag coefficient of the solid particles. Only the particles in true heterogeneous suspension are included in the computation of this average, with the remaining smaller particles contributing to changes in the properties of the transporting fluid.

Briefly the method can be explained as follows:

For any given slurry transport velocity the particle size applying at the change from homogeneous to heterogeneous flow can be found. All particles with a size smaller than this determined particle size form a homogeneous part of the carrying fluid. The carrying fluid properties (density and viscosity) will as a result change, and these new properties can be calculated from known relationships. The remaining particles in the size fraction above the critical size are now transported in a homogeneous fluid with revised properties, and these particles have hindered settling velocities in this fluid.

From the measured settling velocity in clear water of each size of particle in the size range, the equivalent spherical particle diameter (which has the same settling velocity as the average irregular particle) for each size in the range is determined. The drag coefficient for these equivalent spherical particles are then compared with the drag coefficient of the particle size at the change-point to homogeneous flow, thus determining the particle size beyond which all smaller particles are in homogeneous suspension.

The mean drag coefficient for the particles remaining in heterogeneous suspension in the amended carrying fluid is calculated by the method of weighted square root of the individual particle drag coefficients, and applied in an extension of the Zandi [2] expression, modified to incorporate the changed properties of the transporting fluid as follows:

$$\frac{\frac{J_m}{S_F} - J_w}{X \cdot C_V \cdot J_W} = K \left[\frac{V^2 \cdot \sqrt{\overline{C}_D}}{g \cdot D \cdot (S/S_F - 1)} \right]^m \quad (1)$$

where J_m = friction gradient for slurry
J_w = friction gradient of water at the same velocity
V = transport velocity
C_V = volumetric concentration of solids
D = internal pipe diameter
S = specific gravity of solid particles
K = empirical constant
S_F = specific gravity of the carrier fluid
X = the portion of particles coarser than the critical particle diameter, i.e., the portion of the total particle sizes in heterogeneous suspensions
$\overline{C}_D$ = the the weighted mean particle drag coefficient for the proportion of particles (X) in heterogeneous suspension.
m = exponent

In a similar way Zandi's "I-number" expression [2] is modified to give:

$$N_I = \frac{V^2 \cdot \sqrt{\overline{C}_D}}{C_V \cdot D \cdot g\,(S/S_F - 1)} \quad (2)$$

with V being equal to V_c when $N_I = 40$ (variable for different slurries).

A successive approximation technique is used until the assumed transport velocity, which governs the cut-off particle size for the determination of the particles in homogeneous suspension and hence the $\overline{C}_D$ for use in the equations, is equal to the calculated critical velocity.

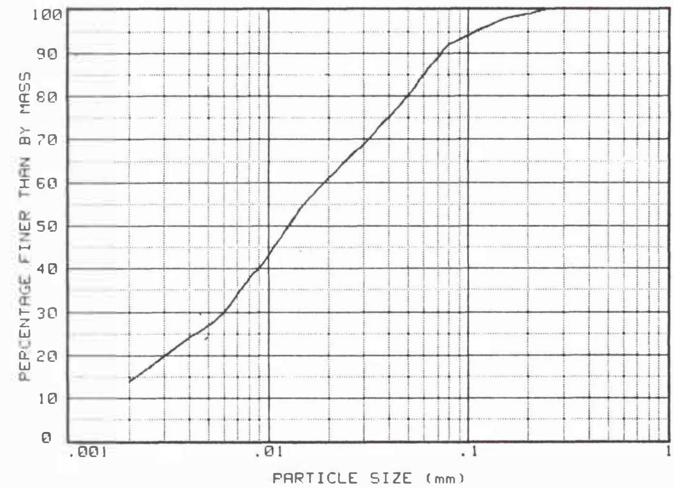

Fig. 1: Particle size distribution (plotted from data)

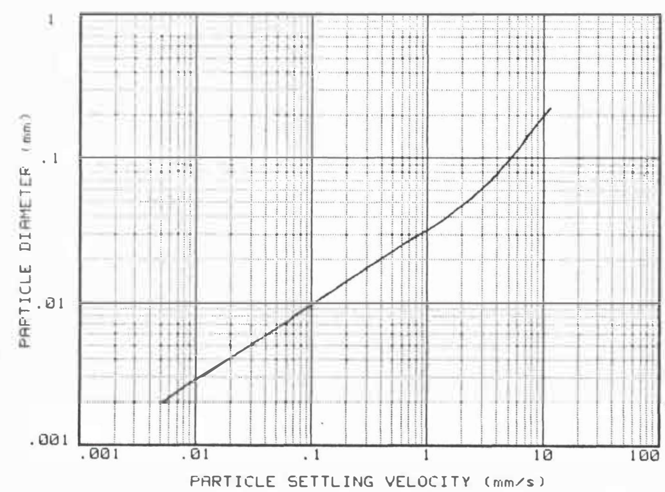

Fig. 2: Particle settling velocities in clear water (from laboratory measurements)

3. Practical Results

The computerised iterative approach described in the preceding section has been applied to more than twenty commercial pumping installations as listed in Table 1, and with satisfactory operational success.

The use of a computer to produce fast, reliable and consistent results has allowed a number of studies to be done for each of the cases listed in order to optimise the pumping solution and to investigate the change in pumping parameters when the particle grading, slurry concentration or solids throughput varies, for each of a series of different pipe sizes. This allows optimum selection of pipe size and safe sizing of pump and motor.

Typical computer output is shown in Figs. 1 to 6.

Pump characteristic curves as presented by most manufacturers are given in terms of flow rate against head in metres of water. These curves can be read as "head in metres of slurry" provided that the efficiency losses for slurry duty are taken into account. Papers by Cave [3] and Selgren [4] deal with the subject of losses in centrifugal pumps for slurry service and give equations and nomographs for determination of these losses.

SOLIDS THROUGHPUT = 10.0 (t/hr)
PIPE DIAMETER = 105.0 (mm)
CRITICAL VELOCITY RUN

Cv(%) / Cw(%) / SG SLURRY (t/m^3)	VEL. REQD. (m/s)	FLOW (m^3/s)	I NO.	% IN HET. SUSP.	SMALLEST PART. IN HET. SUSP. NO.	SIZE (mm)	SF SLURRY (t/m^3)	CRIT VEL. (m/s)	V/Vc
16.30 % / 30.00 % / 1.196	.89	.0077	84.8	20.	8	.055	1.162		
		.0042	40.0	45.	12	.018	1.116	.48	1.87
19.66 % / 35.00 % / 1.236	.74	.0064	64.4	31.	10	.035	1.173		
		.0047	40.0	39.	11	.025	1.156	.54	1.38
23.26 % / 40.00 % / 1.279	.63	.0054	44.1	31.	10	.035	1.208		
		.0048	40.0	39.	11	.025	1.187	.55	1.14

Fig. 3: Friction loss results

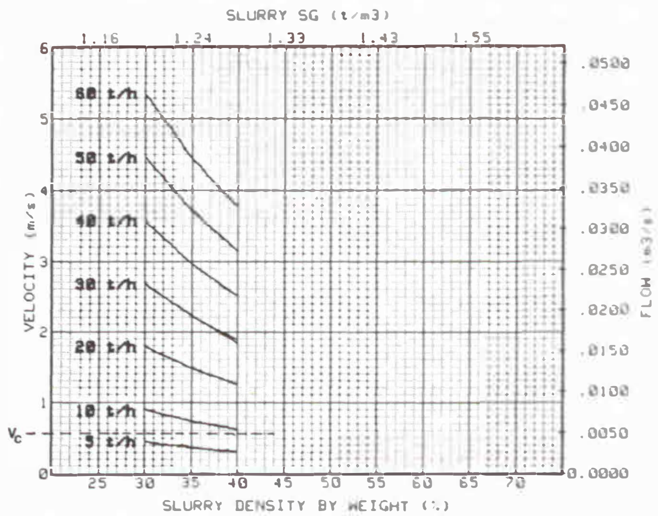

Fig. 4: Slurry throughput curves — this is a direct function of pipe size, slurry concentration and operating velocity. Critical velocity results can be superimposed on to this graph manually.

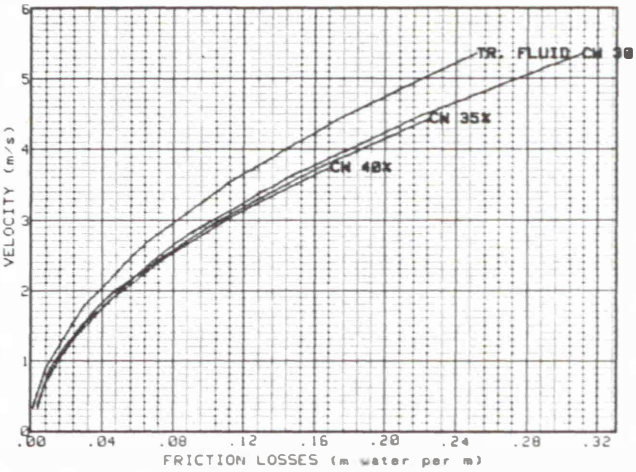

Fig. 5: Friction loss curves as computed by the method described.

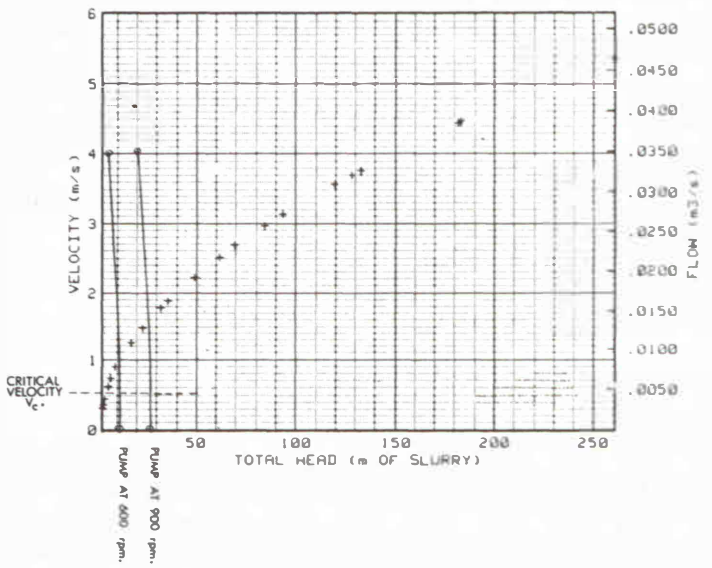

Fig. 6: System curves. These are derived from the friction loss curves, the slurry SG, the pipeline length and the static head applicable. Because static head is in metres of slurry head, the system curves are plotted in the same terms. Manufacturers' published pump curves can be plotted directly on to this system curve.

4. Conclusion

This paper describes the development of equations for slurry flow analysis and shows how a computerised approach has been adopted for their solution. The use of a computer to solve the complex equations and to plot the computed results in graphical form has made the analysis of a given or range of slurry pumping duties a relatively simple affair.

Slurry	Pipe dia. mm	Pipeline length (km)
Gold slimes	500	6.0
Gold slimes	400	9.5
Gold slimes	290	3.1
Gold slimes	250	1.0
Gold slimes	200	1.1
Gold slimes	140	2.5
Phosphate tailings	400	6.0
Phosphate tailings	400	4.5
Phosphate concentrate	150	3.0
Phosphate concentrate	100	3.0
Fluorspar tailings	200	5.5
Copper Ore	200	200.0
Copper tailings	400	8.0
Copper concentrate	200	—
Coal washing plant waste	200	2.6
Kimberlite slimes	250	5.2
Kimberlite slimes	250	2.7
Diamond mine quartz sand	200	3.0
Diatomaceous earth	125	4.6
Diatomaceous earth	200	2.3
Power station fly ash	100	—
Vanadium slimes	80	1.0
Coal in liquid CO_2	860	480.0
	(Hypothetical study)	

Acknowledgements

The author would like to thank his fellow partners and employees of Watermeyer Legge Piesold & Uhlmann Consulting Engineers of Rivonia, South Africa for their assistance in preparing this paper.

Table 1: Schedule of installations designed by computer analysis as in this paper.

References

[1] Uhlmann, H. L. B., "Die Hidrouliese Transportering van Vaste Stowwe" — Tegnikon v. 19, No. 2, June, 1970.

[2] Zandi, I., Govatos, G., "Heterogeneous Flow of Solids in Pipelines" — Proc. A.S.C.E.J. Hydr. Div. (May 1967).

[3] Cave, I., "Effects of Suspended Solids on the Performance of Centrifugal Pumps" Proceedings Hydrotransport 4, BHRA Fluid Eng. (1977).

[4] Sellgren, A. "Performance of a centrifugal pump when pumping ores and industrial minerals" Proceedings Hydro-transport 6, BHRA Fluid Eng. (1979).