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STUDIES OF SMALL PARTICLE SUSPENSIONS FOR L.M.F.R.

PART V. THE EFFECTS OF CONCENTRATION, PIPE DIAMETER AND SOLID DENSITY ON THE HORIZONTAL SETTLING VELOCITY

by

R. C. CAIRNS

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K. S. TURNER

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Abstract

Additional data have been collected for the horizontal settling velocities of small particle suspensions. The effect of concentration, pipe diameter and effective density ratio have been determined.

In almost all cases a moving bed is formed before a stationary bed. For small concentrations, up to several percent by volume, the effect of concentration is negligible.

The following empirical equation holds for the moving bed and stationary bed conditions:–

$$V^a = b(D)^{0.2} \left(\frac{\rho_s - \rho_l}{\rho_l}\right)^{0.3}$$

where a = 1.0, b = 1.9 for a moving bed
and a = 0.85, b = 1.6 for a stationary bed

This equation applies for effective density ratios of 1.7 to 18.3 and pipe diameters of ¾–in. to 2–in.

The Reynolds number of a suspension is not a true indication of the degree of turbulence or particle suspension.

CONTENTS

1. INTRODUCTION

In the course of previous A.A.E.C. work (5), (6), (4) on dilute suspensions of small particles, the horizontal settling velocity has been experimentally determined for a number of systems in a 1–in. pipe and a new empirical correlation has been presented (3).

To extend this correlation to include the effects of concentration and pipe size, further experimental data were required, and these are presented in this report.

For a variety of pipe sizes and concentrations data have been collected for the systems red lead–water, barium sulphate–water, tungsten–water and talc–water. The solids used covered a wide range of density, 2.7 to 19.3 g/cc, and were readily available in the subsieve size range.

Dicon pipes were used of ¾–in., 1–in., 1½–in. and 2–in. nominal internal diameter, and mean concentrations of approximately 5, 10 and 15 percent by weight of barium sulphate and red lead, and approximately 9 percent by weight of tungsten and talc were circulated.

2. EXPERIMENTAL APPARATUS

The loop used is shown in Figure 1, and was similar to that used for the work on barium sulphate in a 1–in. pipe (6). The loop was modified to allow for the interchange of different diameter test lengths in the top horizontal section.

The pipe supports for the top horizontal section were changed to adjustable Vees to facilitate levelling and straightening of the various test pipes and each test pipe was fitted with suitable reducing pieces for ease of installation and to eliminate sudden changes of section. The diameter of each test pipe was measured at both ends, before and, in most cases, after the settling velocity experiments. The diameters were also calculated from the volume of water held by the pipes. The results are given in Table I. The lengths of the test pipes were approximately ten feet, and the full lengths were observed to determine the bed condition.

The projector used previously was not available for all runs but satisfactory illumination was obtained by the use of a 500 watt Barton Foto–Spot spotlight in conjunction with a 150 watt lead–light.

No difficulty was experienced in maintaining the suspension concentration constant except for the tungsten suspensions when an extra agitator was required. The mean concentrations circulated are included in Table I. The method of loop operation and collection of results was similar to that used previously, except that samples for total suspended solids were usually taken when the moving bed condition occurred.

When the ¾–in. pipe was in circuit settling occurred in the 1–in. sections of the loop before the ¾–in. section. In order to measure the horizontal settling velocity in the ¾–in. section, it was necessary to allow approximately 15 minutes for the bed in the larger sections to become stable. Samples were taken at the beginning and end of the discharge for the red lead–water system and no significant concentration difference was noticed. For all other systems in the ¾–in. section, samples were taken half way through the discharge.

For red lead, barium sulphate and talc in 1–in., 1½–in. and 2–in. pipes, samples were taken after the start of discharge. For tungsten in 1–in., 1½–in. and 2–in. pipes, it was found more convenient to sample after circulating at high velocity immediately before each run.

The red lead used was the "non–setting" grade supplied by Commonwealth Litharge and Red Lead Pty. Ltd., of Sydney; the barium sulphate was Blanc Fixe manufactured by Farbenfabriken Bayer, A.G., of Germany and supplied by H. H. York and Co., of Sydney; the tungsten powder was the 2 micron grade (microscopic count) supplied by Broken Hill Proprietary Ltd., of Sydney, and the talc was the T.S. pharmaceutical grade supplied by Austral Rock Milling Pty. Ltd., of Sydney.

Particle size distributions of all the powders were determined before use and the results are given in Table II. The Andreasen pipette method with water as suspending medium was used for the barium sulphate, tungsten and talc, but it was not possible to obtain reproducible results for the red lead. The red lead, however, was 95 percent by weight less than 325 mesh Tyler (43 microns), wet screened.

The talc suspension was found to contain a small amount of impurity which was shown (by spectrographic analysis) to contain iron. This tended to obscure the formation of a bed. The bulk of this impurity was removed by sedimentation from the flowing suspension in the horizontal 2-in. test length, but this involved some loss of talc giving an altered particle size distribution.

To determine the new particle size distribution an Andreasen sample was taken from the discharge stream in a tared calibrated container and the whole of the contents were transferred to the Andreasen vessel. At the same time a sample for total solids was taken from the discharge stream. This method avoided the difficulties in obtaining a representative sample for Andreasen analysis from a bulk sample taken from the loop. The method proved successful and gave satisfactory duplicates. It was used to collect samples of talc slurry after removal of the impurity and after completion of the experimental work. The analyses are given in Table II.

Particle size analyses were also obtained on the dry powders by the Sharples Micromerograph and these results are given in Table II for comparison. In all cases the Andreasen results indicate larger particle diameters than the Micromerograph results which again illustrates the lack of agreement between different methods of particle size analysis for sub-sieve particles.

Demineralised water was used for all experiments. No difficulty was experienced in preparing the suspensions, or re-suspending the solid after closing down.

The supernatant liquid was analysed after the experimental work for each system and the dissolved solids were found to be less than 0.1 percent by weight in all cases.

3. RESULTS AND DISCUSSION

The horizontal settling velocity was determined by reducing the flow rate and observing the point at which a moving bed appeared as well as the point at which a stationary bed appeared in the test length. The number of runs from which means for settling velocities were evaluated varied from 2 to 12.

Both moving and stationary beds were readily obtained for most of the systems and pipe sizes used. Because of the measurable differences between mean velocities for moving and stationary beds both have been reported. The only instances in which both beds were not readily obtained were for the runs with tungsten in ¾-in. and 1-in. tubes where the moving bed condition was not reproducible. The stability of a moving bed for the other runs was frequently confirmed by running the loop at moving bed conditions in the test pipe for a period of 30 minutes. Striations (4) were observed in all cases before and during settling.

The results for the horizontal settling velocities are given in Table III, and are summarized in Table IV. Also included in Table IV, are previous results for tungsten (5) and barium sulphate (6) in 1-in. pipes.

(a) Effect of Concentration

For the L.M.F.R. system, only dilute suspensions are required. For the suspension containing 1 atom of uranium to 100 atoms of sodium at 500°C, the concentration of uranium is approximately 9.2 percent by weight or 0.5 percent by volume. For the UBe_{13}-Na system, the concentration of UBe_{13} in Na at 500° C is approximately 13 percent by weight or 3 percent by volume.

For the barium sulphate–water system, which simulates in many respects a UBe13–Na suspension, the concentration of solids circulated was varied between approximately 5 and 16 percent by weight or 1 and 4 percent by volume, for each of the four pipe sizes used. As seen in Table IV, in some cases there was no effect of concentration on the velocity for the formation of a moving bed or stationary bed, while in others there was a small increase in velocity with concentration.

Inspection of the results in Table IV for the red lead–water system, in which the concentration was varied from approximately 7 to 15 percent by weight or 0.8 to 1.9 percent by volume shows that the concentration has little effect on the horizontal settling velocity for moving and stationary beds.

The maximum increase was of the order of 0.2 feet per second. Although concentration appears to have a small effect, it is considered to be negligible over the concentration range studied and mean velocities and concentrations were evaluated for use in later correlations.

It may be concluded that for dilute small particle suspensions with volume concentrations of up to several percent, the horizontal settling velocities are almost independent of the concentration circulating.

(b) Effect of Pipe Diameter

In Figure 2 horizontal settling velocity is plotted against effective density ratio on semi–log paper. This method of correlation has been previously proposed (3) but it can be seen that the pipe diameter variation has caused a spread of the points for each effective density ratio.

The results were replotted on log–log paper as horizontal settling velocity versus internal pipe diameter for constant effective density ratio and straight lines fitted to the points for each system for both moving and stationary bed conditions. This is shown in Figure 3 and the mean slope of the lines was found to be 0.2 .

$$\text{Hence } V \propto (D)^{0.2} \qquad (1)$$

(c) Effect of Solid Density

The results were also plotted on log–log paper as horizontal settling velocity versus effective density ratio for constant pipe diameter and straight lines fitted to the points for each pipe. This is shown in Figure 4. The mean slope for the stationary bed condition is slightly greater than that for the moving bed condition but this difference was considered insignificant and a mean slope of all the lines was obtained. This was found to be 0.3 and hence:

$$V \propto \left[\frac{\rho_s - \rho_l}{\rho_l}\right]^{0.3} \qquad (2)$$

(d) Expression for Horizontal Settling Velocities

The results were recalculated as shown in Table V, and horizontal settling velocity was plotted against $(D)^{0.2}\left[\frac{\rho_s - \rho_l}{\rho_l}\right]^{0.3}$

This is shown in Figure 5 and equations were obtained for V_m and V_s.

These are:

$$V_m = 1.9(D)^{0.2} \left[\frac{\rho_s - \rho_l}{\rho_l}\right]^{0.3} \quad (3)$$

$$V_s^{0.85} = 1.6\,(D)^{0.2}\left[\frac{\rho_s - \rho_l}{\rho_l}\right]^{0.3} \quad (4)$$

The UO_2–NaK data of Abraham et alia (2) have also been plotted on the moving bed graph in Figure 5. Abraham's data correspond more to the moving bed condition than to the stationary bed condition because of the radiometric method of detecting suspended flow used by Abraham. The agreement is good.

The first lime–water point of Settle and Parkins, quoted by Spells (8) has been plotted on the moving bed graph in Figure 5. Agreement is poor. However, more recent information (7) has been obtained which shows that Spells' data and the data from the A.A.E.C. investigations cannot be compared.

It appears (7) that the lime–water settling velocity data were not obtained by direct observation since none of the test installations used by Settle and Parkins contained any transparent section. For the more dilute suspensions the settling velocity was obtained from log pressure drop versus log velocity curves, which cannot be conclusive (4). For the more concentrated suspensions the settling velocity was deduced by timing the passage of a fluorescein dye injection through the pipe, despite the proved presence of a thick bed. Settle and Parkins state that it was not possible to determine the velocity at which a moving or stationary bed formed. It is interesting to note also that the particle sizes as given by Spells (8) are larger than those used in this investigation.

For these reasons the lime–water data of Spells (8) have been rejected in arriving at equations (3) and (4).

Attempts to provide a correlation in terms of dimensionless groups were unsuccessful. It is believed the main difficulty here is lack of a suitable method of evaluating the effective particle diameter.

In this experimental work, the pipe diameter was varied from 2–in. to ¾–in., a ratio of 2.7 to 1. It is to be noted that for a given velocity and suspension this means that the Reynolds number was varied by a ratio of 2.7 to 1. If the Reynolds number of a suspension is a measure of turbulence, as it is with a homogeneous fluid, then it would be expected that the horizontal settling velocities would be very dependent on the Reynolds number, and decrease with increase in pipe diameter to maintain the same Reynolds number.

However, it has been shown that the horizontal settling velocity increases with $D^{0.2}$, i.e., $Re^{0.2}$. In view of this, it may be concluded that the bulk Reynolds number of a suspension is not a measure of turbulence, or degree of suspension.

4. CONCLUSION

In almost all cases a moving bed is formed before a stationary bed in aqueous suspensions of sub–sieve particles, as the horizontal velocity is reduced. For concentrations up to a few percent by volume, the effect of concentration on the formation of a moving or stationary bed was found to be insignificant.

Empirical equations have been obtained for the horizontal settling velocity of aqueous suspensions for both the moving and stationary bed conditions, which hold for effective density ratios of 1.7 to 18.3 and pipe diameters of ¾–in. to 2–in.

Reynolds number of a suspension evaluated from the bulk properties is not a true indication of the degree of turbulence or particle suspension.

5. FURTHER WORK

It is considered that further experimental work on horizontal settling velocities is not required as sufficient work has been done to enable predictions to be made for the L.M.F.R. system. Attempts should be made, however, to correlate data in this investigation for fine particle sizes and dilute suspensions with data from the literature on large particle sizes and higher concentrations.

6. ACKNOWLEDGMENTS

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7. SYMBOLS

V = horizontal settling velocity, ft/sec.

V_m = moving bed velocity, ft/sec.

V_S = stationary bed velocity, ft/sec.

D = internal pipe diameter, ft.

ρ_s = density of solid, lb/cu. ft.

ρ_l = density of liquid, lb/cu. ft.

Re = Reynolds number, dimensionless.

8. REFERENCES

1. Abraham, B.M., Private Communication, December, 1957.

2. Abraham, B.M. Flotow, H.E. and Carlson, R.D., Advances in Nuclear Engineering, Vol. II, Pergamon Press, p. 473, (1957).

3. Cairns, R.C., A.A.E.C./E17, February, 1958.

4. Cairns, R.C., Paper presented at the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, A/Conf. 15/P/1092, September, 1958.

5. Cairns, R.C., and Turner, K.S., A.A.E.C./E5, August, 1957.

6. Cairns, R.C., and Turner, K.S., A.A.E.C./E16, February, 1958.

7. Settle, J.J., Private Communication, September, 1958.

8. Spells, K.E., Trans. Instn. Chem. Engrs., 33, 79, (1955).

9. APPENDIX

Note: Four significant figures were used in the calculations to avoid cumulative errors.

TABLE I

TEST PIPE	MEASURED DIAMETER		DIAMETER CALCULATED FROM VOLUME		MEAN INTERNAL DIAMETER		SUSPENDED SOLID	MEAN CONCENTRATIONS CIRCULATED
	Mean before experiments	Mean after experiments	Mean before experiments	Mean after experiments				
	in.	in.	in.	in.	in.	ft.		% w/w
¾–in. Dicon (1)	0.759	–	–	–	0.759	0.06325	Red Lead	7.8, 14.2
¾–in. Dicon (11)	0.757	0.756	0.756	0.754	0.756	0.06300	Barium sulphate B.H.P. Tungsten Talc	5.0, 9.1, 15.5 5.8 9.3
1–in. Dicon(New)	1.004	1.002	1.005	1.003	1.004	0.08367	Red Lead B.H.P. Tungsten Talc	6.7, 9.0, 14.8 8.2 9.9
1½–in. Dicon	1.498	1.500	–	1.495	1.498	0.1248	Red Lead Barium sulphate B.H.P. Tungsten Talc	9.5, 15.0 5.7, 9.5, 15.7 8.4 9.7
2–in. Dicon	1.999	2.005	–	2.000	2.001	0.1668	Red Lead Barium Sulphate B.H.P. Tungsten Talc	6.8, 9.4, 14.9 5.6, 9.8, 15.5 8.5 9.7

TABLE II

PER CENT UNDERSIZE BY WEIGHT	STOKES DIAMETER, MICRONS											
	Red lead powder before use		Barium sulphate powder before use		B.H.P. tungsten powder before use		Talc powder as received		Talc after purification		Talc after use	
	Andrea–sen	Micro–merograph	Andrea–sen	Micro–merograph	Andrea–sen	Micro–merograph	Andrea–sen	Micro–merograph	Andrea–sen	Micro–merograph	Andrea–sen	Micro–merograph
100	–	29	–	20	–	15	–	52	–	–	–	–
95	–	7.8	–	8.4	–	10	–	31	–	–	45	–
85	–	4.4	35	6.1	–	7.9	43	24	32	–	27	–
70	–	3.3	33	4.8	–	6.1	32	19	24	–	20	–
50	–	2.3	30	3.7	16	4.8	25	15	17	–	14	–
30	–	1.8	26	2.9	13	3.7	16	11	10.5	–	8.3	–
15	–	1.4	20	2.3	9.2	2.8	8.8	8.4	6.2	–	4.5	–
5	–	1.1	10	1.8	5.7	1.8	4.8	5.7	–	–	–	–
0	–	0.96	–	1.4	–	1.0	–	2.4	–	–	–	–

TABLE III

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett lb.	Suspended solids % w/w	Velocity ft./sec.	Observations
Red lead	4.8.1	36.0	59.2	22.98	7.6	1.85	Moving Bed
¾–in. pipe	.2	38.0	64.4	23.94		1.78	Stationary Bed
	.3	40.5	65.8	25.20	7.7	1.83	Moving Bed
	.4	41.0	63.8	23.41		1.77	Stat. Bed
	.5	29.0	57.2	25.30	7.9	2.11	Moving Bed
	.6	31.0	58.4	25.33	7.9	2.07	Moving Bed
	.7	35.0	61.6	24.14	7.8	1.87	Moving Bed
	.8	36.0	63.6	24.87	8.0	1.87	Moving Bed
	.9a	37.5	63.2	24.69	7.9	1.86	Moving Bed
	.9b	38.0	66.0	23.72		1.71	Stat. Bed
	.10	39.5	64.0	24.63		1.84	Stat. Bed
	4.14.1	35.0	61.2	24.05		1.77	Stat. Bed
	.2	36.0	60.8	23.09		1.71	Stat. Bed
	.3	37.0	61.0	26.92	13.8	1.98	Moving Bed
	.4	38.5	60.8	22.64		1.67	Stat. Bed
	.5	39.5	60.6	25.07	13.7	1.86	Moving Bed
	.6	40.5	60.8	30.70	14.4	2.27	Moving Bed
	.7	41.5	61.0	22.54		1.66	Stat. Bed
	.8	42.0	58.4	31.23	14.7	2.40	Moving Bed
	.9	42.5	60.2	28.25	14.2	2.11	Moving Bed
	.10	43.0	59.6	30.24	14.1	2.28	Moving Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett lb.	Suspended solids % w/w	Velocity ft./sec.	Observations
Red lead 1-in. pipe	4.15.1a	35.0	32.2	27.34	6.5	2.34	Moving Bed
	.2	37.0	31.8	21.06		1.83	Stat. Bed
	.3a	38.0	32.0	23.43	6.7	2.02	Moving Bed
	.3b	38.0	31.8	20.35		1.77	Stat. Bed
	.4a	39.0	32.2	23.67	6.8	2.03	Moving Bed
	.4b	39.0	32.0	22.69		1.96	Stat. Bed
	.5a	39.5	31.2	24.51	6.7	2.17	Moving Bed
	.5b	40.0	31.8	22.20		1.93	Stat. Bed
	.6a	41.0	31.2	24.09	6.6	2.13	Moving Bed
	.6b	41.5	31.4	21.39		1.88	Stat. Bed
	.7a	41.5	31.4	23.51	6.7	2.07	Moving Bed
	.7b	42.5	31.6	18.56		1.62	Stat. Bed
	.8a	42.5	31.2	23.55	6.8	2.08	Moving Bed
	.8b	43.0	31.4	20.58		1.81	Stat. Bed
	.9a	43.5	31.0	24.37	6.9	2.17	Moving Bed
	.9b	44.0	31.2	21.04		1.86	Stat. Bed
	.10a	44.0	31.8	24.30	6.8	2.11	Moving Bed
	.10b	45.0	32.4	21.92		1.87	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett lb.	Suspended solids % w/w	Velocity ft./sec.	Observations
	4.5.1b	38.5	31.6	23.95		2.04	Stat. Bed
	.2b	33.0	31.4	25.19	8.7	2.16	Moving Bed
	.2c	34.5	35.6	25.23		1.91	Stat. Bed
	.3b	35.0	30.8	26.42	8.8	2.31	Moving Bed
	.4b	36.5	31.0	26.76	8.9	2.32	Moving Bed
	.4c	37.5	34.4	25.90		2.03	Stat. Bed
	.5b	38.0	31.8	26.63	8.9	2.25	Moving Bed
	.5c	39.0	33.2	26.90		2.18	Stat. Bed
	.6b	39.0	32.0	23.61		1.99	Stat. Bed
	.7b	40.5	31.6	25.29	8.9	2.15	Moving Bed
	.7c	41.0	35.0	24.69		1.90	Stat. Bed
	.8b	41.5	36.8	30.21	9.0	2.21	Moving Bed
	.8c	42.0	35.0	25.18		1.94	Stat. Bed
	.9b	34.0	32.4	25.43	9.5	2.11	Moving Bed
	.9c	35.0	32.8	24.53		2.01	Stat. Bed
	.10b	36.5	33.2	25.69	9.1	2.08	Moving Bed
	.10c	37.5	36.0	24.88		1.86	Stat. Bed
	4.13.1	34.5	33.0	25.92		2.00	Stat. Bed
	.2a	34.0	32.4	29.73	14.5	2.34	Moving Bed
	.2b	34.5	34.6	27.36		2.02	Stat. Bed
	.3a	35.5	32.0	29.07	14.6	2.32	Moving Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				lb.			
	4.13.3b	36.0	34.2	24.60		1.83	Stat. Bed
	.4a	36.5	33.6	27.66	14.7	2.10	Moving Bed
	.4b	36.5	33.4	23.21		1.77	Stat. Bed
	.5	37.5	31.8	24.79		1.99	Stat. Bed
	.6a	37.5	32.0	30.30	15.2	2.41	Moving
	.6b	38.5	31.6	25.99		2.10	Stat. Bed
	.7a	39.0	31.8	25.69	14.7	2.06	Moving Bed
	.7b	39.0	31.8	23.03		1.85	Stat. Bed
	.8a	39.5	31.8	30.57	14.9	2.45	Moving Bed
	.8b	40.0	31.6	24.20		1.95	Stat. Bed
	.9a	40.0	31.0	27.65	14.7	2.27	Moving Bed
	.9b	40.0	31.8	27.16		2.18	Stat. Bed
	.10a	40.5	31.6	29.28	14.9	2.36	Moving Bed
	.10b	40.5	31.8	25.32		2.03	Stat. Bed
Red lead				cu. ft.			
1½-in. pipe	4.9.1a	31.5	58.6	1.881	9.1	2.62	Moving Bed
	.2a	33.5	61.9	1.912	9.3	2.52	Moving Bed
	.3	36.0	65.6	1.917		2.39	Stat. Bed
	.4	36.5	65.0	1.912		2.40	Stat. Bed
	.5a	37.5	63.0	1.891	9.5	2.45	Moving Bed
	.5b	38.0	65.1	1.917		2.41	Stat. Bed
	.6a	39.0	61.6	1.886	9.5	2.50	Moving Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu. ft.			
	4.9.6b	39.5	65.3	1.923		2.41	Stat. Bed
	.7a	40.5	62.5	1.927	9.5	2.52	Moving Bed
	.8a	41.5	65.0	1.927	9.7	2.42	Moving Bed
	.8b	42.0	62.2	1.866		2.45	Stat. Bed
	.9a	42.5	66.9	1.912	9.5	2.34	Moving Bed
	.9b	42.5	66.2	1.902		2.35	Stat. Bed
	.10a	43.0	64.3	1.907	9.6	2.42	Moving Bed
	.10b	43.5	63.7	1.897		2.43	Stat. Bed
	.11	44.0	64.0	1.923	9.5	2.46	Moving Bed
	4.12.1a	27.5	62.4	1.978	14.7	2.59	Moving Bed
	.2	30.5	68.2	1.943		2.33	Stat. Bed
	.3a	32.0	65.4	1.922	14.8	2.40	Moving Bed
	.3b	33.0	67.2	1.943		2.36	Stat. Bed
	.4a	34.0	66.2	1.968	14.9	2.43	Moving Bed
	.4b	35.0	69.4	1.988		2.34	Stat. Bed
	.5a	36.0	65.6	1.943	15.0	2.42	Moving Bed
	.5b	36.5	69.4	1.937		2.28	Stat. Bed
	.6a	37.5	64.2	1.922	14.9	2.45	Moving Bed
	.6b	38.0	68.6	1.958		2.33	Stat. Bed
	.7a	38.5	64.2	1.943	15.0	2.47	Moving Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett cu.ft.	Suspended solids % $w/_w$	Velocity ft./sec.	Observations
	4.12.7b	39.0	69.6	1.958		2.30	Stat. Bed
	.8a	40.0	64.2	1.937	15.1	2.47	Moving Bed
	.8b	40.0	67.4	1.963		2.38	Stat. Bed
	.9a	41.0	65.0	1.963	15.0	2.47	Moving Bed
	.10a	42.0	62.8	1.917	15.3	2.49	Moving Bed
	.10b	42.0	66.6	1.937		2.38	Stat. Bed
	.11	42.5	67.2	1.922		2.34	Stat. Bed
Red lead 2–in. pipe	4.16.1a	36.0	34.0	1.917	6.7	2.58	Moving Bed
	.2a	38.0	34.6	1.912	6.7	2.53	Moving Bed
	.2b	39.5	39.0	1.927		2.26	Stat. Bed
	.3a	40.0	35.0	1.927	6.7	2.52	Moving Bed
	.3b	40.0	38.2	1.922		2.30	Stat. Bed
	.4a	40.0	35.0	1.917	6.8	2.51	Moving Bed
	.4b	40.5	37.6	1.871		2.28	Stat. Bed
	.5a	40.5	34.0	1.856	6.8	2.50	Moving Bed
	.5b	41.0	38.8	1.912		2.26	Stat. Bed
	.6a	41.5	34.6	1.917	6.8	2.54	Moving Bed
	.6b	41.5	38.4	1.891		2.25	Stat. Bed
	.7a	42.0	34.6	1.943	6.8	2.57	Moving Bed
	.7b	42.0	38.8	1.912		2.26	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % $w/_w$	Velocity ft./sec.	Observations
				cu.ft.			
	4.16.8a	42.0	34.8	1.927	6.8	2.53	Moving Bed
	.8b	42.0	38.4	1.860		2.22	Stat. Bed
	.9a	42.0	34.8	1.927	6.8	2.53	Moving Bed
	.9b	42.0	40.2	1.958		2.23	Stat. Bed
	.10a	42.5	33.8	1.865		2.53	Moving Bed
	.10b	42.5	39.0	1.876		2.20	Stat. Bed
	4.10.3a	42.0	35.2	1.948	9.4	2.53	Moving Bed
	.3b	43.0	36.2	1.948		2.46	Stat. Bed
	.4a	43.0	35.6	1.963	9.6	2.52	Moving Bed
	.4b	43.5	36.6	1.983		2.48	Stat. Bed
	.5a	44.0	35.6	1.978	9.5	2.54	Moving Bed
	.5b	44.0	35.2	1.948		2.53	Stat. Bed
	.6	44.5	35.2	1.948		2.53	Stat. Bed
	.7a	45.0	35.4	1.963	9.6	2.54	Moving Bed
	.7b	45.5	35.6	1.958		2.52	Stat. Bed
	.8a	45.5	34.8	1.922	9.6	2.53	Moving Bed
	.8b	46.0	35.2	1.953		2.54	Stat. Bed
	.9a	45.0	35.4	1.937	9.3	2.51	Moving Bed
	.10a	38.0	34.5	1.958	9.1	2.60	Moving Bed
	.11a	40.0	34.9	1.963	9.3	2.58	Moving Bed
	.11b	42.5	36.4	1.948		2.45	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu.ft.			
	4.10.12a	43.0	34.4	1.896	9.4	2.52	Moving Bed
	.12b	43.0	35.1	1.856		2.42	Stat. Bed
	.13a	44.0	34.8	1.917	9.4	2.52	Moving Bed
	.13b	44.0	35.1	1.866		2.43	Stat. Bed
	.14a	44.5	35.8	1.973	9.5	2.52	Moving Bed
	.14b	44.5	36.7	1.927		2.40	Stat. Bed
	4.11.1a	36.0	33.8	1.923	14.6	2.60	Moving Bed
	.2a	38.0	33.9	1.932	14.8	2.61	Moving Bed
	.2b	38.5	34.3	1.907		2.55	Stat. Bed
	.3a	39.0	33.5	1.907	14.8	2.61	Moving Bed
	.3b	39.5	34.8	1.937		2.55	Stat. Bed
	.4a	40.0	34.4	1.948	15.0	2.59	Moving Bed
	.4b	40.0	33.5	1.896		2.59	Stat. Bed
	.5	40.5	33.0	1.881		2.61	Stat. Bed
	.6a	41.0	33.9	1.923	14.9	2.60	Moving Bed
	.6b	41.5	35.2	2.004		2.61	Stat. Bed
	.7a	42.0	34.2	1.963	14.9	2.63	Moving Bed
	.7b	42.5	35.6	1.999		2.57	Stat. Bed
	.8a	42.5	33.8	1.937	15.1	2.62	Moving Bed
	.8b	43.0	33.8	1.886		2.55	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu. ft.			
	4.11.9a	43.0	35.0	2.104	15.0	2.75	Moving Bed
	.9b	43.5	33.4	1.850		2.54	Stat. Bed
	.10a	44.0	34.0	1.963	15.1	2.64	Moving Bed
	.10b	44.0	34.6	1.937		2.56	Stat. Bed
	.11a	44.5	34.0	1.958	15.0	2.64	Moving Bed
	.11b	45.0	34.2	1.927		2.58	Stat. Bed
	.12	45.5	34.2	1.963	15.1	2.63	Moving Bed
				lb.			
Barium sulphate ¾-in. pipe	4.25.1	26.0	65.2	19.55		1.49	Stat. Bed
	.2	27.5	65.5	21.60	5.1	1.64	Moving Bed
	.3	29.5	66.0	20.19		1.52	Stat. Bed
	.4	31.0	64.4	20.29	5.0	1.57	Moving Bed
	.5	32.5	64.7	18.93		1.45	Stat. Bed
	.6	33.5	64.2	20.26	5.0	1.57	Moving Bed
	.7	34.5	63.8	18.12		1.41	Stat. Bed
	.8	35.5	64.4	18.58		1.43	Stat. Bed
	.9	37.0	63.9	19.46	4.8	1.51	Moving Bed
	.10	38.0	69.5	20.56	4.8	1.47	Moving Bed
	.11	39.0	66.8	19.06		1.42	Stat. Bed
	.12	39.5	65.6	21.36	5.0	1.62	Moving Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett lb.	Suspended solids % $\bar{w}/w$	Velocity ft./sec.	Observations
	4.20.1	32.0	64.9	20.24	8.9	1.50	Moving Bed
	.2	34.5	64.2	20.29	9.0	1.52	Moving Bed
	.3	36.0	65.4	19.31		1.42	Stat. Bed
	.4	38.0	67.3	22.14	9.2	1.58	Moving Bed
	.5	40.5	66.1	21.98	9.2	1.60	Moving Bed
	.6	44.0	65.6	20.12	9.1	1.48	Moving Bed
	.7	34.0	65.4	21.36	9.1	1.57	Moving Bed
	.8	36.5	65.2	18.94		1.40	Stat. Bed
	.9	38.0	64.8	21.30	9.1	1.58	Moving Bed
	.10	40.0	65.0	20.90	9.1	1.55	Moving Bed
	4.19.1	32.0	61.6	22.70	15.7	1.68	Moving Bed
	.2	35.0	62.8	21.89	15.3	1.59	Moving Bed
	.3	36.5	69.8	22.12		1.44	Stat. Bed
	.4	38.0	66.6	22.08	15.1	1.51	Moving Bed
	.5	39.5	63.6	20.93	15.4	1.50	Moving Bed
	.6	40.5	69.8	21.76		1.42	Stat. Bed
	.7	42.5	69.8	22.72	15.3	1.48	Moving Bed
	.8	43.0	67.4	21.69		1.47	Stat. Bed
	.9	44.0	67.6	23.28	15.9	1.57	Moving Bed
	.10	44.5	67.9	22.37	15.8	1.50	Moving Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu.ft.			
Barium sulphate 1½-in. pipe	4.24.1	28.5	86.8	1.926	5.7	1.81	Moving Bed
	.2	29.5	94.2	1.900		1.65	Stat. Bed
	.3a	30.0	86.2	1.900	5.7	1.80	Moving Bed
	.3b	31.0	100.1	1.916		1.56	Stat. Bed
	.4a	31.5	84.6	1.936	5.7	1.87	Moving Bed
	.4b	32.0	97.4	1.916		1.61	Stat. Bed
	.5a	32.5	86.7	1.926	5.7	1.82	Moving Bed
	.5b	33.0	97.0	1.920		1.62	Stat. Bed
	.6a	32.5	86.3	1.931	5.7	1.83	Moving Bed
	.6b	33.0	96.1	1.920		1.63	Stat. Bed
	.7a	34.5	85.7	1.916	5.7	1.83	Moving Bed
	.7c	36.0	96.9	1.906		1.61	Stat. Bed
	.8a	36.0	87.6	1.910	5.7	1.78	Moving Bed
	.8b	36.5	98.8	1.936		1.60	Stat. Bed
	.9a	37.0	88.1	1.916	5.7	1.78	Moving Bed
	.9c	38.0	97.0	1.916		1.61	Stat. Bed
	.10a	38.0	90.5	1.920	5.7	1.73	Moving Bed
	.10b	38.5	96.9	1.906		1.61	Stat. Bed
	.11a	39.0	90.7	1.916	5.7	1.73	Moving Bed
	.11b	39.0	96.8	1.916		1.62	Stat. Bed
	.12a	39.0	89.7	1.936	5.7	1.76	Moving Bed
	.12b	39.5	97.4	1.906		1.60	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu. ft.			
	4.21.1a	30.0	85.1	1.910	9.4	1.83	Moving Bed
	.2a	32.5	82.4	1.916	9.7	1.90	Moving Bed
	.2b	33.0	95.9	1.926		1.64	Stat. Bed
	.3a	34.5	81.9	1.951	9.6	1.95	Moving Bed
	.3b	35.0	97.6	1.931		1.62	Stat. Bed
	.4a	35.5	88.0	1.880	9.5	1.75	Moving Bed
	.4b	36.0	95.8	1.906		1.63	Stat. Bed
	.5a	36.5	85.2	1.916	9.5	1.84	Moving Bed
	.5b	37.0	95.3	1.916		1.64	Stat. Bed
	.6a	37.0	81.0	1.906	9.5	1.92	Moving Bed
	.6b	37.5	95.7	1.926		1.65	Stat. Bed
	.7a	38.0	87.9	1.926	9.5	1.79	Moving Bed
	.7b	38.5	95.8	1.920		1.64	Stat. Bed
	.8a	39.0	85.2	1.916	9.5	1.84	Moving Bed
	.8b	39.0	98.0	1.900		1.58	Stat. Bed
	.9a	39.5	83.9	1.916	9.5	1.87	Moving Bed
	.9c	40.5	93.5	1.931		1.69	Stat. Bed
	.10a	41.0	89.9	1.870	9.5	1.70	Moving Bed
	.11a	42.5	89.7	1.895	9.5	1.73	Moving Bed
	.11b	43.0	96.8	1.916		1.62	Stat. Bed
	.12a	43.0	85.6	1.946	9.5	1.86	Moving Bed
	.12b	44.0	95.9	1.941		1.65	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu.ft.			
	4.18.1a	32.0	79.5	1.895	15.7	1.95	Moving Bed
	.2a	34.5	88.0	1.885	15.7	1.75	Moving Bed
	.2b	34.5	99.2	1.885		1.55	Stat. Bed
	.3a	35.5	88.7	1.906	15.7	1.76	Moving Bed
	.3b	35.5	95.2	1.920		1.65	Stat. Bed
	.4a	36.5	79.3	1.906	15.7	1.96	Moving Bed
	.4b	37.0	92.8	1.906		1.68	Stat. Bed
	.5a	37.5	75.4	1.885	15.7	2.04	Moving Bed
	.5b	38.0	95.9	1.916		1.63	Stat. Bed
	.6a	38.5	79.1	1.895	15.8	1.96	Moving Bed
	.6b	39.0	94.4	1.870		1.62	Stat. Bed
	.7a	39.5	76.9	1.895	15.8	2.01	Moving Bed
	.7b	40.0	92.1	1.880		1.67	Stat. Bed
	.8a	40.5	79.7	1.916	15.7	1.96	Moving Bed
	.8b	40.5	98.7	1.875		1.55	Stat. Bed
	.9a	41.0	82.0	1.926	15.8	1.92	Moving Bed
	.9b	41.0	95.3	1.895		1.62	Stat. Bed
	.10a	41.5	85.3	1.890	15.7	1.81	Moving Bed
	.10b	41.5	101.1	1.910		1.54	Stat. Bed
	.11a	42.5	76.9	1.875	15.8	1.99	Moving Bed
	.11b	42.5	94.0	1.906		1.66	Stat. Bed
	.12a	43.0	80.2	1.916	15.8	1.95	Moving Bed
	.12c	44.0	94.2	1.890		1.64	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu.ft.			
Barium sulphate 2-in. pipe	4.23.1a	27.0	43.7	1.941	5.5	2.03	Moving Bed
	.1b	28.0	52.2	1.946		1.71	Stat. Bed
	.2a	29.0	45.1	1.946	5.5	1.98	Moving Bed
	.2b	29.5	51.6	1.926		1.71	Stat. Bed
	.3a	25.0	44.4	1.946	5.6	2.01	Moving Bed
	.3b	25.5	50.6	1.916		1.73	Stat. Bed
	.4a	26.5	44.7	1.946	5.6	1.99	Moving Bed
	.4b	27.0	51.8	1.926		1.70	Stat. Bed
	.5a	28.0	45.0	1.931	5.6	1.96	Moving Bed
	.5b	29.0	52.4	1.926		1.68	Stat. Bed
	.6a	29.5	46.6	1.931	5.6	1.90	Moving Bed
	.6b	30.0	52.1	1.946		1.71	Stat. Bed
	.7a	30.5	46.6	1.926	5.6	1.89	Moving Bed
	.7b	31.0	51.9	1.926		1.70	Stat. Bed
	.8a	31.5	47.3	1.962	5.6	1.90	Moving Bed
	.8b	32.0	52.3	1.941		1.70	Stat. Bed
	.9a	33.0	46.7	1.926	5.6	1.89	Moving Bed
	.9b	33.0	52.2	1.936		1.70	Stat. Bed
	.10a	34.0	46.8	1.916	5.6	1.87	Moving Bed
	.10c	35.0	52.1	1.926		1.69	Stat. Bed
	.11a	35.5	46.8	1.906	5.6	1.86	Moving Bed
	.11b	36.0	52.6	1.936		1.69	Stat. Bed
	.12a	36.5	48.6	1.916	5.6	1.80	Moving Bed
	.12b	36.5	49.6	1.835		1.69	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu.ft.			
	4.22.1a	31.0	42.2	1.910	9.7	2.07	Moving Bed
	.2a	34.0	43.0	1.926	9.8	2.05	Moving Bed
	.2b	35.0	49.0	1.941		1.81	Stat. Bed
	.3a	36.0	43.2	1.936	9.7	2.05	Moving Bed
	.3b	36.0	49.7	1.941		1.79	Stat. Bed
	.4a	37.0	42.7	1.906	9.8	2.04	Moving Bed
	.4b	37.0	50.0	1.936		1.77	Stat. Bed
	.5a	38.0	45.1	1.946	9.8	1.98	Moving Bed
	.5b	38.0	50.4	1.931		1.75	Stat. Bed
	.6a	39.0	44.3	1.920	9.8	1.98	Moving Bed
	.6b	39.0	50.1	1.926		1.76	Stat. Bed
	.7a	39.5	45.3	1.916	9.8	1.94	Moving Bed
	.7b	39.5	51.6	1.936		1.72	Stat. Bed
	.8a	40.0	45.4	1.916	9.8	1.93	Moving Bed
	.8b	40.0	51.2	1.920		1.72	Stat. Bed
	.9a	40.5	46.0	1.936	9.9	1.93	Moving Bed
	.9b	40.5	51.1	1.926		1.73	Stat. Bed
	.10a	41.0	45.5	1.931	9.8	1.94	Moving Bed
	.10c	41.5	51.7	1.946		1.72	Stat. Bed
	.11a	42.0	45.4	1.920	9.9	1.94	Moving Bed
	.11b	42.0	51.8	1.936		1.71	Stat. Bed
	.12a	42.5	45.1	1.916	9.8	1.94	Moving Bed
	.12b	42.5	51.5	1.926		1.71	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu.ft.			
	4.17.1a	29.0	43.5	1.931	15.5	2.03	Moving Bed
	.2a	32.0	43.0	1.967	15.5	2.09	Moving Bed
	.2b	33.0	49.8	1.946		1.79	Stat. Bed
	.3a	34.5	44.0	1.951	15.5	2.03	Moving Bed
	.3b	35.0	51.9	1.936		1.71	Stat. Bed
	.4a	35.5	44.1	1.941	15.5	2.01	Moving Bed
	.4b	36.0	49.8	1.926		1.77	Stat. Bed
	.5a	37.0	43.6	1.920	15.5	2.02	Moving Bed
	.5b	37.0	50.1	1.920		1.75	Stat. Bed
	.6a	37.5	43.5	1.920	15.5	2.02	Moving Bed
	.6b	38.0	50.5	1.926		1.75	Stat. Bed
	.7a	38.5	43.3	1.910	15.5	2.02	Moving Bed
	.7b	39.0	50.6	1.916		1.73	Stat. Bed
	.8a	39.5	44.1	1.916	15.5	1.99	Moving Bed
	.8b	40.0	50.2	1.885		1.72	Stat. Bed
	.9a	40.0	44.2	1.910	15.5	1.98	Moving Bed
	.9b	40.5	51.5	1.926		1.71	Stat. Bed
	.10a	41.0	44.2	1.896	15.5	1.96	Moving Bed
	.10b	41.0	49.7	1.916		1.76	Stat. Bed
	.11a	41.5	44.5	1.916	15.5	1.97	Moving Bed
	.11b	42.0	50.6	1.896		1.72	Stat. Bed
	.12a	42.0	45.5	1.957	15.5	1.97	Moving Bed
	.12c	42.5	51.2	1.890		1.69	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				lb.			
B.H.P. tungsten ¾–in. pipe	4.29.1	30.5	41.6	22.00	5.9	2.58	Stat. Bed
	.2	31.5	41.6	20.76	5.6	2.44	Stat. Bed
	.3	33.0	40.8	23.67	6.3	2.82	Stat. Bed
	.4	33.5	39.4	18.23	5.4	2.27	Stat. Bed
	.5	34.0	39.4	20.49	6.0	2.54	Stat. Bed
	.6	35.0	39.7	22.41	6.0	2.75	Stat. Bed
	.7	36.0	39.9	22.70	6.0	2.77	Stat. Bed
	.8	36.5	39.6	20.69	5.8	2.55	Stat. Bed
	.9	37.0	39.7	17.21	5.0	2.13	Stat. Bed
	.10	38.0	39.9	21.04	5.9	2.57	Stat. Bed
	.11	38.0	39.3	21.41	6.1	2.65	Stat. Bed
	.12	38.5	40.7	20.01	5.4	2.41	Stat. Bed
				cu.ft.			
B.H.P. tungsten 1–in. pipe	4.26.1	26.5	121.8	1.895	8.4	2.83	Stat. Bed
	.2	28.5	117.8	1.875	8.1	2.90	Stat. Bed
	.3	30.5	124.7	1.880	8.2	2.74	Stat. Bed
	.4b	33.0	118.2	1.880	8.2	2.89	Stat. Bed
	.5	34.0	130.5	1.880	7.9	2.62	Stat. Bed
	.6	35.0	129.0	1.885	8.0	2.66	Stat. Bed
	.7	35.5	130.0	1.910	8.1	2.67	Stat. Bed
	.8	36.0	123.6	1.885	8.3	2.77	Stat. Bed
	.9	37.0	124.3	1.895	8.2	2.77	Stat. Bed
	.10	37.5	124.7	1.900	8.1	2.77	Stat. Bed
	.11	38.0	129.7	1.885	8.2	2.64	Stat. Bed
	.12a	38.5	125.3	1.880	8.2	2.73	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu.ft.			
B.H.P. tungsten 1½–in. pipe	4.27.1a	30.0	49.2	1.890	8.2	3.14	Moving Bed
	.1b	31.0	50.2	1.885		3.07	Stat. Bed
	.2a	32.0	49.2	1.870	7.9	3.11	Moving Bed
	.2b	32.5	50.8	1.895		3.05	Stat. Bed
	.3a	33.0	49.6	1.875	8.4	3.09	Moving Bed
	.3b	33.5	50.7	1.890		3.05	Stat. Bed
	.4a	34.5	50.2	1.885	8.3	3.07	Moving Bed
	.4c	35.5	50.6	1.870		3.02	Stat. Bed
	.5a	36.0	51.0	1.910	8.4	3.06	Moving Bed
	.5b	36.5	51.5	1.890		3.00	Stat. Bed
	.6a	37.0	50.7	1.895	8.4	3.05	Moving Bed
	.6b	37.0	50.8	1.865		3.00	Stat. Bed
	.7a	37.5	50.2	1.880	8.5	3.06	Moving Bed
	.7b	38.0	51.8	1.885		2.97	Stat. Bed
	.8a	38.0	51.0	1.895	8.5	3.04	Moving Bed
	.8c	38.5	52.6	1.905		2.96	Stat. Bed
	.9a	39.0	51.1	1.905	8.5	3.05	Moving Bed
	.9b	39.0	52.0	1.895		2.98	Stat. Bed
	.10a	39.5	50.4	1.875	8.8	3.04	Moving Bed
	.10b	39.5	51.7	1.885		2.98	Stat. Bed
	.11a	39.5	50.7	1.880	8.6	3.03	Moving Bed
	.11b	39.5	51.5	1.875		2.98	Stat. Bed
	.12a	40.0	51.3	1.905	8.6	3.03	Moving Bed
	.12b	40.0	51.9	1.885		2.97	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % $v/_w$	Velocity ft./sec.	Observations
				cu.ft.			
B.H.P. tungsten 2–in. pipe	4.28.1a	28.5	30.3	2.161	8.3	3.26	Moving Bed
	.1b	29.5	31.5	2.172		3.16	Stat. Bed
	.2a	30.5	31.1	2.192	8.6	3.23	Moving Bed
	.2b	31.0	32.6	2.202		3.09	Stat. Bed
	.3a	31.5	31.3	2.192	8.3	3.20	Moving Bed
	.3b	32.0	32.8	2.202		3.07	Stat. Bed
	.4a	32.5	31.8	2.197	8.3	3.16	Moving Bed
	.4c	33.5	32.6	2.172		3.05	Stat. Bed
	.5a	34.0	31.4	2.167	8.4	3.16	Moving Bed
	.5b	34.0	32.7	2.187		3.06	Stat. Bed
	.6a	34.5	31.9	2.202	8.5	3.16	Moving Bed
	.6b	35.0	32.5	2.182		3.07	Stat. Bed
	.7a	35.0	31.7	2.182	8.3	3.15	Moving Bed
	.7b	35.0	32.7	2.182		3.05	Stat. Bed
	.8a	35.5	31.9	2.187	8.6	3.14	Moving Bed
	.8b	36.0	31.7	2.187		3.16	Stat. Bed
	.9a	36.0	31.6	2.172	8.6	3.15	Moving Bed
	.9b	36.5	32.6	2.197		3.08	Stat. Bed
	.10a	36.5	31.7	2.187	8.6	3.16	Moving Bed
	.10b	37.0	32.0	2.167		3.10	Stat. Bed
	.11a	37.0	32.1	2.192	8.7	3.13	Moving Bed
	.11b	37.0	33.1	2.207		3.05	Stat. Bed
	.12a	37.0	32.2	2.182	8.5	3.10	Moving Bed
	.12b	37.0	31.8	2.161		3.11	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett lb.	Suspended solids % w/w	Velocity ft./sec.	Observations
Talc ¾–in.pipe	5.4.2	26.0	68.1	20.82	9.2	1.49	Moving Bed
	.3	28.0	70.3	20.79	9.4	1.44	Moving Bed
	.4	29.0	70.2	19.14	9.2	1.33	Moving Bed
	.5	30.0	69.7	17.53		1.22	Stat. Bed
	.6	31.0	70.1	17.33		1.20	Stat. Bed
	.7	31.5	69.8	16.96		1.18	Stat. Bed
	.8	32.0	69.6	15.72		1.10	Stat. Bed
	.9	33.0	70.5	18.41	9.4	1.27	Moving Bed
	.10	33.5	70.6	16.89		1.16	Stat. Bed
	.11	34.0	70.3	19.35	9.2	1.34	Moving Bed
	.12	34.5	70.2	16.86		1.17	Stat. Bed
Talc 1–in.pipe	5.3.1a	25.5	47.9	23.07	9.9	1.32	Moving Bed
	.1b	26.0	51.8	22.23		1.18	Stat. Bed
	.2a	26.5	44.1	22.99	9.9	1.43	Moving Bed
	.2b	27.0	51.4	20.70		1.11	Stat. Bed
	.3a	27.5	43.8	22.73	9.8	1.42	Moving Bed
	.3b	28.0	55.0	23.79		1.19	Stat . Bed
	.4a	28.5	44.5	22.75	9.8	1.40	Moving Bed
	.4b	29.0	51.9	23.53		1.24	Stat. Bed
	.5a	29.5	44.1	23.77	9.9	1.48	Moving Bed
	.5b	30.0	50.8	23.15		1.25	Stat. Bed
	.6a	30.5	46.7	23.42	9.9	1.38	Moving Bed
	.6c	31.5	50.8	22.95		1.24	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				lb.			
	5.3.7a	32.0	45.4	23.86	9.9	1.44	Moving Bed
	.7b	32.0	49.7	22.72		1.25	Stat. Bed
	.8a	32.5	44.7	23.60	9.8	1.45	Moving Bed
	.8c	33.0	52.3	23.08		1.21	Stat. Bed
	.9a	33.5	45.5	23.22	9.9	1.40	Moving Bed
	.9b	33.5	53.6	24.51		1.25	Stat. Bed
	.10a	34.0	46.0	24.21	9.9	1.44	Moving Bed
	.10b	34.0	51.2	23.30		1.25	Stat. Bed
	.11a	34.0	43.1	23.13	9.9	1.47	Moving Bed
	.11b	34.0	54.3	23.52		1.19	Stat. Bed
	.12a	34.5	43.1	22.13	9.9	1.41	Moving Bed
	.12b	34.5	50.7	22.35		1.21	Stat. Bed
				cu.ft.			
Talc 1½–in. pipe	5.2.1a	26.0	99.5	1.885	9.7	1.55	Moving Bed
	.1b	26.0	129.4	1.890		1.19	Stat. Bed
	.2a	27.0	102.2	1.900	9.7	1.52	Moving Bed
	.2b	27.5	125.1	1.910		1.25	Stat. Bed
	.3a	29.0	107.0	1.900	9.7	1.45	Moving Bed
	.3b	29.5	114.8	1.900		1.35	Stat. Bed
	.4a	30.0	106.7	1.895	9.6	1.45	Moving Bed
	.4c	31.5	120.0	1.905		1.30	Stat. Bed
	.5a	31.5	110.9	1.895	9.7	1.40	Moving Bed
	.5b	32.0	117.3	1.895		1.32	Stat. Bed
	.6a	32.5	111.6	1.900	9.7	1.39	Moving Bed
	.6b	32.5	119.3	1.885		1.29	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu.ft.			
	5.2.7a	33.0	107.8	1.900	9.7	1.44	Moving Bed
	.7b	33.0	116.9	1.905		1.33	Stat. Bed
	.8a	33.0	106.4	1.900	9.8	1.46	Moving Bed
	.8b	33.5	116.4	1.920		1.35	Stat. Bed
	.9a	34.0	107.3	1.895	9.7	1.44	Moving Bed
	.9c	34.5	117.9	1.895		1.31	Stat. Bed
	.10a	35.0	110.1	1.885	9.8	1.40	Moving Bed
	.10b	35.0	117.6	1.895		1.32	Stat. Bed
	.11a	35.0	109.4	1.905	9.8	1.42	Moving Bed
	.11b	35.0	117.5	1.895		1.32	Stat. Bed
	.12a	35.0	107.0	1.895	9.8	1.45	Moving Bed
	.12b	35.0	117.9	1.900		1.32	Stat. Bed
Talc 2–in. pipe	5.1.1a	22.0	49.1	1.925	9.7	1.80	Moving Bed
	.1b	23.5	62.4	1.915		1.41	Stat. Bed
	.2a	24.5	52.1	1.925	9.7	1.69	Moving Bed
	.2b	25.5	62.5	1.900		1.39	Stat. Bed
	.3a	26.5	53.8	1.910	9.6	1.63	Moving Bed
	.3b	26.5	66.1	1.915		1.33	Stat. Bed
	.4a	27.5	52.7	1.885	9.7	1.64	Moving Bed
	.4b	28.0	64.2	1.920		1.37	Stat. Bed
	.5a	28.5	54.9	1.925	9.6	1.61	Moving Bed
	.5c	30.0	64.7	1.915		1.36	Stat. Bed
	.6a	30.0	55.9	1.920	9.7	1.57	Moving Bed
	.6b	30.5	63.0	1.895		1.38	Stat. Bed

TABLE III (Contd.)

Material and pipe size	Run	Temperature °C	Time secs.	Discharge nett	Suspended solids % w/w	Velocity ft./sec.	Observations
				cu.ft.			
	5.1.7a	31.0	56.5	1.900	9.7	1.54	Moving Bed
	.7b	31.0	63.6	1.905		1.37	Stat. Bed
	.8a	31.5	56.7	1.915	9.7	1.55	Moving Bed
	.8c	32.0	63.6	1.895		1.36	Stat. Bed
	.9a	32.5	57.5	1.920	9.7	1.53	Moving Bed
	.9b	32.5	63.2	1.890		1.37	Stat. Bed
	.10a	33.0	56.8	1.910	9.7	1.54	Moving Bed
	.10b	33.0	64.0	1.925		1.38	Stat. Bed
	.11a	33.0	52.8	1.936	9.8	1.68	Moving Bed
	.11b	33.0	62.5	1.905		1.40	Stat. Bed
	.12a	33.5	53.6	1.905	9.8	1.63	Moving Bed
	.12b	33.5	65.2	1.915		1.34	Stat. Bed

TABLE IV

SYSTEM	Effective Density ratio $\frac{\rho_s-\rho_l}{\rho_l}$		¾-inch pipe: Mean Concentration Circulated %w/w	¾-inch pipe: Mean Concentration Circulated %v/v	¾-inch pipe: Moving Bed Velocity V_m ft/sec.	¾-inch pipe: Stationary Bed Velocity V_s ft/sec.	1-inch pipe: Mean concentration Circulated %w/w	1-inch pipe: Mean concentration Circulated %v/v	1-inch pipe: Moving Bed Velocity V_m ft/sec.	1-inch pipe: Stationary Bed Velocity V_s ft/sec.	1½-inch: Mean Concentration Circulated %w/w	1½-inch: Mean Concentration Circulated %v/v
Talc–water	1.7		9.3	3.7	1.37	1.17	9.9	3.9	1.42	1.21	9.7	3.8
Barium sulphate–water	3.5		5.0	1.2	1.56	1.45	5.5	1.3	1.45*	1.34*	5.7	1.3
			9.1	2.2	1.55	1.41	9.6	2.3	1.59*	1.41*	9.5	2.3
			15.5	3.9	1.55	1.44	16.2	4.1	1.63*	1.42*	15.7	4.0
		Means	9.9		1.55	1.43	10.4		1.56*	1.39*	10.3	
Red Lead–water	8.1		–	–	–	–	6.7	0.79	2.12	1.84	–	–
			7.8	0.92	1.92	1.78	9.0	1.1	2.20	1.98	9.5	1.1
			14.2	1.8	2.15	1.70	14.8	1.9	2.29	1.97	15.0	1.9
		Means	11.0		2.04	1.74	10.2		2.20	1.93	12.3	
HR1 Tungsten–water	18.3		–	–	–	–	6.2	0.34	–	2.62†	–	–
BHP Tungsten–water	18.3		5.8	0.32	–	2.54	8.2	0.46	–	2.75	8.4	0.48

* AAEC/E 16

† AAEC/E 5

TABLE V

System	Test Pipe	V_m ft/sec	V_s ft/sec	D ft	$(D)^{0.2}$	$\frac{\rho_s-\rho_l}{\rho_l}$	$\left[\frac{\rho_s-\rho_l}{\rho_l}\right]^{0.3}$	$(D)^{0.2}\left[\frac{\rho_s-\rho_l}{\rho_l}\right]^{0.3}$
Talc–water	¾ in.	1.37	1.17	0.06300	0.5753	1.7	1.172	0.674
	1 in.	1.42	1.21	0.08367	0.6088	1.7	1.172	0.714
	1½ in.	1.45	1.30	0.1248	0.6595	1.7	1.172	0.773
	2 in.	1.62	1.37	0.1668	0.6988	1.7	1.172	0.819
Barium sulphate–water	¾ in.	1.55	1.43	0.06300	0.5753	3.5	1.456	0.838
	1 in.	1.56	1.39	0.08367	0.6088	3.5	1.456	0.886
	1½ in.	1.85	1.62	0.1248	0.6595	3.5	1.456	0.960
	2 in.	1.97	1.73	0.1668	0.6988	3.5	1.456	1.017
Red lead–water	¾ in.	2.04	1.74	0.06325	0.5757	8.1	1.874	1.079
	1 in.	2.20	1.93	0.08367	0.6088	8.1	1.874	1.141
	1½ in.	2.47	2.38	0.1248	0.6595	8.1	1.874	1.236
	2 in.	2.57	2.43	0.1668	0.6988	8.1	1.874	1.310
HR1 tungsten–water	1 in.	–	2.62	0.08292	0.6077	18.3	2.392	1.454
B.H.P. tungsten–water	¾ in.	–	2.54	0.06300	0.5753	18.3	2.392	1.376
	1 in.	–	2.75	0.08367	0.6088	18.3	2.392	1.456
	1½ in.	3.06	3.00	0.1248	0.6595	18.3	2.392	1.578
	2 in.	3.17	3.09	0.1668	0.6988	18.3	2.392	1.672
UO_2–NaK(2) 25°C	0.437 in(1)	2.1		0.03642	0.5156	11.5	2.081	1.073
450°C	0.437 in(1)	2.4		0.03642	0.5156	13.2	2.169	1.118
Lime–water(8) 10%	10.2 cm	0.90		0.3344	0.8032	1.0	1.0	0.803

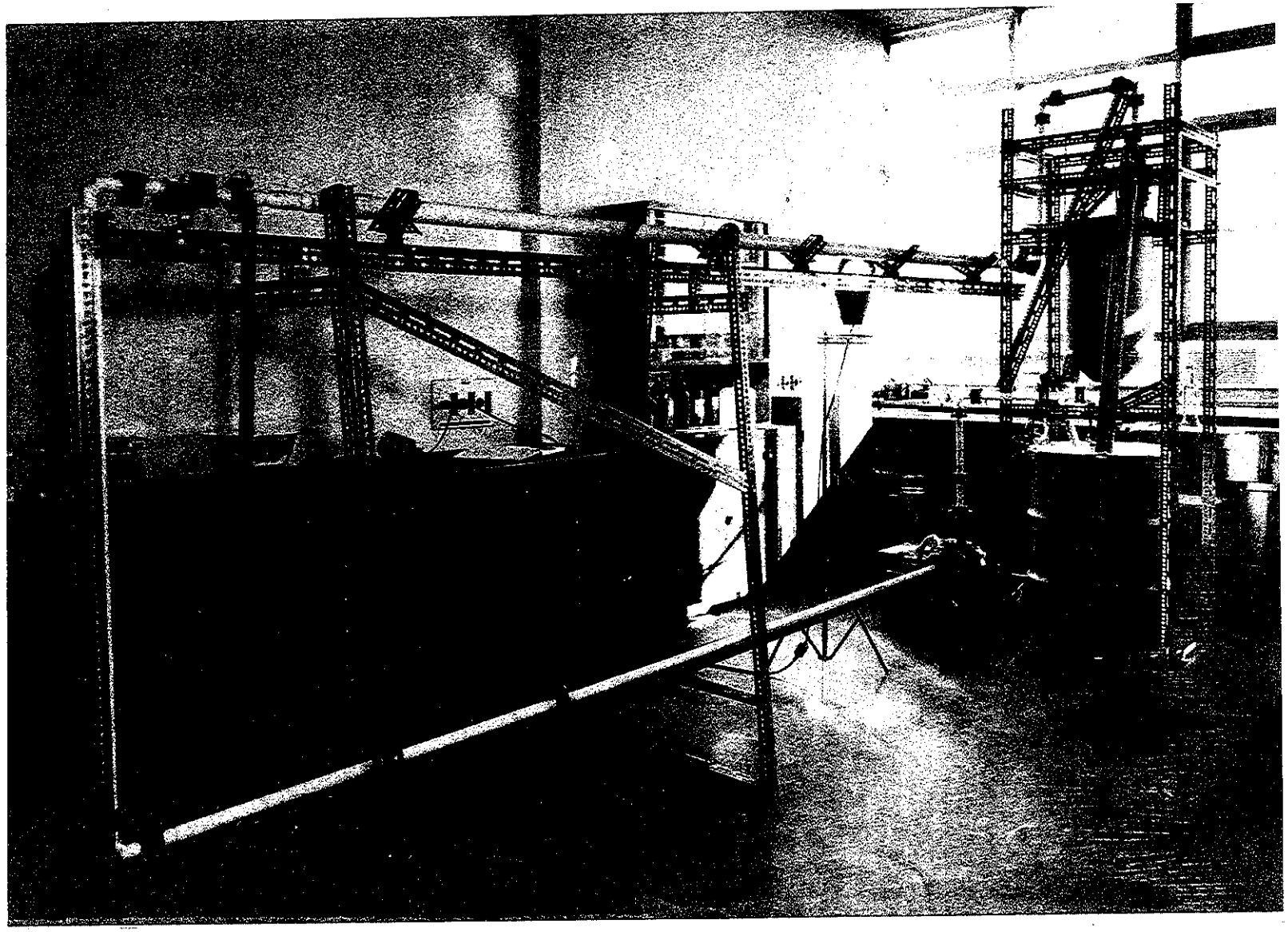

FIGURE 1 : Photograph of loop operating with 2-in. test pipe installed.

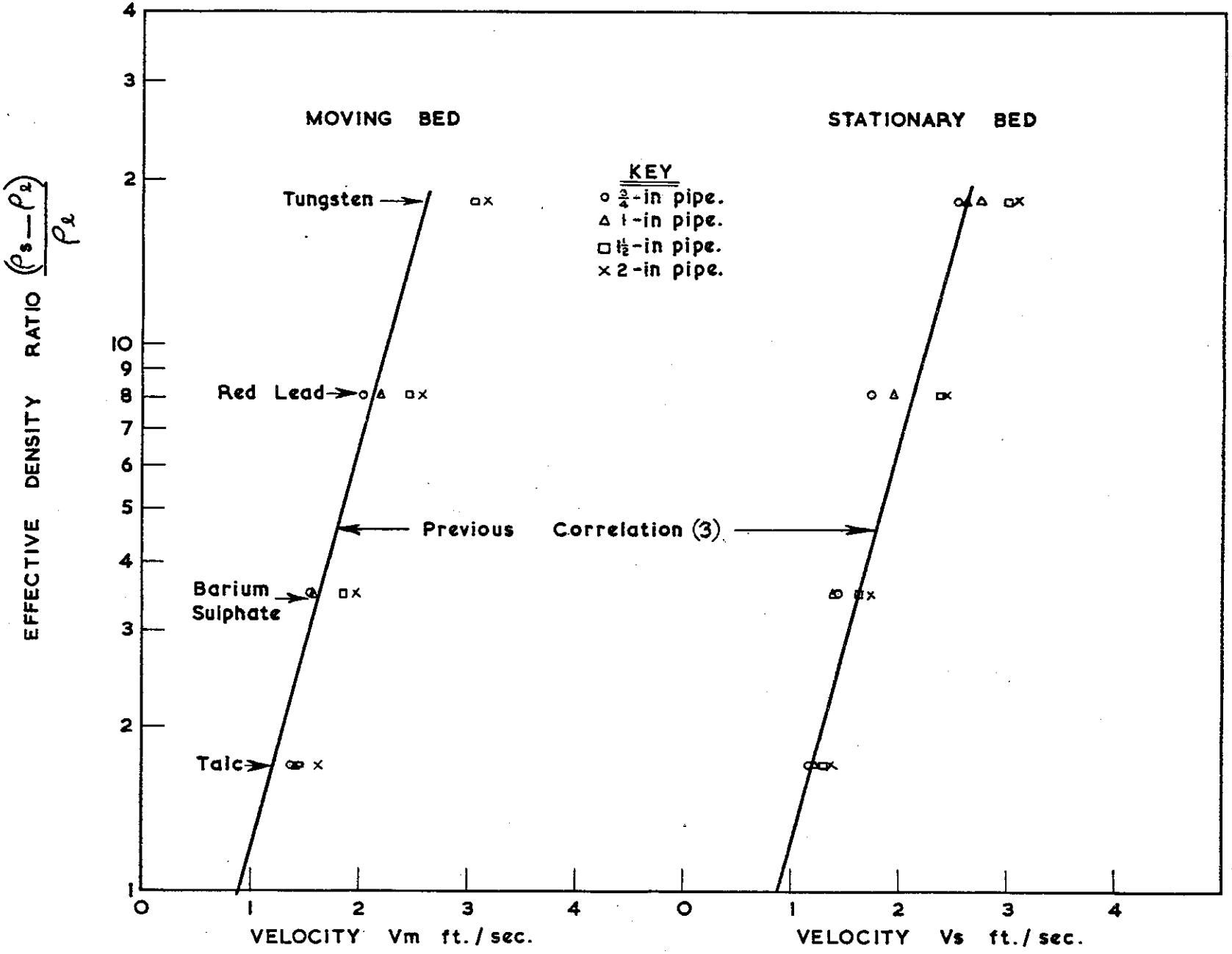

Fig. 2. Effective Density Ratio vs Horizontal Settling Velocity.

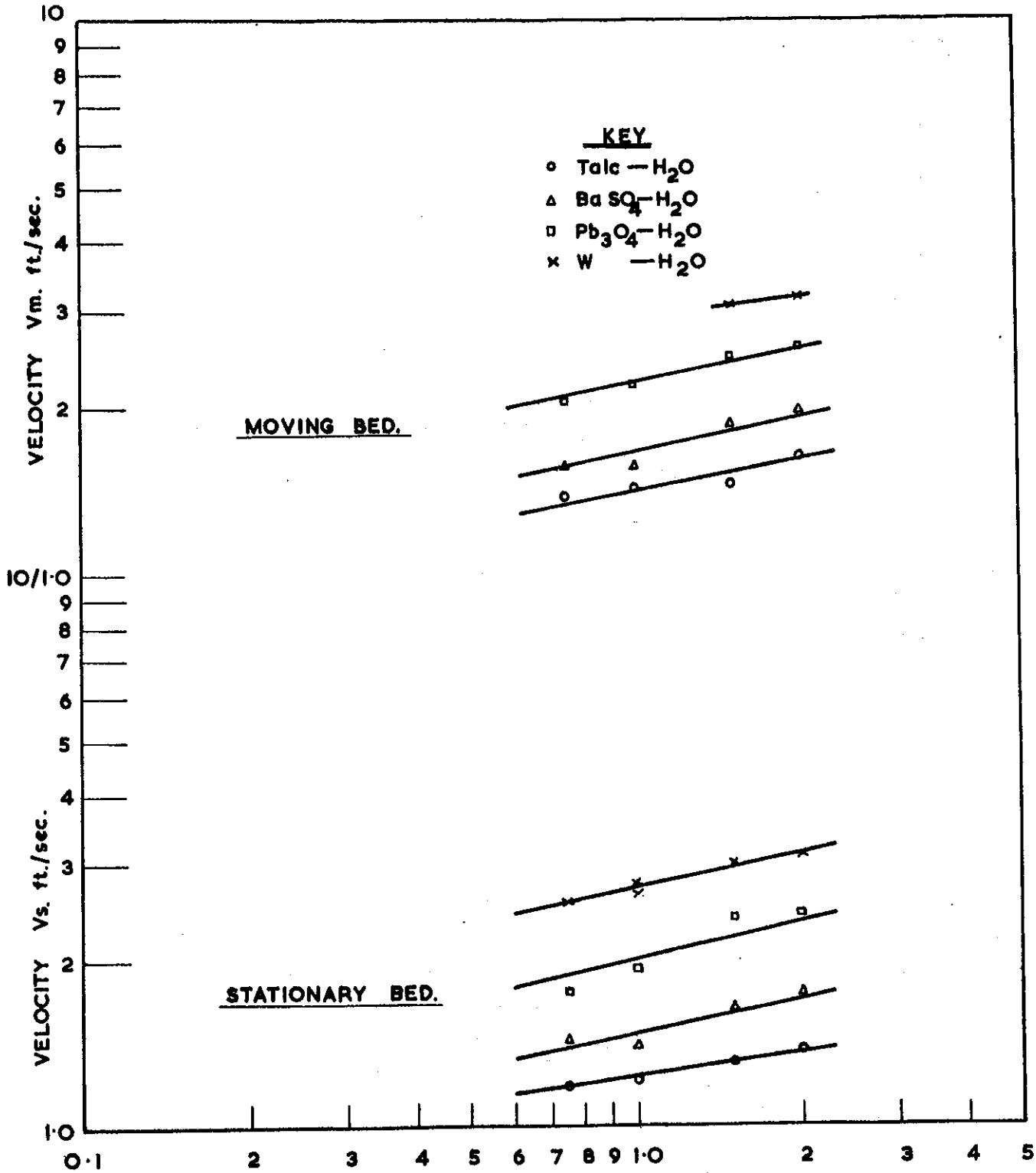

Fig. 3, Horizontal Settling Velocity vs Internal Pipe Diameter.

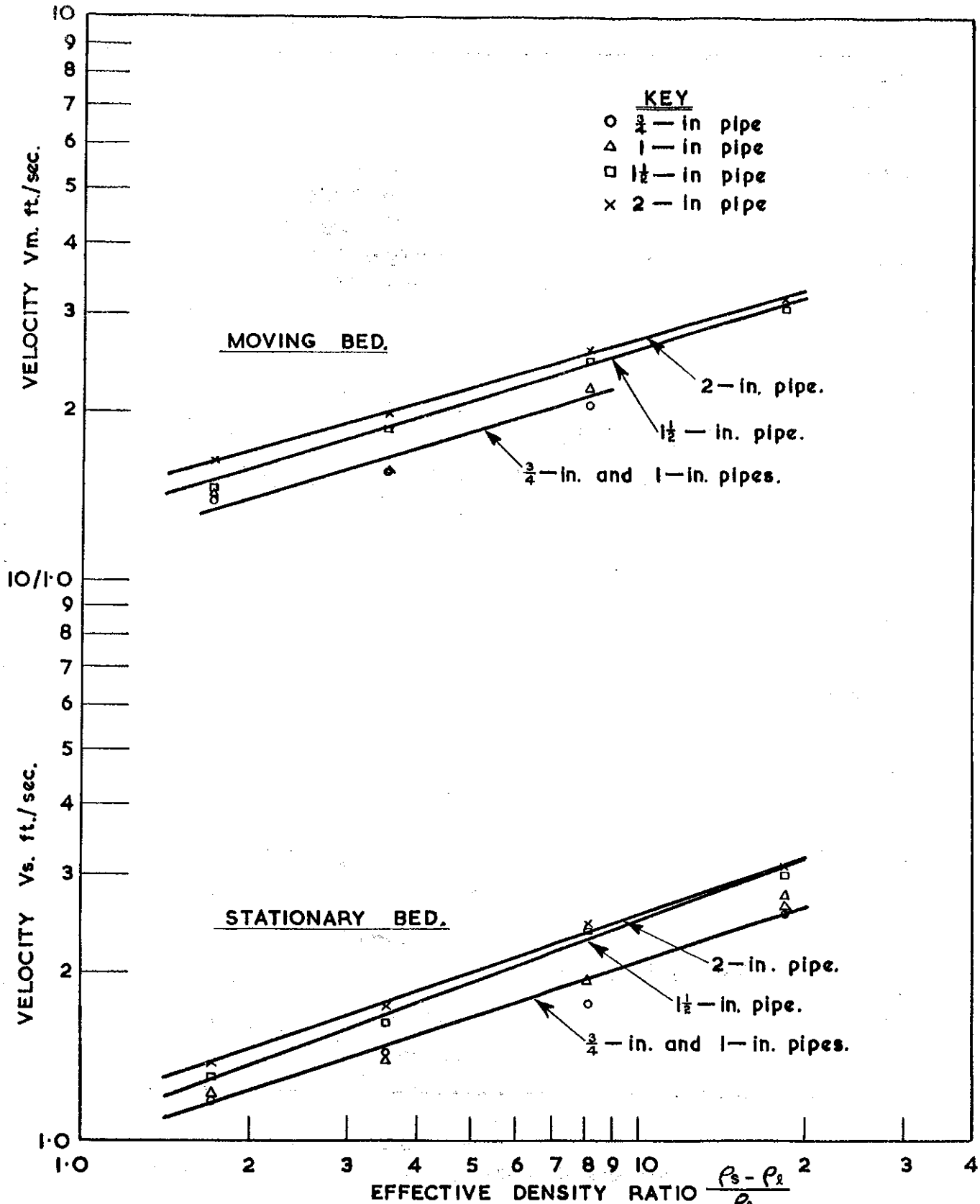

Fig. 4. Horizontal Settling Velocity vs. Effective Density Ratio.

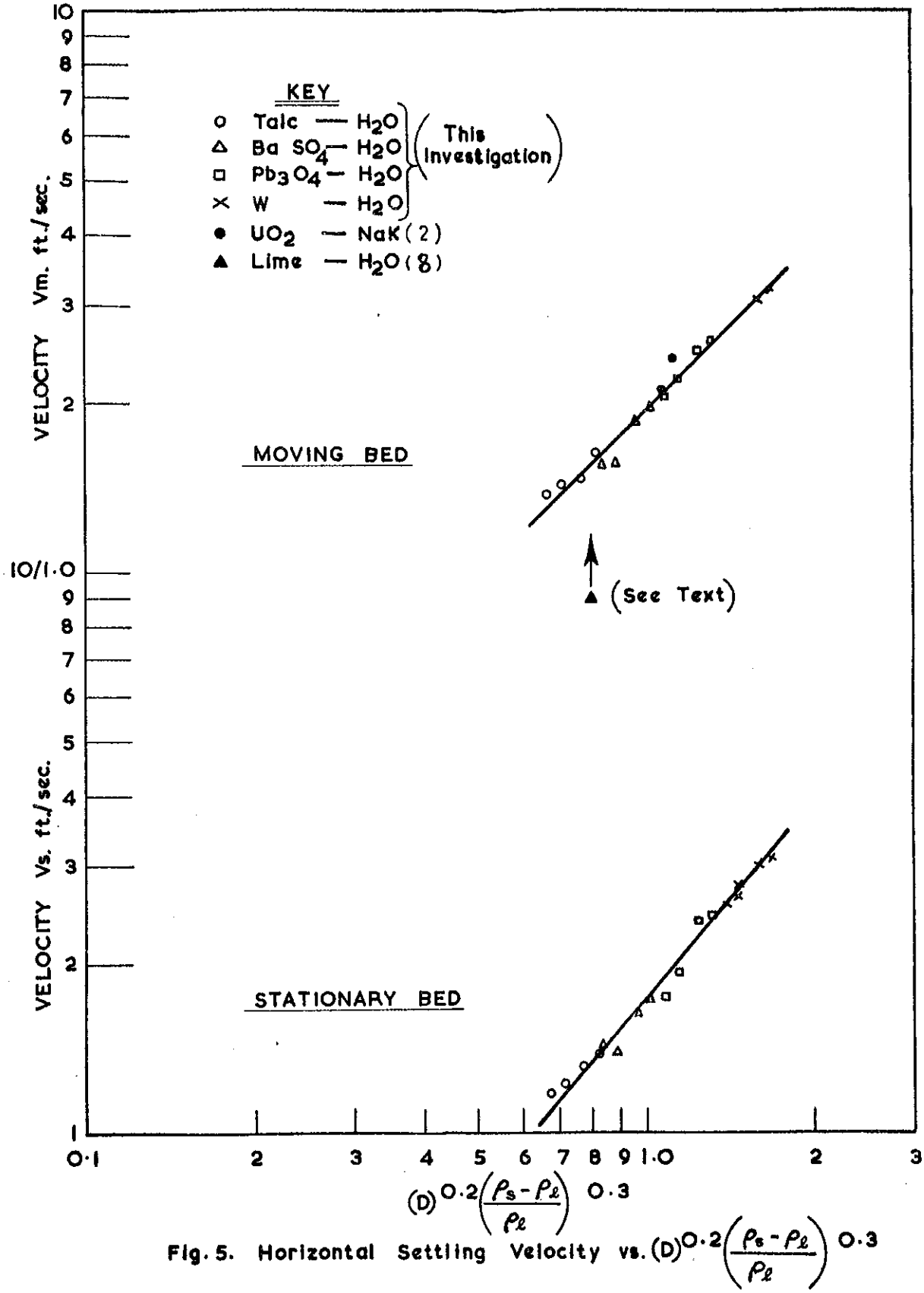

Fig. 5. Horizontal Settling Velocity vs. $(D)^{0.2}\left(\frac{\rho_s-\rho_l}{\rho_l}\right)^{0.3}$