MINTEK

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THE SUITABILITY OF DOPPLER FLOWMETERS FOR USE IN THE MINERALS-PROCESSING INDUSTRY

by

G.T.W. Ormrod

3rd January, 1983

COUNCIL FOR MINERAL TECHNOLOGY
200 Hans Strijdom Road
RANDBURG
South Africa

MINTEK

(MEASUREMENT AND CONTROL DIVISION)

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Investigators	G.T.W. Ormrod and J. Vida
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All correspondence to Mintek, Private Bag X3015, Randburg, 2125 South Africa

SYNOPSIS

In this report, six commercially available Doppler flowmeters, which were operated under conditions likely to be encountered in the minerals-processing industry, are evaluated. The effects of the density and particle-size distribution of a flowing slurry and the optimum siting of the flowmeter probe are considered and the results of tests on the response and linearity of the flowmeters are reported.

SAMEVATTING

'n hierdie verslag word ses Doppler-vloeimeters wat in die handel verkrygbaar is en wat gebruik is onder omstandighede wat waarskynlik in die mineraalverwerkingsbedryf teëgekom sal word, geëvalueer. Die uitwerking van die digtheid en partikelgrootteverdeling van 'n vloeiende bry en die optimale plasing van die vloeimetersonde word oorweeg en die resultate van toetse in verband met die responsie en lineariteit van die vloeimeters word aangegee.

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1. INTRODUCTION

Flowmeters using the Doppler effect were recently advocated for the measurement of the flows of slurries. One advantage claimed for the Doppler flowmeter is that the flow sensor is non-intrusive and can be readily fixed to the pipework of the equipment without interruption of the process; another advantage is that the costs involved in measurement of the flow are not related to the diameter of the pipe. (When magnetic flowmeters are used, the cost increases with increased pipe diameter.)

Addie and Di Napoli[1] used a Doppler flowmeter in their tests on slurries, and concluded that the meter is inexpensive and accurate, and, when properly applied, gives reproducible results.

The present investigation was undertaken so that those claims could be examined with the particular needs of the minerals-processing industry in mind. Several vendors of Doppler flowmeters lent instruments to the Council for Mineral Technology (Mintek) and asked for their flowmeters to be evaluated at Mintek.

2. PRINCIPLE OF OPERATION OF THE DOPPLER FLOWMETER

An ultrasonic beam is transmitted through the wall of a pipe and is backscattered or reflected from particles in the slurry or ore, or from air bubbles. If these particles are moving, their velocities are added to (or subtracted from) the velocity of the reflected ultrasonic beam in the medium. The resulting change in frequency between the incident and reflected beam is known as the Doppler shift, and is in direct proportion to the velocity of the particles. A combination of the Doppler equation and Snell's law shows that the change in frequency (Δf) is

$$\Delta f = f_t - f_r = \frac{2V\cdot\cos\theta}{C}, \quad \ldots\ldots \quad (1)$$

where f_t, f_r are the frequencies of the transmitted and reflected ultrasonic beams respectively,

θ is the angle between the axis of the pipe and the incident ultrasonic beam,

C is the velocity of the sound in the medium, and

V is the velocity of the reflecting particles, and is much smaller than C.

The mode of operation of the flowmeters is illustrated in Figure 1.

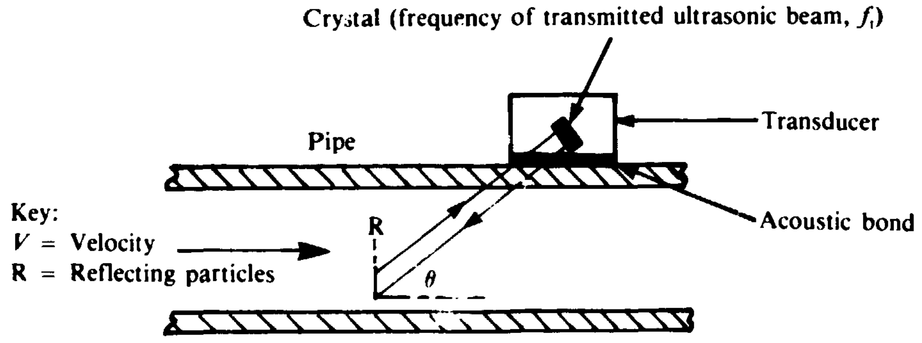


FIGURE 1. The mode of operation of the Doppler flowmeter

For transmission of the ultrasonic beam, there must be an acoustic bond between the transducer and the pipe, and the wall of the pipe and the slurry must transmit the ultrasound. It has been shown[2] that Rayleigh backscattering depends upon the size of the particles (a relation to the third power), so the slurry must contain particles of a certain size and in a certain concentration. One manufacturer of a Doppler flowmeter relates the desired size to the concentration of the solid particles in a slurry. This relation is plotted in Figure 2. The y-axis shows the particle size, and the x-axis the minimum concentration of particles required for efficient operation of the flowmeter when used on a pipe of 100 mm diameter.

Mineral processes, such as the carbon-in-pulp (CIP) process, employ flowing slurry systems with a normal velocity of 2 m/s to keep the slimes in suspension. The size and distribution of the solid particles in typical CIP pulps from plants in the Witwatersrand area are shown in Table 1, together with the flowrates for the pulps.

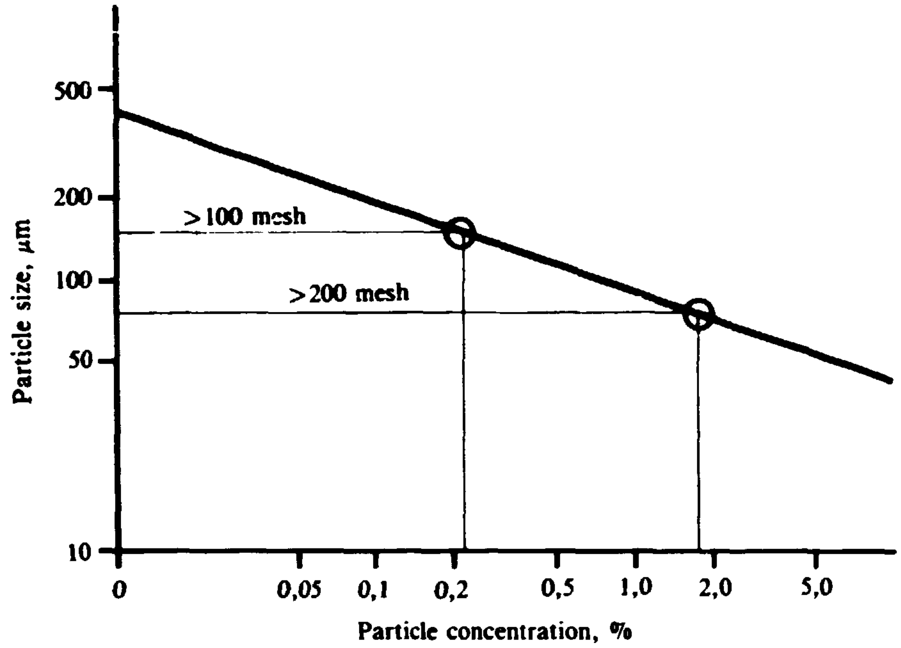


FIGURE 2. Desired size versus minimum concentration of particles in a slurry suitable for the efficient operation of a Doppler flowmeter

TABLE 1

Typical size gradings and flowrates for solids from four carbon-in-pulp plants processing ore in the Witwatersrand area

Particle size		Solids, %			
Mesh	μm	From A	From B	From C	From D
>48	295	1	1	-	-
>100	147	4	6	2	1
>200	74	20	25	23	17
<200	74	75	68	75	82

A, B, C, D = Carbon-in-pulp plants processing ore from the Witwatersrand Supergroup

Velocity of pulp
Normal 2 to 2,4 m/s
Minimum 1,22 m/s
Critical flowrate (with loss of suspension) 1,17 m/s.

The gradings of the solids from all four plants show that the concentration of particles larger than 200 mesh is greater than 18 per cent or, say, has an abundance of 9 per cent in a normal pulp. An abundance of less than 2 per cent is all that is required by the manufacturer's criterion as shown on the graph (Figure 2).

A pulp system therefore has sufficient particles acting as reflectors to fulfil the requirements of a measurement system based on the Doppler effect.

The ability of the flowmeter to detect a particle of a certain size depends upon the frequency of the ultrasound, since smaller particles are detected at the higher frequencies. However, the higher the frequency, the greater is the attenuation of the beam in the slurry. Manufacturers generally compromise on a frequency of 650 kHz, although 1 MHz is also used. Table 2 shows the frequencies measured for the various flowmeters tested.

TABLE 2

Measured frequency of ultrasound for various Doppler flowmeters

I	II	III	IV	V	VI
1 MHz	650 kHz	670 kHz	640 kHz	800 kHz	630 kHz

Doppler flowmeters are not recommended for flow velocities lower than 0,3 m/s, i.e., a Reynolds number of 10^4 for a 100 mm pipe, where the flow pattern becomes laminar. However, the flow velocity of mining pulps is normally 2 m/s, as can be seen in Table 1. At that velocity, the flow pattern is turbulent, and a Reynolds number of 2×10^5 can be calculated for a 100 mm pipe. The recommended maximum for the flow velocity is 10 m/s, but flow velocities over 5 m/s are not encountered in mining pulps. It has been stated[3] that the velocity of a fluid is not uniform in cross-section in a pipe, since the fluid at the centre of the pipe moves more quickly than that adjacent to its walls. The velocity profile depends upon the mode of flow, i.e., whether it is turbulent or laminar, the velocities for the latter mode having a wider distribution. Like other instruments for measuring flow, Doppler flowmeters should not be situated near bends or other obstructions that distort the velocity flow pattern. Under such conditions, a symmetrical flow profile can be developed only by a rising slurry in a vertical pipe.

Two main systems for the mounting of the transducers are used on Doppler flowmeters. Figure 3 shows the transducers mounted in tandem, with the transmitter and receiver side by side, and Figure 4 shows the transducers opposed, which, it is claimed, improves the interception of particles by the ultrasonic beam.

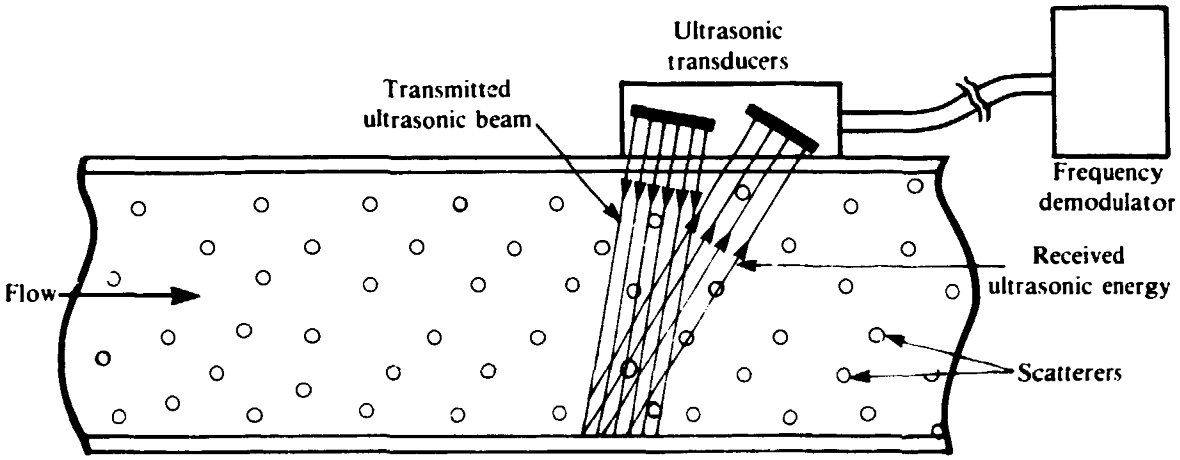


FIGURE 3. A Doppler flowmeter with the transducers mounted in tandem

3. THE MINTEK FLOW RIG

The Mintek facility for the calibration of flowmeters (the flow rig) is shown in Figure 5. A centrifugal pump, the speed of which is controlled by a variable-speed drive, circulates the slurry to a sump, normally by way of a horizontal and vertical test section of pipe.

The first test section of the pipe is horizontal and is situated 4 m after a bend so that a fully developed flow profile can be established and the flow pattern straightened. The next bend occurs 2 m after this section, and the vertical test section is situated 4 m after the second bend. For proper operation, most types of flowmeters, particularly orifice, vortex, and target flowmeters, require that there should be long runs of straight pipes before and after the sensor. As the diameter of the Mintek pipework is nominally 100 mm, the sections approaching the sensor and those following it are 40 and 20 pipe diameters in length respectively.

The pipework terminates in a flexible tube bearing a fishtail that is moved by a pneumatic piston. A jet of fluid can thus be prevented from circulating back to the sump by being diverted over a splitter plate into a weighing tank that is supported by three flexure types of load cells of which the total capacity is 2250 kg. A sensor on the fishtail detects the point of diversion and starts a digital timer.

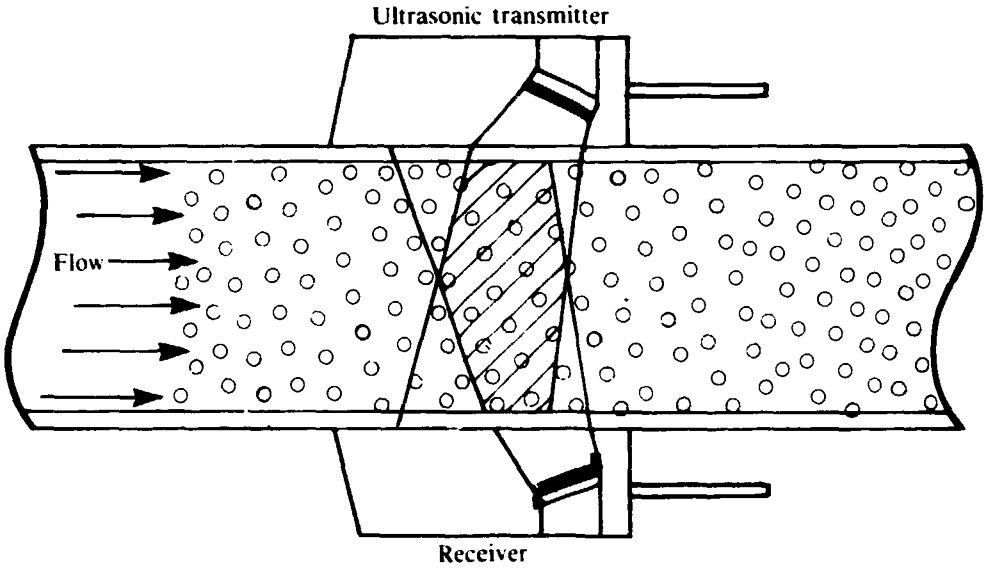


FIGURE 4. The opposed mounting for the transducers of the Doppler flowmeter

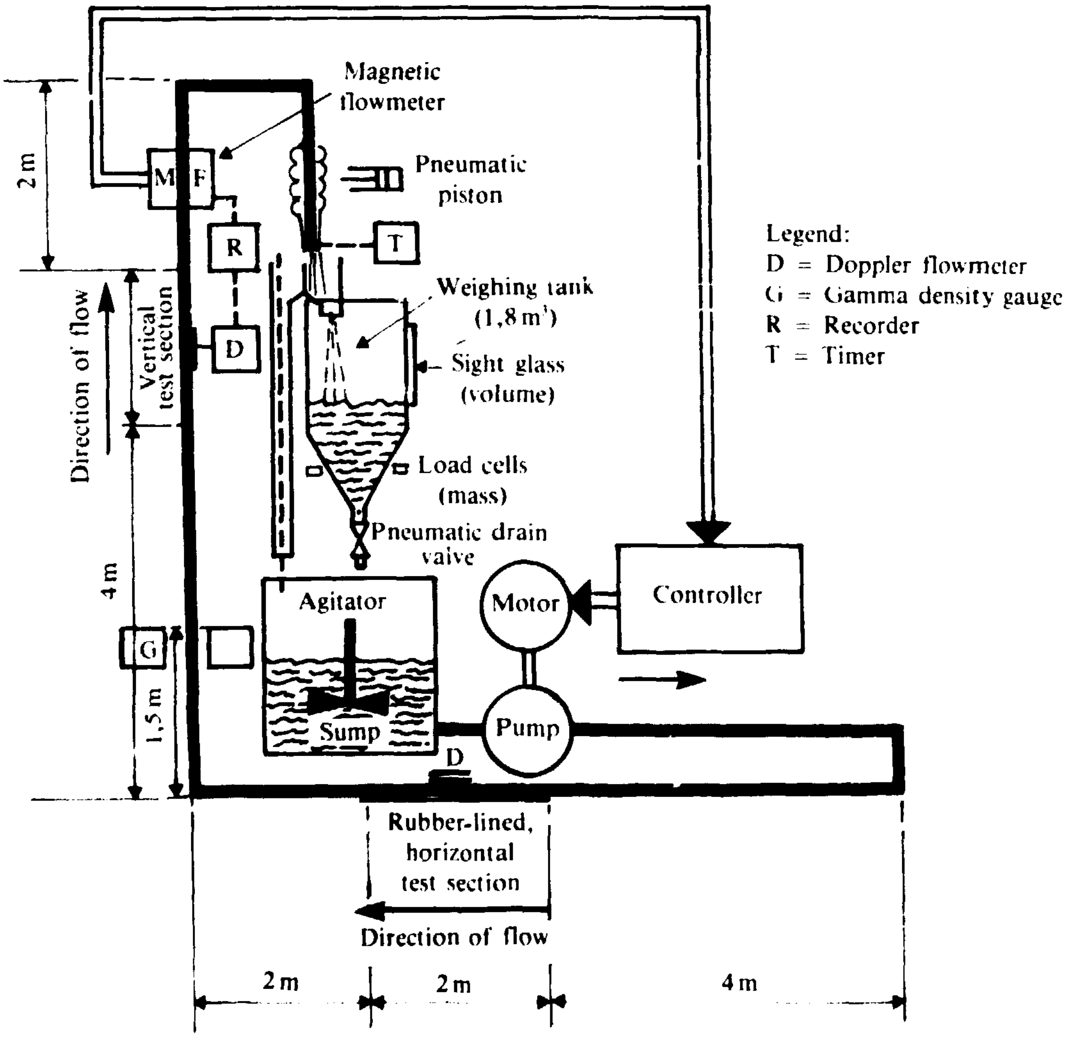


FIGURE 5. The flow rig at Mintek

The accuracy of the calibration is 0,1 per cent, but a drift in temperature can decrease the accuracy of the calibration to 0,2 per cent. The weighing tank has a volumetric capacity of 1,8 m^3, a conical bottom terminating in a pneumatically operated sleeve valve, and a sight glass on its side that enables measurements of volume to be made. In this calibration, it is convenient for the mass and the volume of water in the weighing tank to be equated. All the required parameters, such as mass, time, and volume are therefore available for primary calibration of the flow.

The sump has a volume of 5 m^3 and is agitated so that slurries are kept in suspension. The sump feeds the centrifugal pump, which pumps the medium at a maximum rate of 50 l/s or a velocity of 6 m/s. The minimum flowrate is approximately 10 l/s.

After the vertical test section, there is a magnetic-induction flowmeter (MF) that measures the velocity of the flow in the circuit. The operation of the original flowmeter was based on coil energization by direct-current (d.c.) pulses. At a later date, this meter was replaced by one having coil energization by alternating current (a.c.). The flowmeter is calibrated by use of the primary method to form a working standard. The signal from this meter is fed to a three-term controller and recorder (R), and the signal from the controller operates the variable-speed drive for the pump, enabling steady flow conditions to be maintained.

The instrumentation on the flow rig is supplemented by a gamma density gauge (G) (of which the output is also recorded). This gauge shows any changes in density that occur during runs. The range of relative densities covered is 1,0 to 1,5.

A third recorder channel (4 to 20 mA) is provided for the output of the meter being tested.

4. EXPERIMENTAL WORK

4.1. Calibration with Mintek Sands

The various Doppler flowmeters were attached to the vertical test section of the rig by the agents of the manufacturers, so that the installation would be done correctly. The method of mounting was simple, the paint being removed from the pipe and the transducer being attached to a pipe with settable silicon rubber that acted as an acoustic bond. Plastic tape was wound round the pipe and the transducer to join them mechanically. The transducers were aligned along the axis of the pipe, and their position was verified electronically by a light-emitting diode or a meter (where fitted) to ensure that ultrasonic reflections were being obtained. Although all the transducers were mounted on the same test section of the pipe, only one was activiated at a time so that they would not interfere with one another. The original slurry in the rig was very dilute (0,01 per cent), but there was sufficient acoustic reflection to operate all of the flowmeters. The flowmeters were zeroed when there was no flow, and their current outputs were set at 4 mA.

The flow rig was set for a maximum flow velocity of 6 m/s, (or 47 l/s for the 100 mm d.c. magnetic flowmeter). A typical trace by a d.c. magnetic flowmeter (Figure 6) shows a range of flow velocities from 1,5 to 5,4 m/s. The results for the dilute slurry were calibrated by use of the weighing tank and the timer. The details are given in Figure 7.

At a flow of 3 m/s, all the Doppler flowmeters were adjusted to an output current of 12 mA and to read 50 per cent. So that all the readings would be comparable, no further adjustments were made to the meters throughout the run.

Calibration runs were made at 1,5 m/s, 2,4 m/s, 3,6 m/s, and 4,8 m/s, and the outputs of the Doppler flowmeters and the d.c. magnetic flowmeter were recorded side by side to enable them to be compared (Figures 8 and 9). The outputs of all the Doppler flowmeters were linear, but at flows of high velocity the noise level was higher for some of them.

Mintek sand (waste ore) was added to the sump of the flow rig and agitated. A relative density (r.d.) of 1,1 was calculated by use of the ratio of the mass to the volume of some of the slurry collected in the weighing tank.

Unfortunately, the d.c. magnetic flowmeter became extremely noisy (registering 20 per cent on the scale), and therefore of no use as a controller. It was suspected that the Mintek sand contained some magnetic material but, on analysis, the magnetic content of the sand was found to be less than 0,4 per cent.

The Doppler flowmeters, on the other hand, were even less noisy than before, and the primary system of evaluation, i.e., by measurement of the mass, time, and volume, was chosen. Three suitable input currents to the variable-speed controller were selected, which gave flow velocities of approximately 1,5 m/s, 3,6 m/s, and 5 m/s respectively. A volume (approximately 1200 litres) of slurry was collected in the weighing tank at each step, the mass, volume, and time of collection being noted.

4.2. Calibration with Mine Sands

The slurry containing Mintek sand was disposed of and replaced with a slurry of sand from a mine in the Witwatersrand area. As there was no decrease in the noise made by the d.c. magnetic flowmeter,

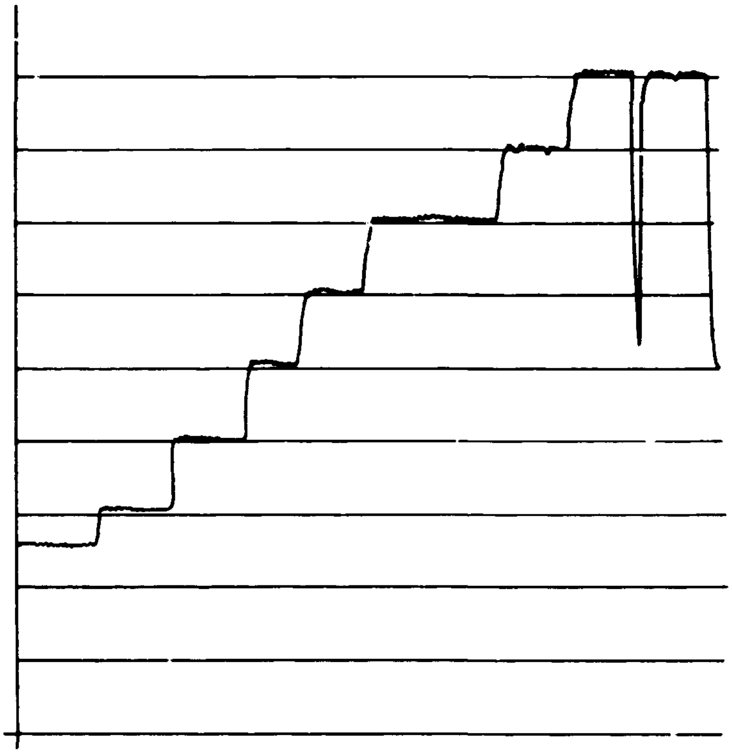
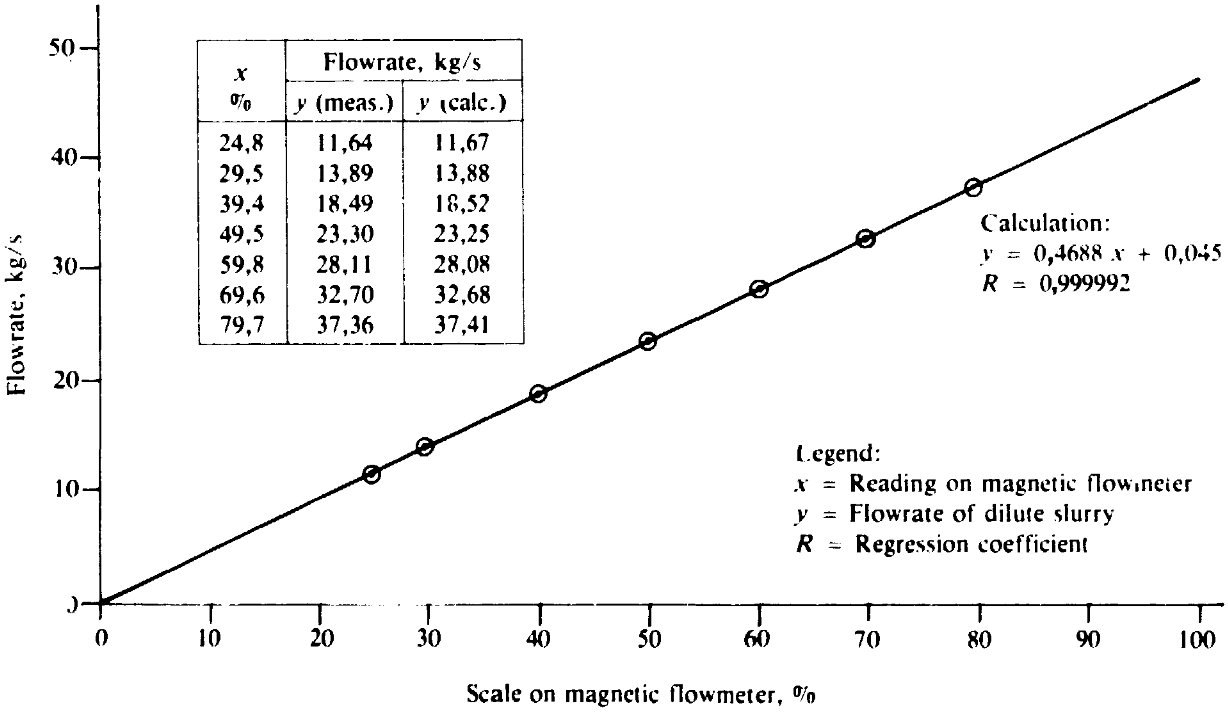


FIGURE 6. A calibration trace by a d.c. magnetic flowmeter (full scale = 6,0 m/s)



x %	Flowrate, kg/s	
	y (meas.)	y (calc.)
24,8	11,64	11,67
29,5	13,89	13,88
39,4	18,49	18,52
49,5	23,30	23,25
59,8	28,11	28,08
69,6	32,70	32,68
79,7	37,36	37,41

Calculation:
$y = 0{,}4688\,x + 0{,}045$
$R = 0{,}999992$

Legend:
x = Reading on magnetic flowmeter
y = Flowrate of dilute slurry
R = Regression coefficient

FIGURE 7. Calibration of the d.c. magnetic flowmeter on very dilute slurry

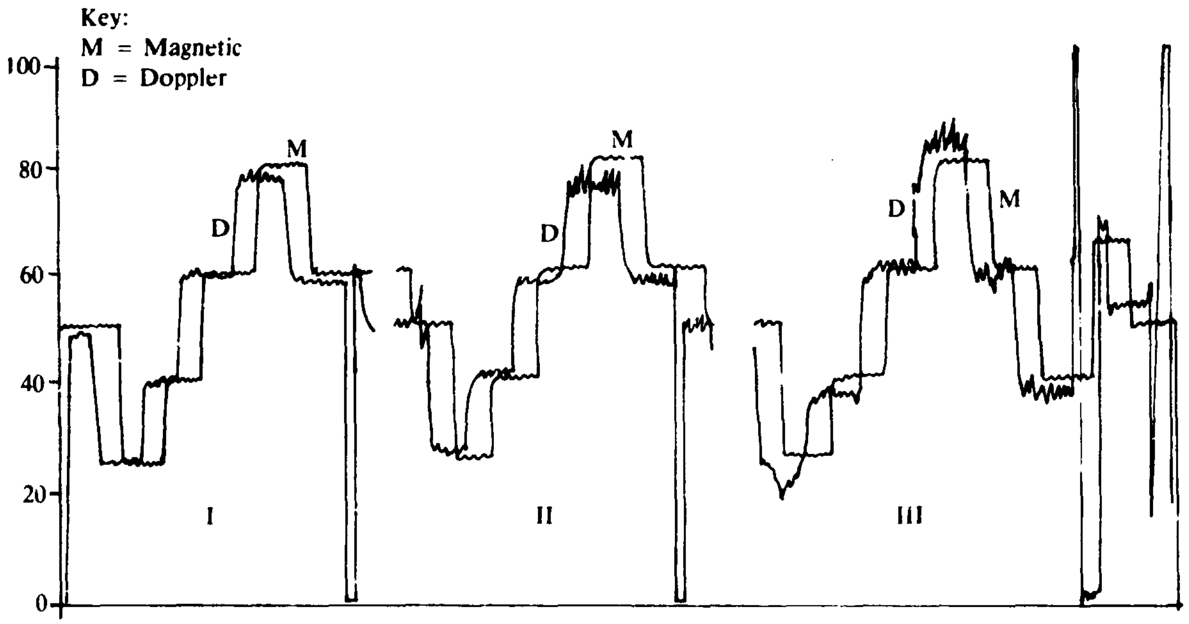


FIGURE 8. Comparative traces on dilute (0,01 per cent) slurry by Doppler flowmeters I to III and the d.c. magnetic flowmeter

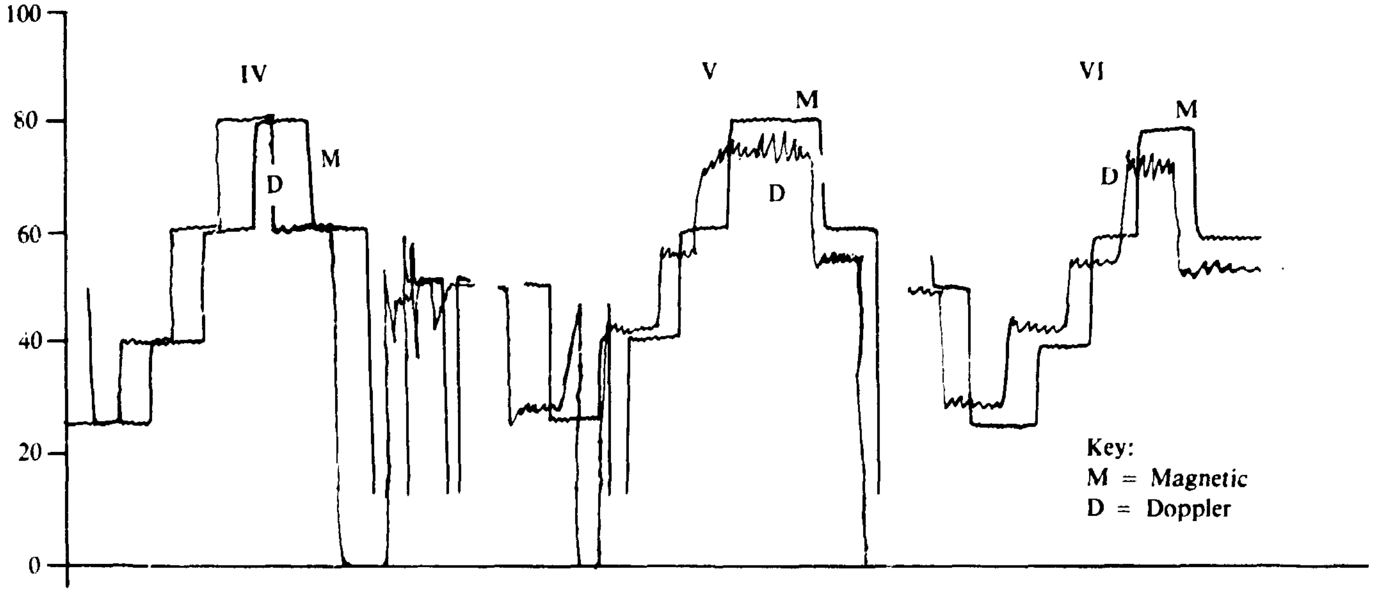


FIGURE 9. Comparative traces on dilute (0,01 per cent) slurry by Doppler flowmeters IV to VI and the d.c. magnetic flowmeter

the manual procedure that had been used before was adopted. Tests were conducted on the mine-sand slurry at three relative densities: 1,040, 1,167, and 1,271 respectively. Each of these was the average r.d. over many runs of a particular slurry.

The compositions of the Mintek sands and the mine sands are given in Table 3.

These slurries were prepared and accurately measured in the test rig so that the effect of their densities on the readings of the Doppler flowmeters could be evaluated.

4.3. Response on the Rubber-lined Pipe

In another experiment, each Doppler flowmeter was used with a pipe of which the lower horizontal test section (normally 100 mm diameter) had been lined with rubber 6 mm thick. The velocity of the slurry

TABLE 3

The compositions of Mintek sand and mine sand

Particle size, μm	Mass of fraction g	Fraction, %
Mintek sands		
>212	17,13	4,81
>150 to 212	34,22	9,61
>106 to 150	58,75	16,50
>75 to 106	52,49	14,74
>53 to 75	64,51	18,12
>38 to 53	39,79	11,18
By diff. to 38	89,10	25,03
Total	355,99	99,99
Magnetic material		0,36
Mine sands		
>212	13,61	6,00
>150 to 212	43,51	19,17
>106 to 150	57,48	25,33
>75 to 106	36,63	16,14
>53 to 75	39,19	17,27
>38 to 53	20,03	8,83
By diff. to 38	16,47	7,26
Total	226,92	100,0
Magnetic material		0,06

in this section was expected to increase by a factor of 1,29 as a result of the decreased area of the cross-section of the pipe.

The transducers were mounted on each of these sections as before, and tests were run (Table 4).

4.4. Limited Calibrations with an a.c. Magnetic Flowmeter

The magnetic flowmeter used originally was of the d.c. type with chopped excitation at 3 Hz.

In later experiments, an a.c. magnetic flowmeter became available. This operated at 50 Hz and, probably because of its narrower bandwidth, the noise effect was eliminated. Two Doppler flowmeters were tested during this period with this a.c. flowmeter.

Slurries with r.d.s of 1,19 and 1,39 were prepared from Mintek sands and used in tests that were conducted according to the secondary calibration method (that in which the results for the Doppler and a.c. magnetic flowmeters were compared directly). Figure 10 is a recording of one of these runs, in which the outputs for the Doppler and the a.c. magnetic flowmeters are presented on the same chart as the r.d. of the slurry.

5. RESULTS

5.1. Test on Mintek Slurry

In Figures 11 and 12, the x-axes give the values for the volume flowrates of the slurry, which are derived from the mass flow divided by the average r.d. With this method, the sight glass is not used, and the limitations inherent in its use are avoided. The y-axis represents the percentage output of each flowmeter. All the flowmeters responded well to changes in the flow, and gave linear outputs to within 2 per cent of the maximum.

Emphasis was placed on the linearity of each instrument being tested, and the instrumental settings remained unchanged throughout the test.

5.2. Calibration with Mine-sand Slurries

In Figures 13 to 18, the volume flowrates are compared with the percentage outputs of the flowmeters. With one exception (flowmeter III on a slurry with an r.d. of 1,040), there is linear correlation to within 2 per cent of the maximum.

However, in all instances, the slope of the response decreases as the density of the slurry increases.

TABLE 4

Readings on Doppler flowmeters used with rubber-lined pipes

Doppler flowmeter	Control current mA	Flow readings		Flowrate		Relative density
		Meter	Recorder	kg/s	l/s	
I	6,60	37	37	12,250	11,788	1,039
	12,00	76	74	28,840	27,830	1,036
	17,50	103	103	41,656	39,657	1,050
					Av.	1,042
II	6,60	32	32	12,198	11,740	1,300
	12,00	70	70	28,853	27,752	1,040
	17,50	96	96	41,776	40,237	1,038
					Av.	1,039
III	6,60	33	33	12,293	11,845	1,038
	12,00	78	80	28,903	27,596	1,047
	17,50	o/s	o/s	41,822	40,335	1,039
					Av.	1,041
IV	6,59	25	26	12,021	11,485	1,047
	12,00	68	67	28,815	27,790	1,037
	17,50	100	97	41,818	40,496	1,033
					Av.	1,039
V	6,60	–	29	12,013	11,573	1,038
	12,00	–	80	28,823	27,460	1,050
	17,50	–	o/s	41,755	40,505	1,031
					Av.	1,040
VI	6,60	5,5*	33	12,157	11,680	1,040
	12,00	13,00*	61	28,738	27,460	1,047
	17,50	18,6*	o/s	41,635	40,230	1,035
					Av.	1,041

* Feet per second on the indicator of the meter
o/s = off scale

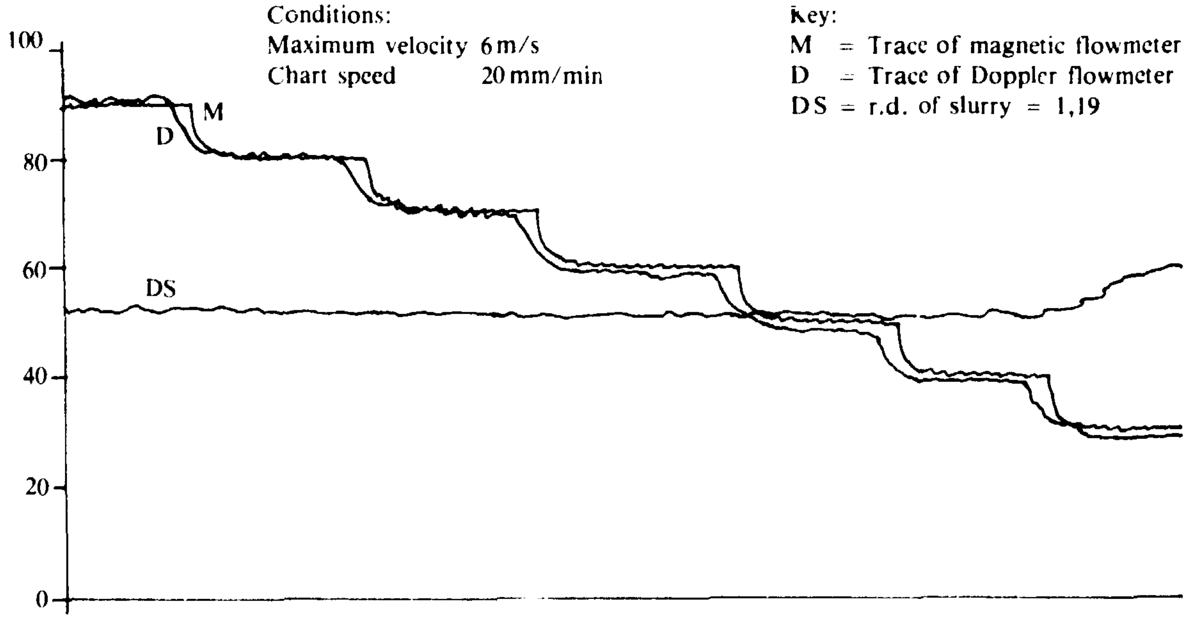


FIGURE 10. Comparison of the recordings for the a.c. magnetic flowmeter and a Doppler flowmeter

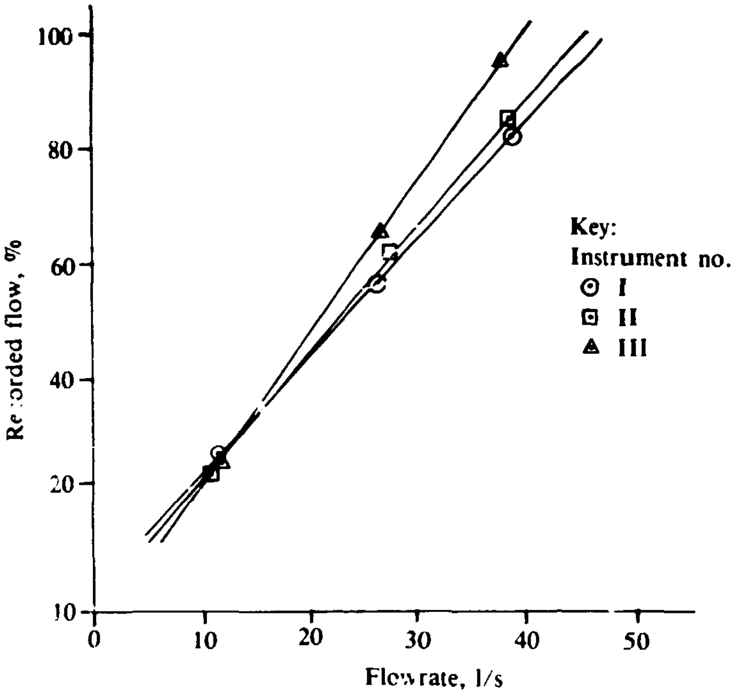


FIGURE 11. Responses of Doppler flowmeters I to III to changes in flow of Mintek slurry (r.d. 1,103)

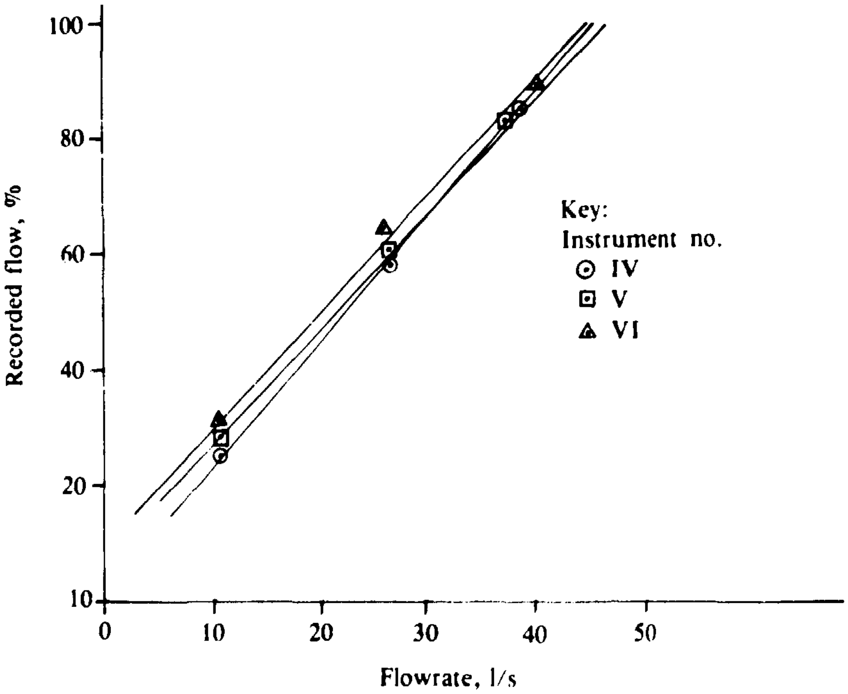


FIGURE 12. Responses of Doppler flowmeters IV to VI to changes in flow of Mintek slurry (r.d. 1,103)

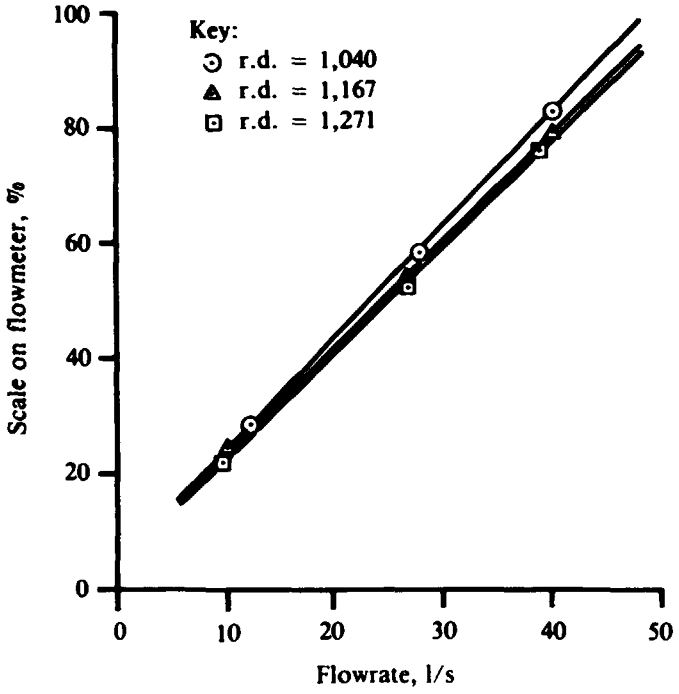


FIGURE 13. Responses of Doppler flowmeter I to changes in flow of mine-sand slurries of different r.d.s

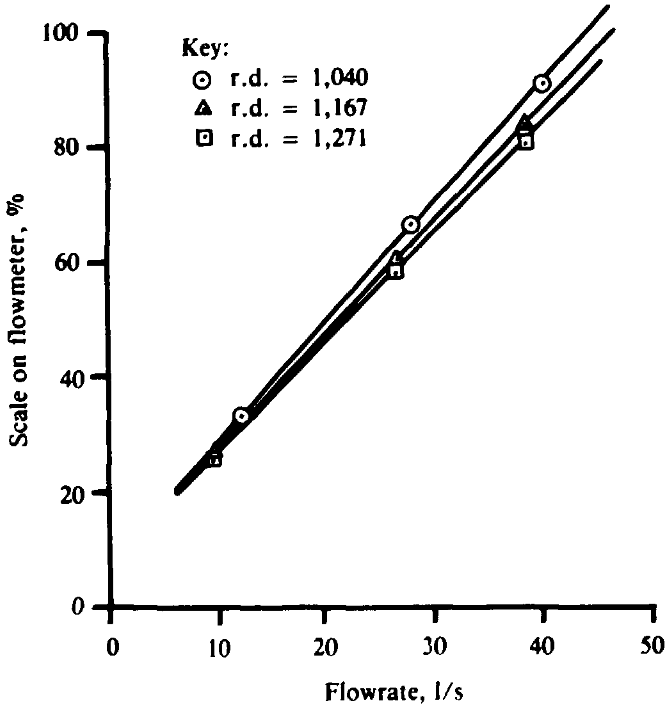


FIGURE 14. Responses of Doppler flowmeter II to changes in flow of mine-sand slurries of different r.d.s

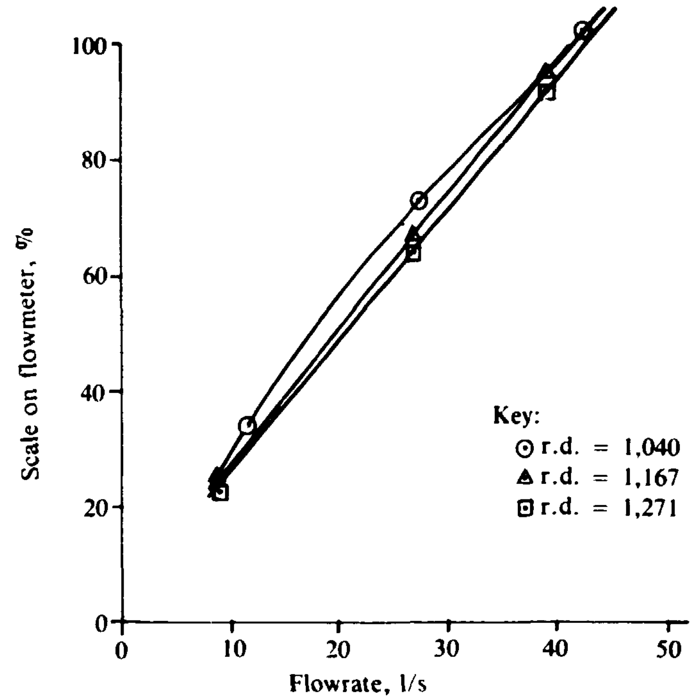


FIGURE 15. Responses of Doppler flowmeter III to changes in flow of mine-sand slurries of different r.d.s

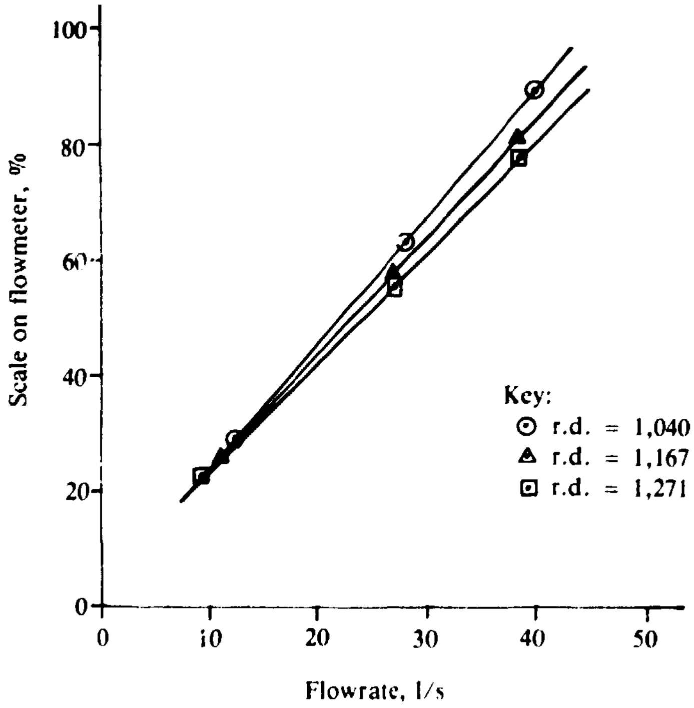


FIGURE 16. Responses of Doppler flowmeter IV to changes in flow of mine-sand slurries of different r.d.s

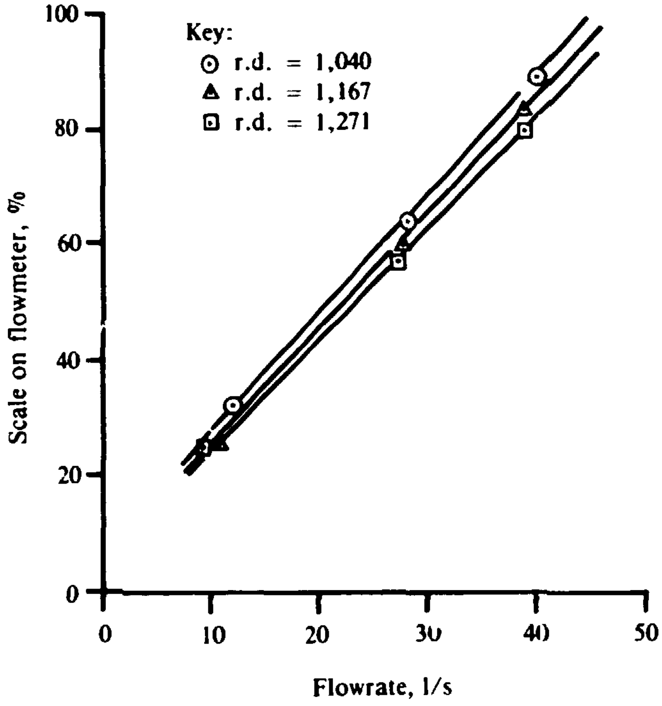


FIGURE 17. Responses of Doppler flowmeter V to changes in flow of mine-sand slurries of different r.d.s

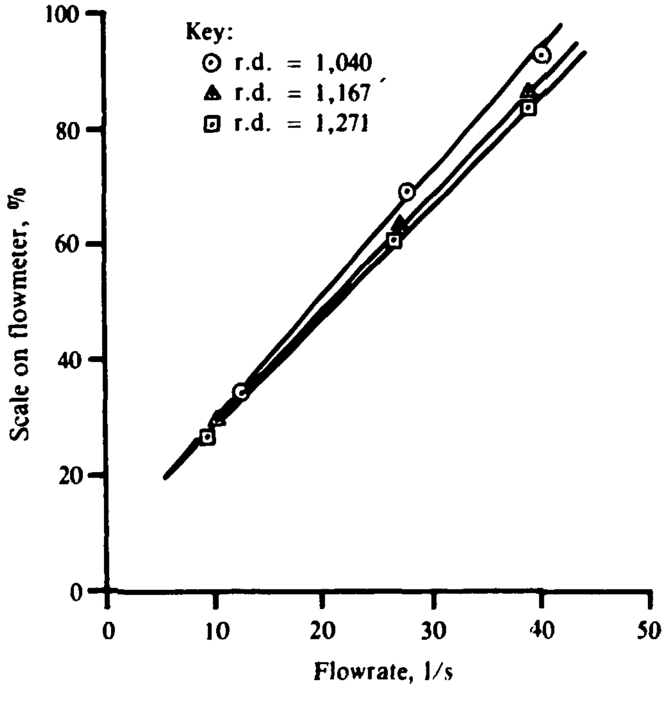


FIGURE 18. Responses of Doppler flowmeter VI to changes in flow of mine-sand slurries of different r.d.s

5.3. Response on the Rubber-lined Pipe

All of the flowmeters responded to changes in the flowrates of the slurries although it can be seen from Table 4 that the readings for each flowmeter were higher than those obtained from earlier calibrations. This was because of the increased velocity of the slurry as it passed through the section of pipe narrowed by the rubber lining (Section 4.3).

5.4. Limited Calibration with an a.c. Magnetic Flowmeter

The results are plotted in Figures 19 and 20. The simplicity of these measurements enabled increased accuracy to be achieved, and the graphs for these measurements made by the Doppler and the a.c. magnetic flowmeters agree in linearity to within 1 per cent.

As before, increasing r.d. decreased the slope of the response. For an increase in r.d. of 0,2 the opposed flowmeter (Figure 18) has a reduction of 7 per cent in the slope of the response; the tandem flowmeter (Figure 19) has a similar reduction of 10 per cent in the slope.

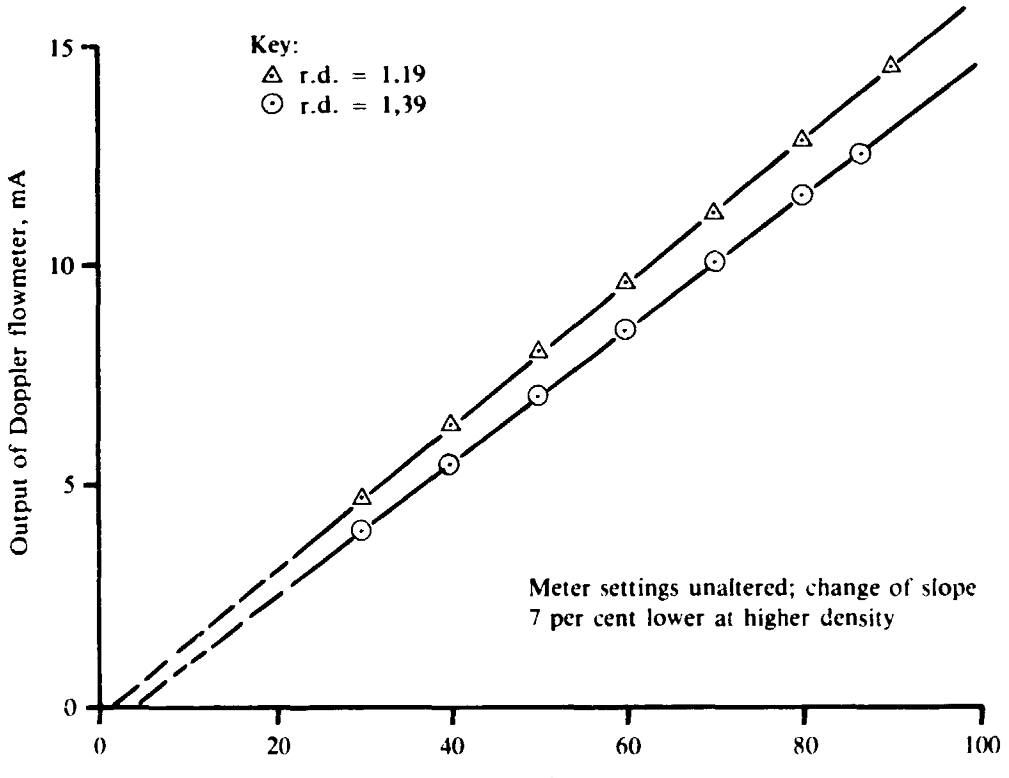


FIGURE 19. Comparison of the outputs of the Doppler flowmeter (in opposed-mounting mode) and the a.c. magnetic flowmeter

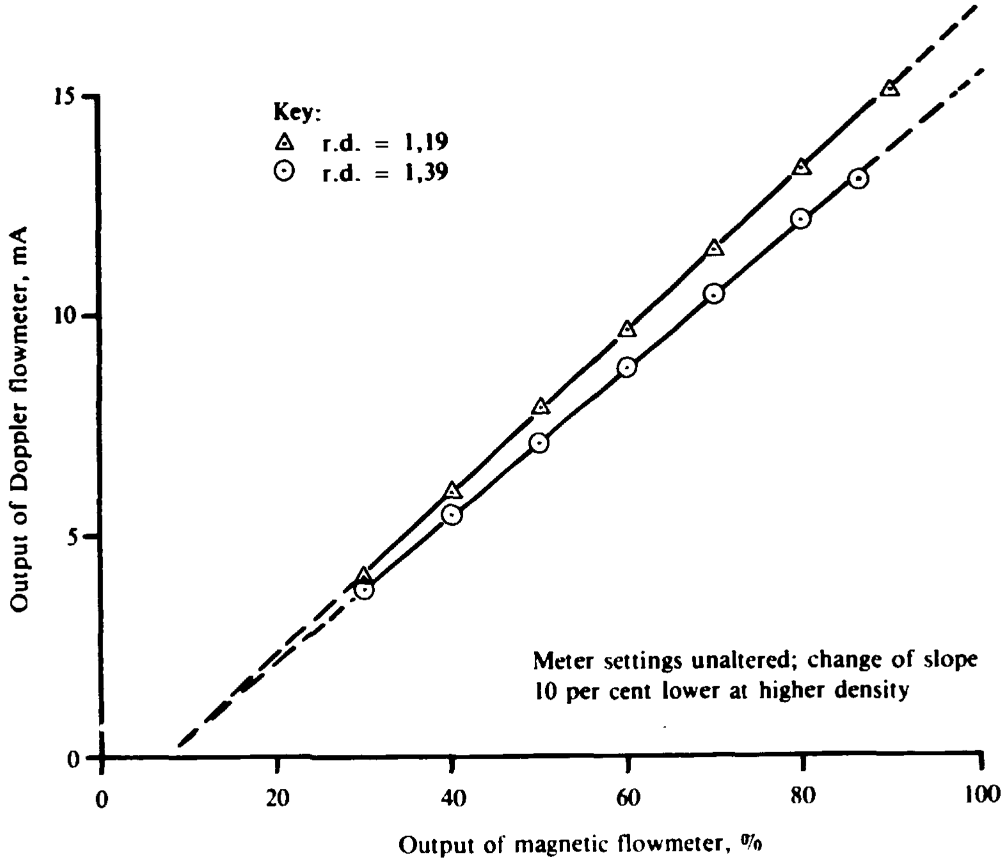
5.5. General

The response time of a Doppler flowmeter is apparently longer than that of a d.c. magnetic flowmeter, as is demonstrated by the comparative recordings in Figure 10.

A further guide to the behaviour of Doppler flowmeters is signal noise. The noise levels of the various flowmeters can be observed in Figures 8 and 9. Noise decreases with the r.d. of the slurry, and increases with the velocity of the flow, i.e., with a greater number of particles acting as reflectors and a narrower spread in the velocities of the particles.

6. CONCLUSIONS

It is apparent that, unlike magnetic flowmeters, Doppler flowmeters measure the velocity of the particles in a slurry rather than the velocity of the liquid phase of the slurry. This effect can be seen by the slower response of the Doppler flowmeters to a step change in the velocity of a flowing slurry. This is because solid particles, which have greater inertia, take longer to reach a required velocity than a liquid does.



Meter settings unaltered; change of slope 10 per cent lower at higher density

FIGURE 20. Comparison of the outputs of the Doppler flowmeter (in tandem-mounting mode) and the a.c. magnetic flowmeter

It appears that the velocity of the slurry decreases with increasing density when measured by a Doppler flowmeter. When a magnetic flowmeter is used, this effect is not observed. A possible reason for this effect of density is given in Section 7. It is therefore incorrect for one to calibrate a system and flowmeter for, say, a slurry of low density, and to assume that the calibration will hold good for a slurry of high density. Although manufacturers provide flow-setting parameters for their flowmeters, these should be applied as a preliminary step and, where possible, another method for the standardization of flows should be used in verification of the setting.

Flow measurements were easily obtained with no mechanical intrusion from Doppler flowmeters. This statement holds good for plain and rubber-lined pipes of 100 mm diameter containing mine-sand slurries up to an r.d. of 1,4.

In nearly all instances, all the flowmeters showed good linearity at particular density levels. The operation of the flowmeters depends primarily on the size of the particles in the slurry and, to a lesser extent, on the concentration of the particles.

With slurries at very low r.d.s and high flow velocities, the noise emitted by Doppler flowmeters varied, flowmeters I and IV being less noisy than the others. However, it should be noted that this r.d. is lower than that required by most manufacturers for optimum operation.

7. DISCUSSION AND RECOMMENDATIONS

Figure 21 illustrates the flow profile for slurry rising in a vertical pipe. At low density, the ultrasonic beam can penetrate to a point A, and the high particle velocity, V_1, can be measured. However, in a slurry of high r.d., the beam can penetrate only to a point B, and the lower velocity, V_2, is measured. It is recommended that the 'target area' of an ultrasonic beam penetrating slurries of various r.d.s should be investigated. The power and frequency of the ultrasound are obvious parameters.

The particles in the slurry move at various velocities and, for more accurate average velocities to be obtained, more particles should act as reflectors. In this respect, it appears that some advantage is to be gained from opposed mounting of the transducers (flowmeter I). However, the noise emitted by one of

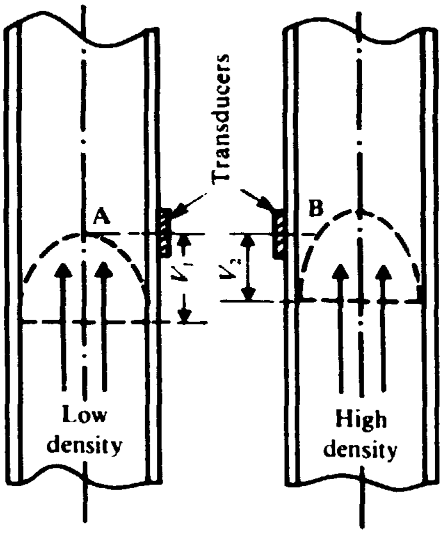


FIGURE 21. The velocity profile of slurry in a vertical pipe

the flowmeters using tandem mounting (IV) was also low. The opposed mounting is limited by the diameter of the pipe, and it is understood that this system can measure mine pulps in pipes of 150 mm diameter, but not in pipes of 250 mm diameter.

The Doppler flowmeter is recommended for use on plants, particularly for spot tests on the flow. The measured slurry must have the requisite size and abundance of particles (or of air bubbles), and the test probe must be sited correctly so that the flow profile is symmetrical. Absolute calibration of the flowmeter is best achieved with the probe *in situ*, the measurement of the flow being checked by an alternative method.

The distance between the transducers and the instrument is limited, because the high frequencies employed necessitate transmission by coaxial cable. As the instrument will be in a plant environment, it should be hoseproof, and the part of the instrument required for conversion of the signals to analogue signals (the pre-amplifier) should be waterproof. With such a pre-amplifier, long cable runs become possible in plants, and the output cable is cheaper than coaxial cable. The flowmeters with this feature (hoseproof and waterproof) are flowmeters II, III, and V. (Flowmeter VI is a portable model and the feature does not apply.)

It is recommended that a separate indicator should be installed that would show whether sufficient ultrasonic reflection is being obtained. This second signal could also serve as a 'pipe empty' alarm. The flowmeters with this feature (a separate indicator) are flowmeters I, IV, V, and VI.

Separate twin transducers enable opposed or tandem mounting to be used. The instrument with this feature is flowmeter I.

8. REFERENCES

1. ADDIE, G.R., and DI NAPOLI, L. Comparison of a Doppler (ultrasonic) flowmeter with a magnetic flowmete. on different slurries in the G.I.W. Hydraulics Test Laboratory. vol. 7. *PROCEEDINGS OF THE 8TH ANNUAL MINING AND METALLURGY DIVISION SYMPOSIUM AND EXHIBIT, MAY 14-16, 1980, PHOENIX, ARIZONA. Kurzinski, E.F. (ed.).* Pittsburgh, Instrument Society of America, 1980. p. 403.
2. PFAU, B. Continuous particle-size measurement with ultrasound. *Verfahrenstechnik*, vol. [illegible], no. 9. 1974. pp. 258–260.
3. SCHMIDT, T.R. What you should know about clamp on ultrasonic flowmeters. *InTech*, May 1981. pp. 59–62.

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Corrigendum: Report M68

Table 4, page 9 : The relative density of Doppler flowmeter II at a control current of 6,60 mA should read 1,039 and *not* 1,300.

200 HANS STRIJDOM RD, RANDBURG
ALL CORRESPONDENCE TO:
PRIVATE BAG X3015, RANDBURG,
2125 SOUTH AFRICA

TEL. ADD. MINTEKSA JOHANNESBURG
TELEX 4-24867 SA
TEL. (011) 793-3511