UNCLASSIFIED

AAEC/E 38
COPY NO

AAEC/E 38

AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS

STUDIES OF SMALL PARTICLE SUSPENSIONS FOR L.M.F.R.
PART VI
CONCENTRATION PROFILES ACROSS A BEND AND A VERTICAL PIPE

by

R. C. CAIRNS

K. R. LAWTHER

Sydney, September, 1958.

UNCLASSIFIED

UNCLASSIFIED

AUSTRALIAN ATOMIC ENERGY COMMISSION

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

PART VI

CONCENTRATION PROFILES ACROSS A BEND AND A VERTICAL PIPE

by

R. C. Cairns

K. R. Lawther

Abstract

This report completes the work on suspension studies for L.M.F.R.

Concentration profiles have been measured for a tungsten suspension flowing through a smooth elbow and a vertical pipe.

It has been shown that uniform suspension at a smooth elbow is not achieved for velocities up to 13.8 feet per second. Approximately four feet of vertical pipe is required after the smooth elbow to destroy the gradients set up in a horizontal pipe for velocities of approximately 3 and 13.5 per second.

No evidence for "coring" was found.

CONTENTS

		Page
1.	Introduction	1
2.	Experimental Method	1
	(a) Equipment	1
	(b) Experimental Procedure	1
	(c) Air Entrainment	2
	(d) Solution Check	2
3.	Results and Discussion	2
	(a) Traverses across 90° Elbow	2
	(b) Traverses across Vertical Pipe	3
4.	Conclusions	4
5.	Further Work	4
6.	Acknowledgments	4
7.	Symbols Used	4
8.	References	5
9.	Appendix	5

1. INTRODUCTION

Following previous work (1) on concentration gradients in flowing suspensions, further work has been directed towards the measurement of concentration profiles. These have been measured across a bend and a more detailed study of profiles in a vertical pipe has been made.

Wolfe and Murphy (5) have reported a condition in upward vertical flow of suspensions called "coring" in which the solid phase collects at the centre of the pipe in a core and maintains a higher average velocity than the fluid.

It has already been shown (1) that concentration gradients exist in horizontal flow, and that a uniform concentration is obtainable in vertical flow for mean velocities from 2.6 to 6.3 feet per second in a 1–in. square pipe. Since the core of the L.M.F.R. would consist of vertical channels, the object of the present work is to investigate the behaviour at the entry into a vertical pipe from a horizontal pipe through a smooth 90° elbow, to establish whether the suspension is uniform throughout the vertical length, and to determine whether the condition referred to as "coring" occurs for the system studied.

2. EXPERIMENTAL METHOD

(a) Equipment

The loop was essentially the same as that described as Suspension Loop Mark III (1) and is shown in Figure 1. A vertical Perspex pipe of 1–in. square section, 4 ft. 8 in. long was preceded by a smooth 90° elbow of 1–in. square section with a centre–line radius of curvature of 4–in. The distance from vertical and horizontal centre lines to corresponding flanges on the elbow was 9–in. A 5 ft. 4 in. length of horizontal square pipe was joined to the upstream end of the bend. Matched flanged joints with P.V.C. gaskets, 0.010 in. thick, were used and care was taken to ensure that the gaskets did not interfere with the flow.

The concentration gauge, utilising a radiometric technique, and the associated traversing equipment have been fully described previously (1) (4). The equipment is shown in Figure 2, set up at the 90° elbow.

Provision was made for moving the traversing equipment to different locations on the pipe, so that traverses could be obtained at positions either on the 90° elbow or over the full length of the vertical section.

The suspension consisted of the same 2 micron grade (by microscopic count) tungsten powder as used previously (1), which had been obtained from B.H.P. Co. Ltd., Newcastle, Australia.

(b) Experimental Procedure

The concentration of the suspension was maintained at approximately 8 percent tungsten by weight as indicated by samples taken from the loop discharge or readings with the concentration gauge.

To determine the effect of the mean velocity on the concentration profile at a bend, a number of runs at different velocities were made with the concentration gauge set up across the centre of the 90° elbow at an angle of 45° as shown in Figure 2. For these runs, the suspension was first circulated to achieve uniform suspension. After adjusting the flow rate by means of the loop and by–pass valves, the temperature was noted and the flow rate determined by weighing the discharge obtained in a weighing vessel in a known time. The discharge was replaced and after five minutes a traverse was started across the pipe and a sample taken from the loop discharge to determine the approximate concentration of suspended solids. Counts obtained on the scintillation counting unit in 100 seconds, as timed by a stopwatch, were recorded at increments of 1/32–in. across the pipe and regularly at a position clear of the pipe to serve as a reference count. Traverses were taken across the pipe section and back for each flow setting to ensure that the concentration was not changing considerably with time. After a series of readings, another sample was taken from the discharge, the loop temperature again noted, and the flow rate re–determined.

For all the vertical pipe runs two velocities were used; a low velocity corresponding to a flow rate just above the settling velocity, as indicated by visual observation of very heavy striations (1) (2); and a high velocity corresponding to a flow rate with the by–pass shut and loop valve full open. From previous runs, these correspond to average velocities of approximately 3 and 13.5 feet per second, respectively. In view of the finding during this work that velocity has only a small influence on the profiles it was not necessary to determine velocities accurately for these runs.

Traverses were made at several positions on the vertical pipe at intervals of approximately 3 or 6 inches starting from a position corresponding to approximately the lowest point on the elbow where the walls were vertical. This point was $5\ ^1/_8$–in. below the lower face of the flange joining the 90° elbow and the vertical section. The lower face of the flange was used as a reference plane from which all vertical distances were measured. This reference plane was 9–in. above the horizontal pipe centre line.

(c) Air Entrainment

Difficulty was encountered in preventing entrained air from circulating through the system. This is important since it was found that the concentration profiles were affected by the presence of entrained air and, depending on the amount, the concentration could have uniform or exaggerated profiles.

The precautions taken to exclude entrainment were maintenance of a high suspension level in the tank, replacement of the 2 HP stirrer motor by a 1 HP motor and re–adjustment of the positions of the stirrers in the tank. For runs on the bend where a number of flow rates had to be determined, the distance of the discharge pipe above the surface of suspension in the tank was kept to a minimum, and the discharge directed into a larger pipe which extended below the surface. For other runs, the discharge pipe was extended below the surface of suspension in the tank.

Before and after each run a check was made to determine whether air was being entrained. This consisted in quickly shutting the loop valve and observing whether air bubbles appeared in the pipes. It was found that small numbers of very tiny air bubbles (of the order of 100 microns diameter and less) would often slowly appear, but these were not significant since their presence had no effect on the reproducibility of the profiles.

(d) Solution Check

To ensure that any concentration profiles obtained were not due to irregularities in the pipe itself, traverses were taken across the 90° elbow and the vertical pipe at the corresponding positions with the pipe filled with sodium tungstate solution. The solution used contained approximately 8 per–cent tungsten by weight corresponding to the average concentration of the suspension.

3. RESULTS AND DISCUSSION

(a) Traverses across 90° Elbow

Count rates obtained on the scintillation counter assembly were corrected for the associated paralysis or effective dead time, τ (1). The count rate relative to that through air becomes –

$$\frac{I}{I_A} = \frac{N}{N_A} \cdot \frac{1 - N_A \tau}{1 - N\tau}$$

The value of N_A used was the mean of the reference counts in air before and after each set of readings of N. The value of τ was 1.4×10^{-6} second (1).

From readings with the elbow filled with sodium tungstate solution, a variation in the internal dimension was indicated across the width of the pipe, as shown in Figure 3. Corrections were applied to the relative count rates, I/I_A, using the corresponding thickness correction factors in Table I. These factors were obtained from relative values of $\frac{N}{N_A}$ on the curve in Figure 3 taking the reference scale reading of 32–32nds as the centre of the pipe where the dimension is known.

The concentration gauge had been calibrated (4) for a section of Perspex pipe of ¼ in. wall thickness and internal diameter 0.999 in. Measurements of the internal dimension at the 45° position on the bend were made by the Metrology Division of C.S.I.R.O., National Standards Laboratory, Chippendale, Sydney, using an air gauge technique. The widths of the square bend in the direction of the gamma beam for three positions located about the centre, ¼ in. apart and a temperature of 68° F were 0.978, 0.974 and 0.969 in. The accuracy associated with these measurements was ±0.002 in.

Corrections were made to the original calibration data to allow these to be used for a width of suspension of 0.974 in. These corrections are derived in the Appendix, and the calibration data used for the bend is given in Table II and Figure 4.

The results of the traverses are presented in Figure 5, showing the variation in tungsten concentration for six different loop velocities from 2.5 to 13.8 feet per second. The velocities given in Figure 5 correspond to flow rates measured before and after each traverse. The concentration of dissolved tungsten present in the water during these experiments was less than 0.02 percent.

The flattening of the concentration profiles with increase in velocity is consistent with results on concentration gradients in a horizontal pipe (1). The profiles in Figure 5 show that at the position traversed uniform suspension is not obtained even at the highest velocity used of 13.8 feet per second.

(b) Traverses across Vertical Pipe

The concentrations indicated for the vertical pipe were all very similar and it was not necessary to evaluate actual tungsten concentrations. For comparison purposes, and in order to determine whether suspension is uniform or not for the full length of the vertical pipe, the results have been presented in terms of the relative count rate N/N_A. These when plotted have the same shape, although inverted, as concentration profiles.

The results for runs with the suspension in the vertical pipe are given in Figures 6 and 7. The results of the runs with sodium tungstate solution in the pipe are given in Figure 8.

The consistent readings in Figure 8 show that the profiles in Figures 6 and 7 are due to the distribution of tungsten in the flowing suspension and not to pipe dimension variation. It is apparent that the concentration profiles flatten as the suspension travels up the pipe which indicates that mixing is taking place along the pipe.

It appears that the flattening of the profiles is due to the gradients established in the horizontal section being destroyed and that considerable distance is needed to achieve this after a smooth elbow. For velocities of approximately 3 and 13.5 feet per second, this distance is about 4 feet from the start of the straight vertical pipe, assuming that uniformity is achieved when relative count rates across the pipe are consistent to ±0.5 percent. Insufficient turbulence is present even at the highest velocity (Re = 119,000) to provide immediate mixing after the bend. This is supported by other recent work (6) which shows that Reynolds number is not a measure of turbulence or particle suspension.

There was no visual evidence of "coring" for the flow conditions encountered and indeed in Figures 6 and 7 it is seen that the concentration is always either uniform or slightly lower at the centre. The lower concentration at the centre of the pipe is difficult to explain in the absence of velocity profile measurements but it would appear that there is a concentration of particles towards the walls and/or corners because of the lower velocity of suspension near surfaces.

4. CONCLUSIONS

Concentration profiles have been measured at a smooth 90° elbow located between a horizontal and a vertical pipe for various velocities of tungsten suspension. Relative concentration profiles have been obtained also for vertical flow for velocities of approximately 3 and 13.5 feet per second.

The results show that at the highest velocity used of 13.8 feet per second, a gradient still exists at the 45° position of the elbow. To destroy these gradients in the vertical pipe, a straight distance of approximately 4 feet is needed for velocities of approximately 3 and 13.5 feet per second.

No evidence of "coring" (5) was observed in this work.

5. FURTHER WORK

No further work is planned since sufficient information on the behaviour of suspensions has been collected in Parts I to VI of Studies of Small Particle Suspensions for L.M.F.R. to warrant cessation of all experimental work on simulated suspensions.

6. ACKNOWLEDGMENTS

Acknowledgments are due to Mr. R.B.Beer and Mr. E.J.Lee who assisted with the experimental work, and to the Analytical Chemistry Services Group for all analytical work. The co-operation of the Isotopes Section, in particular Mr. J.S.Watt, is gratefully acknowledged. Helpful discussions with Mr. C.L.W.Berglin are also acknowledged.

7. SYMBOLS USED

C_t = concentration of tungsten, gm/ml. suspension.

C_w = concentration of water, gm/ml. suspension.

I = intensity of collimated gamma radiation incident on the scintillation detector.

- I_A = through air only.
- I_B = through the bend containing suspension.
- I_P = through the straight pipe containing suspension.
- I_{A+B} = through the bend containing air only.
- I_{A+P} = through the straight pipe containing air only.
- I_{W+P} = through the straight pipe containing demineralised water.

N = number of counts registered per second on the scintillation counter unit.

- N_A = through air only.

X = internal pipe dimension in the direction of the gamma beam, cm.

τ = paralysis or effective dead time of the scintillation counting equipment, sec.

μ_{mt} = mass absorption coefficient of tungsten for radiation from the gamma source, cm^2/gm.

μ_{mw} = mass absorption coefficient of water for radiation from the gamma source, cm^2/gm.

8. REFERENCES

1. Cairns, R.C., and Lawther, K.R., AAEC/E37, July, 1958.
2. Cairns, R.C., and Turner, K.S., AAEC/E5, August, 1957.
3. Watt, J.S., – Private Communication.
4. Watt, J.S., and Lawther, K.R. Paper presented at the Symposium on the Peaceful Uses of Atomic Energy in Australia, Sydney, June 1958.
5. Wolfe, H.E., and Murphy, G., ISC-874, March, 1957.
6. Cairns, R.C., and Turner, K.S., AAEC/E34, September, 1958.

9. APPENDIX

The calibration data for the concentration gauge (4) applies to the square Perspex pipe for an internal dimension of 0.999 in. in the direction of the beam. For the 45° position on the Perspex bend, the central internal dimension has a value of 0.974 in. and the following calculation allows for this smaller suspension thickness and also for any difference in the wall thickness.

For a suspension of tungsten in water, thickness X,

$$I = I_{A+P}\, e^{-X(\mu_{mw} C_w + \mu_{mt} C_t)} \qquad (1)$$

and so for corresponding concentrations, in the bend and pipe,

$$I_B/I_A = I_P/I_A \cdot \frac{I_{A+B}/I_A}{I_{A+P}/I_A} \cdot e^{-\delta X(\mu_{mw} C_w + \mu_{mt} C_t)} \qquad (2)$$

It is required to evaluate I_B/I_A in terms of I_P/I_A.

From measurements at the central positions on the empty bend and empty pipe, the following data were obtained.

$$I_{A+B}/I_A = 0.798 \pm 0.001$$

$$I_{A+P}/I_A = 0.785 \pm 0.001$$

Values of μ_{mw} were calculated from original data obtained in the calibration experiments (3), substituting in equation (1) for measurements with water, viz.,

$$\mu_{mw} = \frac{1}{C_w X} \ln \frac{I_{A+P}}{I_{W+P}} \qquad (3)$$

For tungsten concentrations between 0 and 0.2 gm/ml suspension, μ_{mw} was found to vary from 0.16 to 0.14, so a mean value of 0.15 was used.

From equation (1) it can be shown that:

$$I_2/I_A = I_1/I_A \quad e^{-\mu_{mt}\,\delta C_t X} \tag{4}$$

or

$$\mu_{mt} = \frac{1}{\delta C_t X} \ln \frac{I_1/I_A}{I_2/I_A} \tag{5}$$

where I_1/I_A and I_2/I_A are values of I/I_A corresponding to a difference in tungsten concentration, δC_t, at a mean concentration, C_t. Values of μ_{mt} corresponding to this concentration C_t were evaluated by substituting original calibration data (Table II in ref. (1)) into equation (5). Steps of $\delta C_t = 0.04$ were used.

C_t	μ_{mt}	$\mu_{mt} C_t$
0.06	2.94	0.176
0.08	2.68	0.214
0.10	2.44	0.244
0.12	2.22	0.266
0.14	2.04	0.286
0.16	1.83	0.293
0.18	1.69	0.304
0.20	1.67	0.334

The required values of I_B/I_A were then calculated by substituting in equation (2) using the values of I_P/I_A given in Table IV of ref. (1).

% tungsten w/w	C_t	I_P/I_A	I_B/I_A
5.71	0.06	0.324	0.336
7.47	0.08	0.281	0.292
9.19	0.10	0.247	0.257
10.84	0.12	0.220	0.230
12.4	0.14	0.197	0.206
14.0	0.16	0.178	0.186
15.4	0.18	0.164	0.172
16.9	0.20	0.150	0.157

This data is plotted in Figure 4 as I_B/I_A versus percent tungsten by weight.

TABLE I

Thickness Correction Factors for 90° Elbow 45° Position

Beam Position in 1/32-in. on reference scale	Thickness Correction Factor (TCF) from Figure 3
18	0.991
20	0.992
22	0.993
24	0.995
26	0.996
28	0.998
30	0.999
32	1.000
34	1.001
36	1.003
38	1.004
40	1.006
42	1.007
44	1.008
46	1.010

TABLE II

Calibration Data for 90° Elbow

(See Appendix)

I/I_A	Tungsten Concentration % w/w
0.336	5.71
0.292	7.47
0.257	9.19
0.230	10.84
0.206	12.4
0.186	14.0
0.172	15.4
0.157	16.9

Gamma Source – Thulium 170 (1)

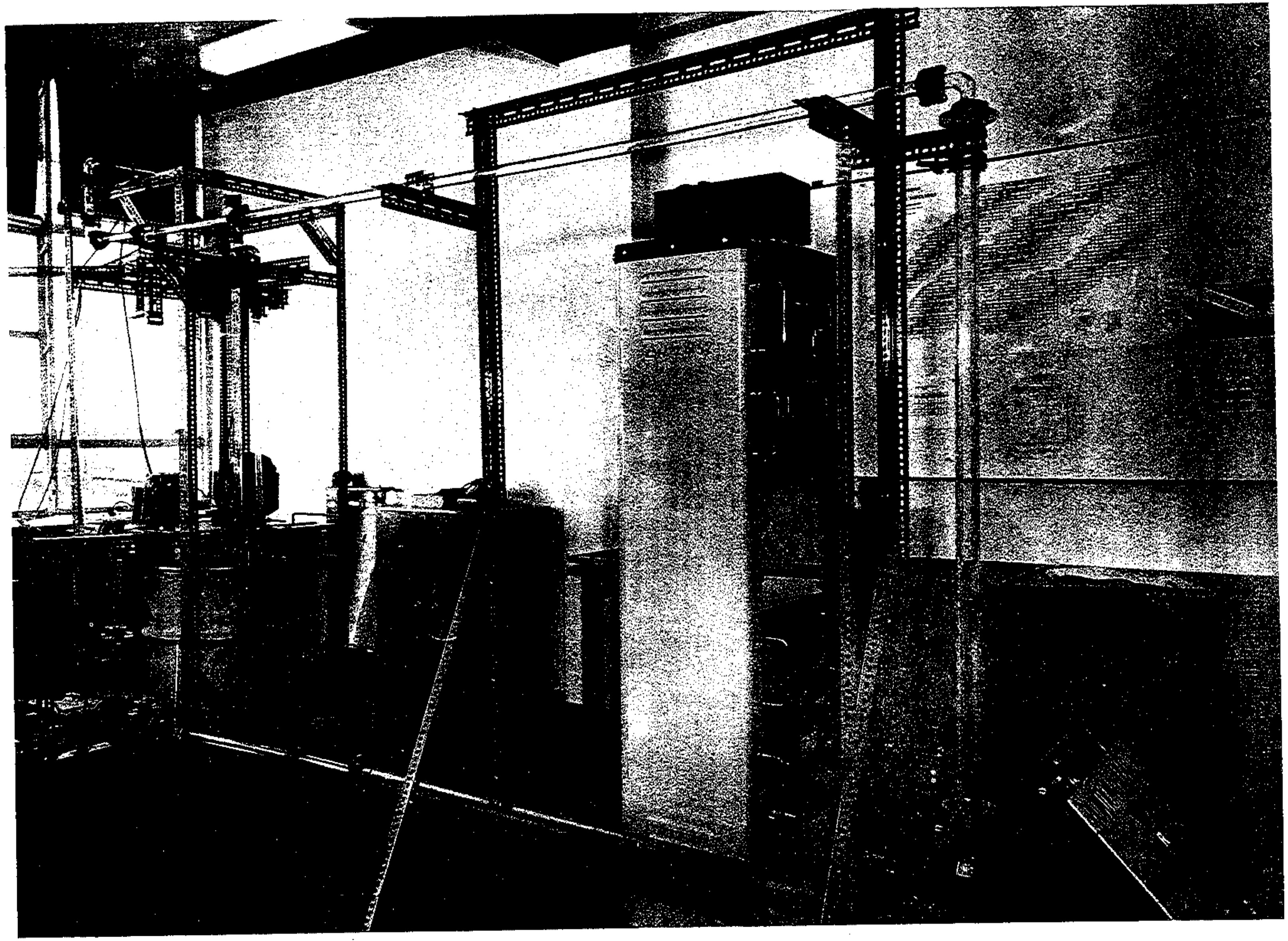

FIGURE I - VIEW OF SUSPENSION LOOP

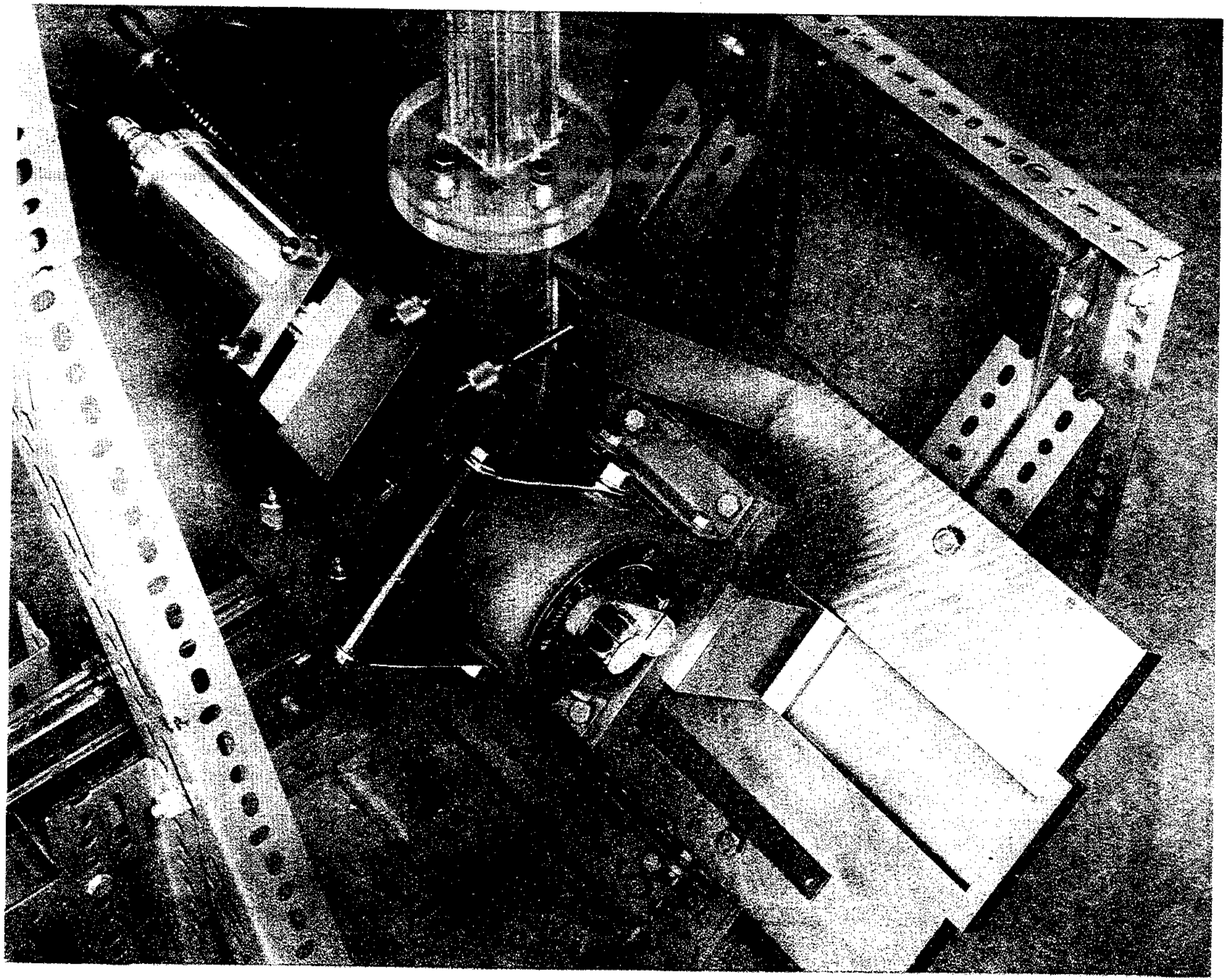

FIGURE 2 – CONCENTRATION GAUGE SET UP AT THE BEND

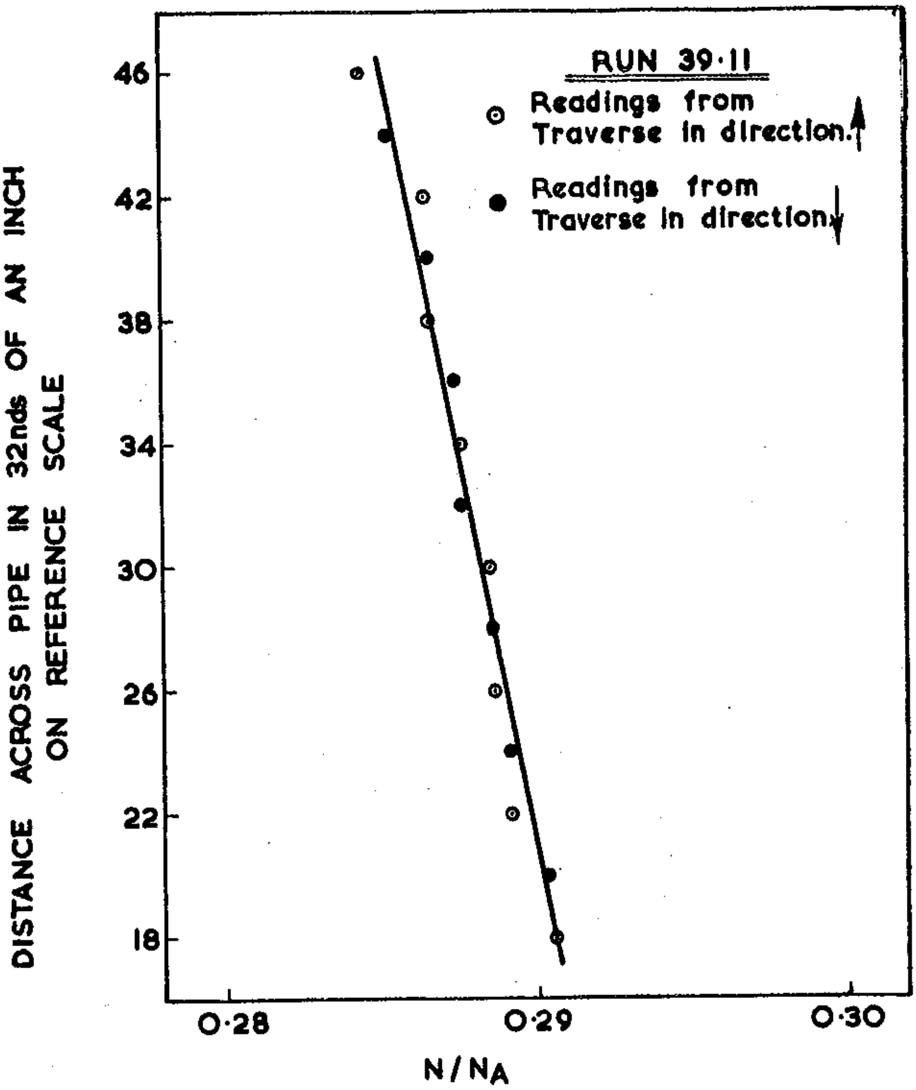

Fig. 3. Traverse At Centre of 90° Elbow Containing Sodium Tungstate Solution.

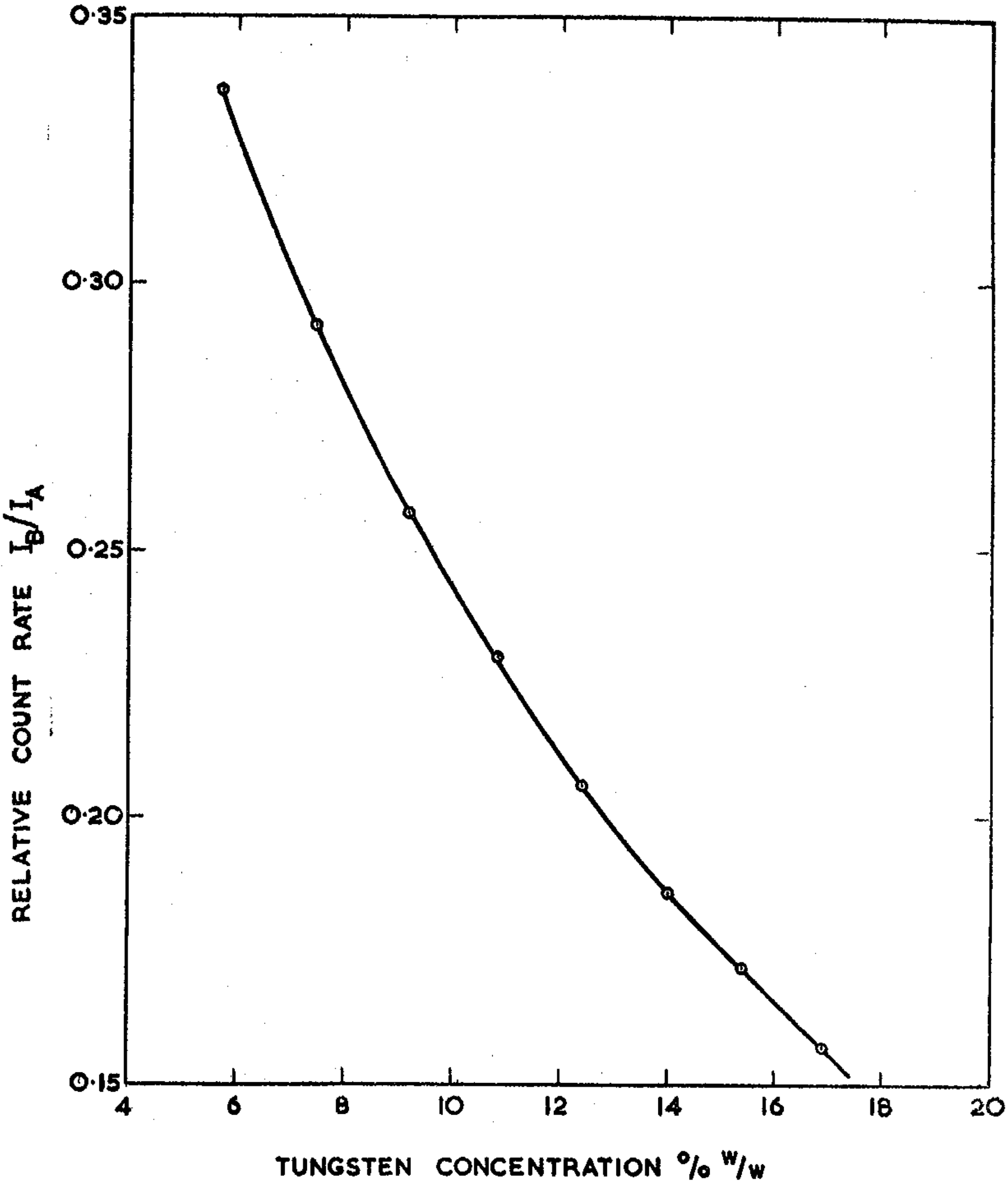

Fig. 4. Calibration Curve for 45° Position on 90° Elbow.

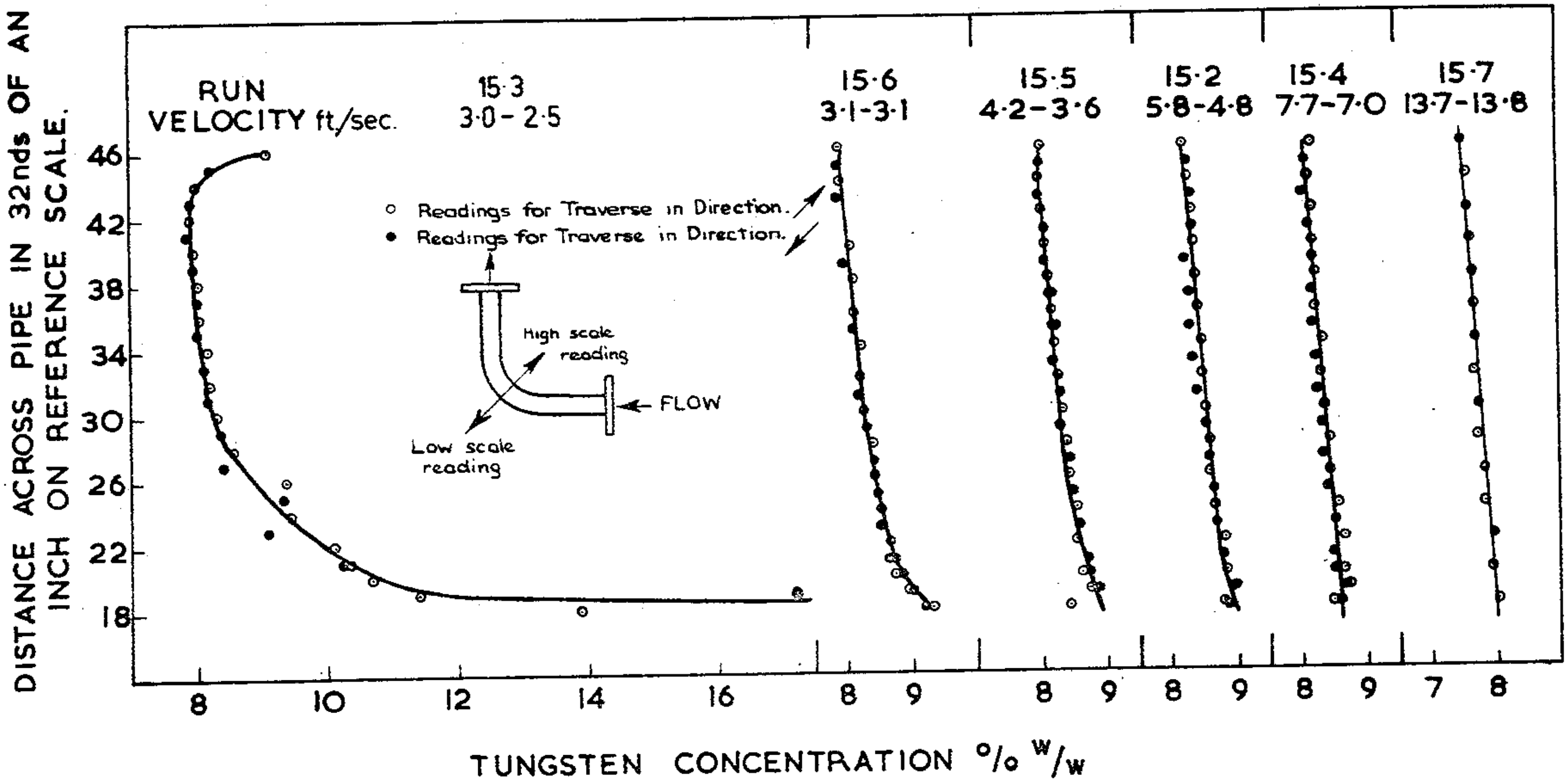

Fig. 5. Traverses Across Centre of 90° Elbow.

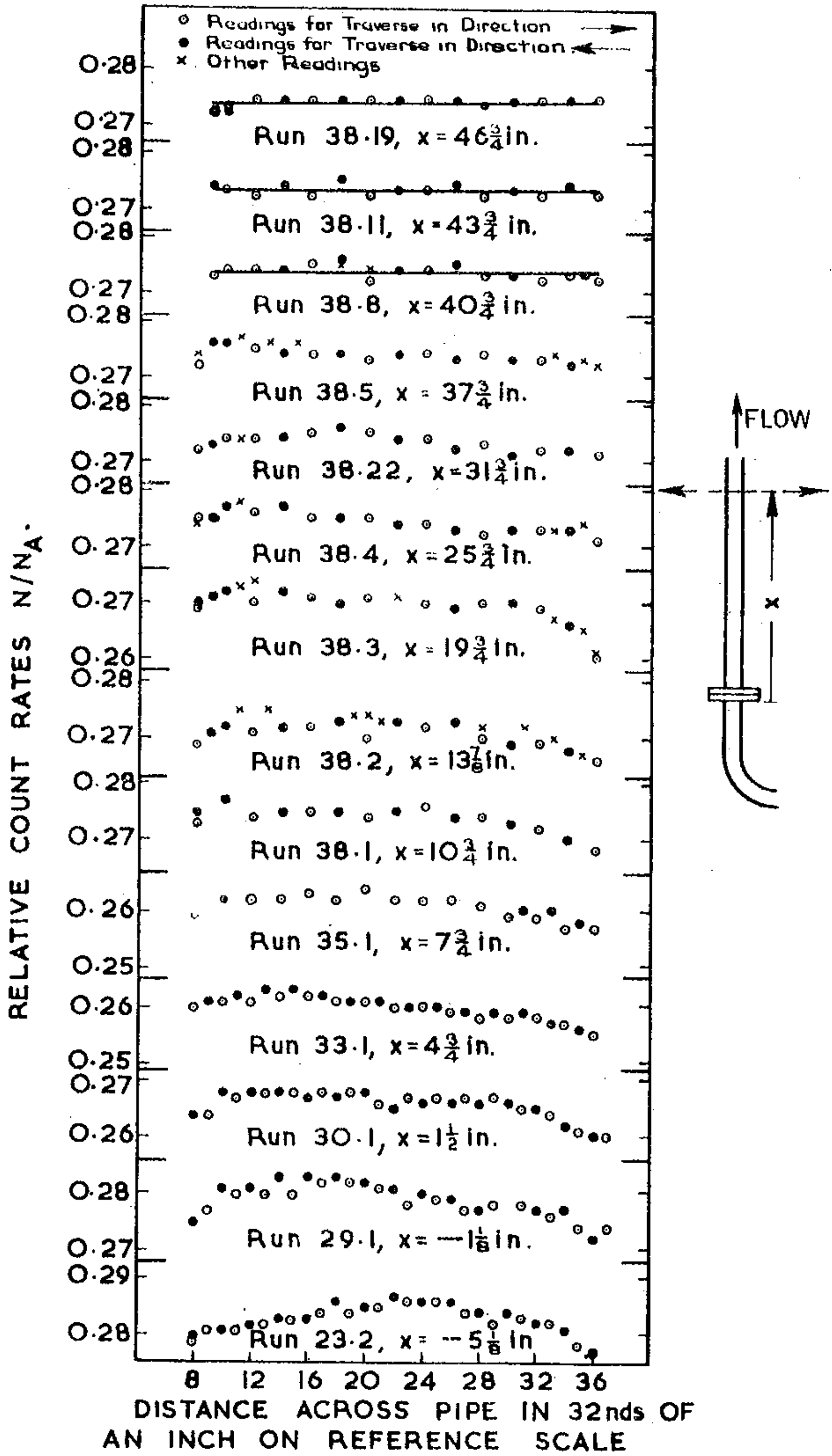

Fig. 6. Traverses on Vertical Pipe For Low Velocity Of Suspension (~ 3 ft./sec.)

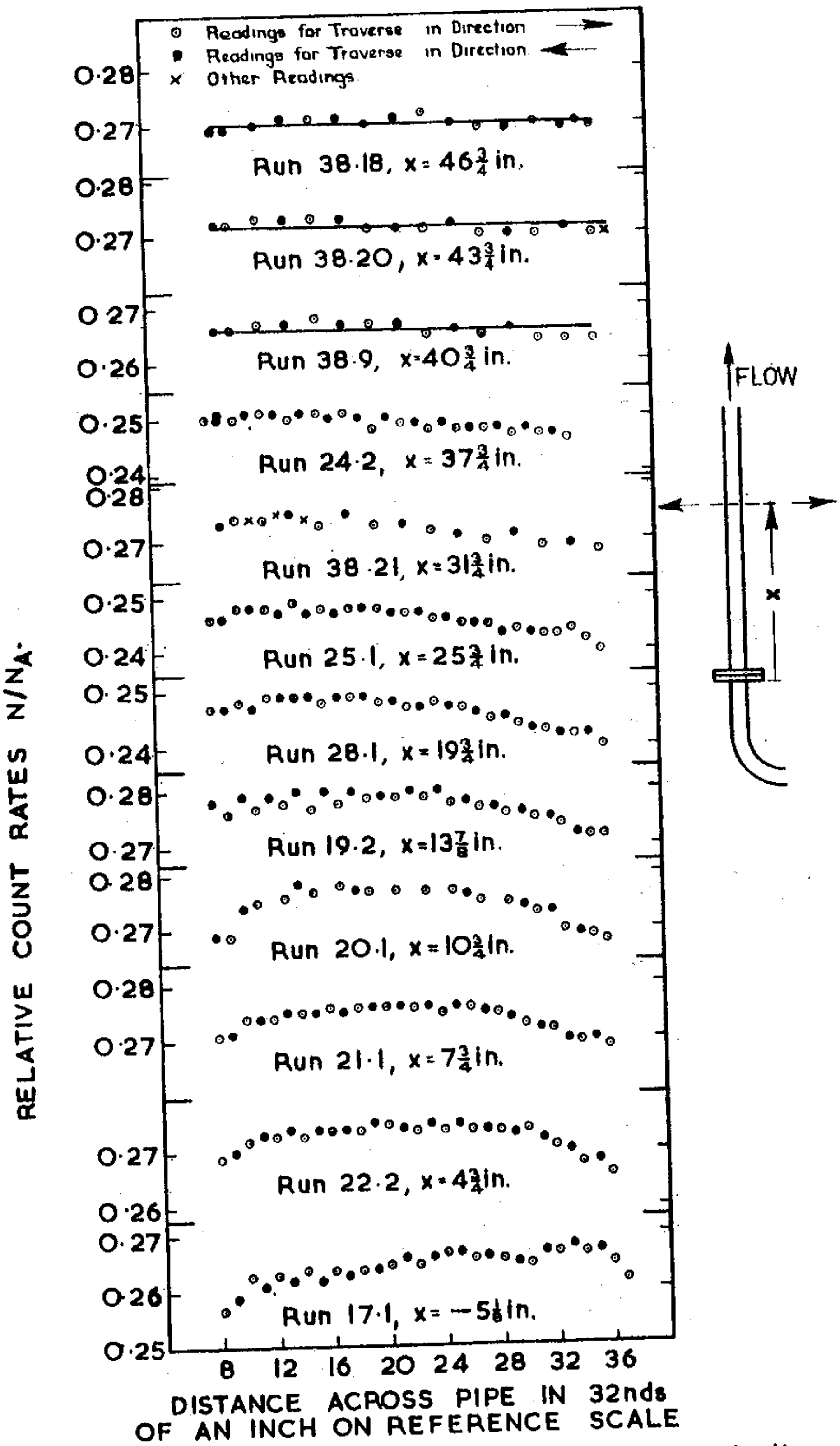

Fig. 7. Traverses on Vertical Pipe For High Velocity Of Suspension (~ 13.5 ft/sec.)

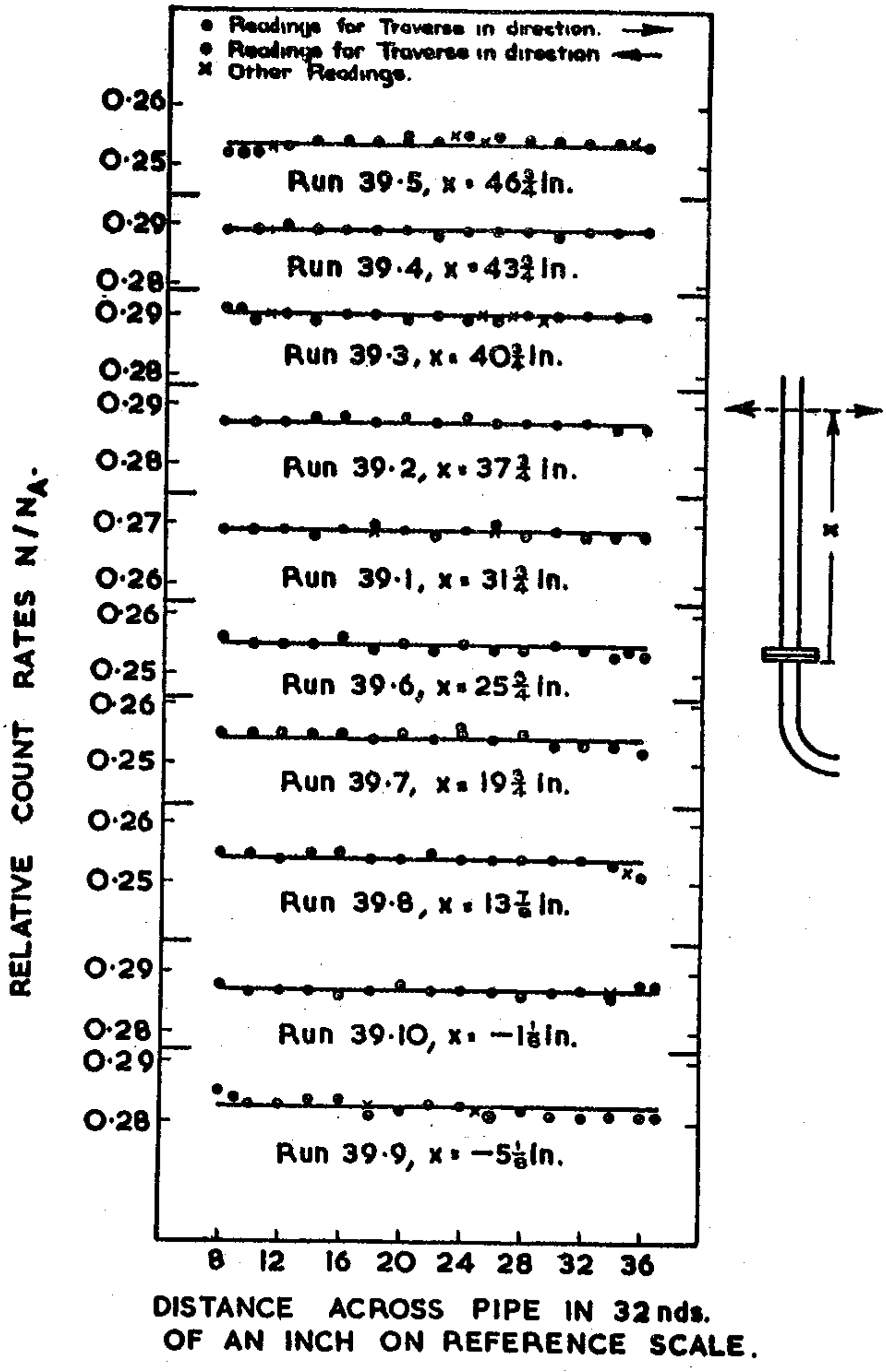

Fig. 8. Traverses on Vertical Pipe Containing Sodium Tungstate Solution.