EXPERIMENTS ON A NEW TYPE OF DUST SEPARATOR FOR STEADY AND PULSATING FLOW

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SUMMARY

This report presents an account of the development and operational qualities of a cyclone dust separator characterized essentially by straight cylindrical walls and a conical insertion pointing upwards, in the lower part of the body of the separator supported by the cover plate of the dust bunker.

A previous investigation had ascertained the principal dimensions of the separator body. The experiments described derive optimum values in terms of the exhaust tube diameter, of the position, diameter, height and shape of the insertion which was placed coaxially with, and above the dust hopper. They were carried out with light magnesium oxide dust in the range of 0–12 μ diameter and 0·1 g./c.c. density at different dust concentrations as well as with fly ash for steady flow conditions. Hereby, the beneficial influence of partially filling the dust bunker with oil was established. Further tests were conducted with pulsating air flows as are produced by a single cylinder engine. Thereby the effects of variations of frequency on the performance of the separatoı were studied.

Certain ranges of inlet velocities were found to ensure maximum separating efficiencies for steady and pulsating flows for which the static pressure drop was also measured. Its magnitude expressed in terms of the inlet velocity head together with the separating efficiency and the mean diameter and density of the dust allow to establish the quality of a separator as an "equivalent pressure loss" which decreases with more efficient operation.

1. PRINCIPLES OF THE NEW SEPARATOR

The conventional cyclonic separator appears to have a number of shortcomings: Firstly, the flow of the gas to be cleaned within the separator is made, due to its conical shape to change its direction suddenly at a point where its velocity is nearly maximum, if viewed along its radius, and near the region where it is required to deposit its impurities. The result is that the gas, in the course of suddenly changing its direction, has a tendency to pick up those particles which have actually been separated immediately before, and this tendency interferes with the desired separating operation.

Secondly, there is a considerable pressure drop due to the acceleration of the gas as it approaches the narrow portion of the conventional separator, and on account of the sharp reversal of the direction of the flow of the gas there which, for example, affects the output of an engine fitted with such a separator.

Thirdly, in the constructional design of the conventional type of separator, the exit tube, which is usually made of metallic material, protrudes inside the body of the separator, with the result that in the application of the separator to thermal power plants, especially gas turbines, operating on fuel of high residue content, this part becomes unduly heated and is thus rendered liable to deformation or cracking.

The principal object of the new separator is to obviate the abovementioned drawbacks and to provide an improved construction which tends to avoid the re-circulation of particles which have already been separated from the gas at an earlier stage of the operation and to thus ensure a supply of practically clean gas at the outlet of the separator.

Another object of the design is to avoid considerable pressure losses of the air or gas stream. A still further object is to provide a construction which is simple to manufacture from heat-resisting materials and which can be cooled easily.

The new separator design is based on the cyclonic principle. The suspended particles, separated from the gas, are led into a region of small circumferential gas velocity, *i.e.*, towards the periphery or outer wall of the cylindrical body of the separator by centrifugal action, assisted by an insertion member provided inside the body of the separator and arranged to cause the clean gases or air to escape through an outlet provided in the cover of the separator. The insertion member is of conical or curved shape appearing convex when viewed from the interior of the separator body, with straight or curved sides, pointing or directed upwards towards the outlet, and a lower portion of the insertion member extending along but spaced from the opposite portion of the outer wall of the separator. Between the outer wall of the separator and the insertion member a narrow annular passage exists through which the separated particles pass to their space of deposition.

2. REVIEW OF PREVIOUS WORK

Previous work on conventional cyclone separators is confined mainly to the study of the flow pattern, the theory and design, and the general mechanism of dust separation.

2.1. *Flow pattern*

Sheppard and Lapple[1] conducted an experimental investigation with a 12″ glass cyclone and came to the conclusion that the flow within the cyclone consists primarily of an outer downward spiral and an inner upward spiral of generally higher velocity.

The flow in immediate proximity of the wall of the separator body and the exit pipe wall was found to have a greater downward angle than that in the middle of the annular space bounded by these walls. The rotational velocity at any point in the cyclone chamber below the exit duct was found to vary inversely as the square root of the radius.

Mulder and Ter Linden[2] undertook investigations on the flow pattern in a cyclone and arrived at the following results:—

1. With the exception of a core of low pressure in the centre of the cyclone, the pressure is otherwise high. The core extends throughout the length of the cyclone and may be considered as a cylinder with a radius of $\cdot 4d$, where $d =$ diameter of the exit duct. This low pressure area continues into the dust bunker where it creates a vacuum.

2. The tangential velocity increases from the wall of the separator towards the centre upto a radius of $r_0 = 0{\cdot}65 r_e$ beyond which it quickly decreases. Here r_e denotes the radius of the exhaust pipe.

3. In the cylindrical part of the cyclone the distribution of the tangential velocity C_t along the radius can be represented by

$$C_t\, r^n = \text{constant}.$$

wherein $n = \cdot 52$.

4. The vertical velocity is directed downwards at the outer wall and in its neighbourhood, and upwards everywhere else.

5. The radial velocity is directed towards the centre throughout the greater part of the cyclone and shows the tendency to carry the particles to the centre against the action of the centrifugal force. In the centre the flow direction seems to be directed generally upwards.

2.2. *Effect of cyclone dimensions*

Lee[3] conducted tests with two geometrically similar cyclones, one 5', and the other 1' diameter both operating with a similar gas at the same peripheral gas velocity, density and size of particles. The formula for the radial distance travelled by the particle allowed to conclude that a smaller cyclone has a better chance of successful operation.

Lissman[4] found the smaller diameter cyclone to give a better performance with regard to collection efficiency for the same pressure drop.

Whitton[5] conducted experiments on cyclones of 1', 2' and 3' diameter. He found that for the same massflow the efficiency fell with an increase of cyclone diameter but the value of the pressure loss was lower. He, furthermore, points out that the selection of the diameter of the cyclone depends mainly on the allowable pressure loss.

Ter Linden[6] conducted tests on different cyclone models and derived the value of K from the following formula for determining the pressure loss:—

$$\Delta P = K \frac{V_1^2}{2g} \gamma,$$

where

V_1 = velocity of gas at cyclone inlet,

g = acceleration due to gravity,

γ = density of gas, and

K = the pressure loss factor which depends on the shape and dimensions of the cyclone.

Ter Linden[2] has further reported on the results of experiments on cyclones of different diameters. Whilst keeping the exhaust tube diameter d constant, the cyclone body diameter was increased and a gain in efficiency was observed. The author has also determined the effect of the exhaust tube diameter on the collection efficiency for a given cyclone and for a particular size of the particles. He found that an increase of the size of the exhaust tube was accompanied by a fall of the collection efficiency for different sizes of particles: the smaller the tube diameter the higher was the overall collection efficiency. The collection efficiency of a test cyclone was found to vary also with the length of the exhaust tube projection inside the body of the separator and showed an optimum value when it was slightly more than the exhaust tube diameter. The investigation further covered various sizes of rectangular inlet ducts and it was found that a square inlet was a good choice. Best figures were obtained when the inlet angle was kept at 180°. The total length of the cyclone body was found to affect its performance: a value of $6d$ to $7d$ led to optimum operation.

2.3. *Effects of variation of massflow*

Lapple and Sheppard[1] have found that the frictional loss in a cyclone varies with the square of the inlet velocity. The pressure loss depends on the inlet velocity of the gases and thereby on the massflow and increases with an increase of its value. The inlet velocity should be chosen in such a way that the pressure drop is within allowable limits whilst the efficiency is at its maximum.

2.4. *Dust concentration*

Whitton[5] found experimentally that the increase of dust concentration increases slightly the collection efficiency of the cyclone. Parent,[7] however, found hat "dust loading" had very little effect on the collection efficiency—all other factors remaining constant.

2.5. *Effect of density change of dust*

If the performance of the cyclone separator is to be predicted with a powder of different density a new relationship canbe evolved fro m considerations of Stoke's Law whereby points of equal efficiency will be transformed in accordance with the root of the ratio: density of the test dust/density of the new dust.

Stairmand,[8] however, has stated the following limitations:—

1. It is unwise to carry this transposition too far since it can only apply if the flow pattern is not changed due to the change of the powder. He has suggested that transpositions within density ranges of 1-4 g./c.c. are likely to be satisfactory.

2. The correction covers only particle density, no allowance being made for particle shape, etc., which may influence also the efficiency.

2.6. *The new separator*

A number of laboratory tests were conducted by Mahulikar[9] on several models of the novel separator provided with the conical insertion pointing upwards which resulted in the belowmentioned geometrical relations—in terms of the exit diameter *d*—which were accepted as basis for the investigation:

(*a*) Diameter of separator: $2 \cdot 5d$.

(*b*) Overall height of separator: $7d$.

(*c*) Height of cylindrical portion: $5d$.

(*d*) Height of dust bunker: d.

(*e*) Diameter of dust bunker: $4d$.

(*f*) Length of exhaust tube projection inside the body of the separator: d.

(*g*) A scroll type of inlet duct having an inlet angle $\beta = 180°$.

3. Aim and Scope of the Investigation

The aim of the investigation was to clarify whether the general conception of the new separator was practical and would lead to an apparatus of satisfactory performance. The interdependence between, *e.g.*, separation efficiency and pressure loss and the dimensions of the body and the insertion as well as its relative position might well hide the possibilities of the design.

Therefore the consequences of modifications to the geometry of the insertion in regard to pressure loss and efficiency of separation were ascertained and the final dimensions and a superior method of placing the insertion were thereby evolved. In addition the effect of providing a liquid in the dust hopper to arrest deposited matter was studied.

One of the advantages of the cyclonic separator principle is its independence from servicing and thus it is particularly suited for long-range operation and application to reciprocating internal combustion power plants working under these conditions. It became therefore necessary to investigate the effects of the intermittent airflows as occur in the intake duct of, especially, single cylinder engines, on the separator operation and effectiveness.

4. TEST APPARATUS AND PROCEDURE

4.1. *Continuous flow*

A schematic diagram of the test rig containing the dust feeding mechanism and the associated equipment used in this investigation is shown in Fig. 1 *a*.

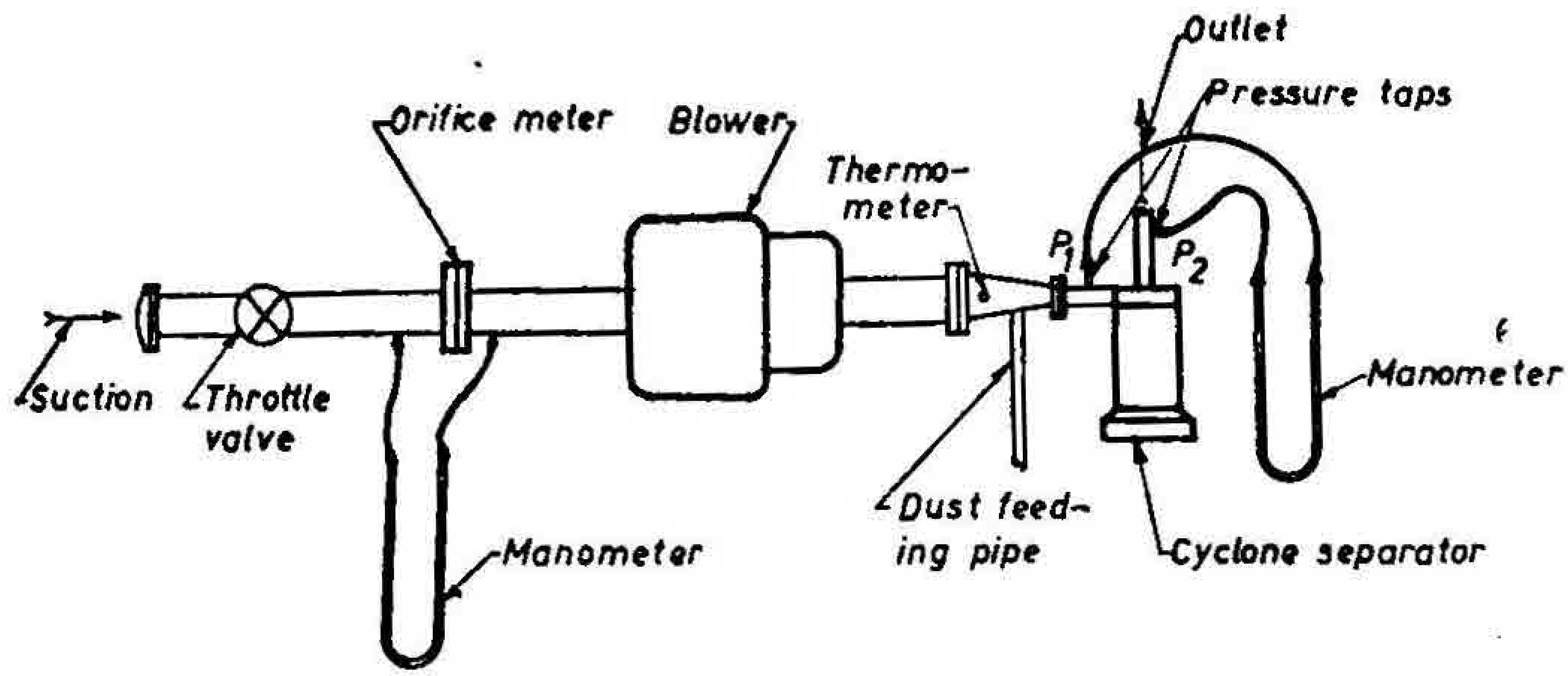


FIG. 1 *a*. Schematic diagram of the test rig for steady flow.

Air was drawn into the blower through a regulating valve and discharged into the cyclone collector through a horizontal duct and thence, directly to the atmosphere. A venturi section was provided in the duct upstream of the cyclone for the introduction of dust. Its rate of admission was governed by a vibrator unit which allowed to change its frequency of operation and the amplitude of the vibrations.

The airflow was measured by an orifice meter in conjunction with a U-tube manometer while the pressure drop across the cyclone was measured by means of a tap P_1 upstream of the cyclone inlet and a tap P_2 located on the exhaust tube. The latter was arranged at a sufficient distance namely 5 times the diameter of the tube from the top cover of the separator so as to avoid disturbances.

4.2. *Pulsating flow*

The diagram of the test rig is shown in Fig. 1 *b*.

Air was sucked through the separator by the engine whereby a venturi section upstream of the cyclone allowed for the introduction of the dust and a throttle valve

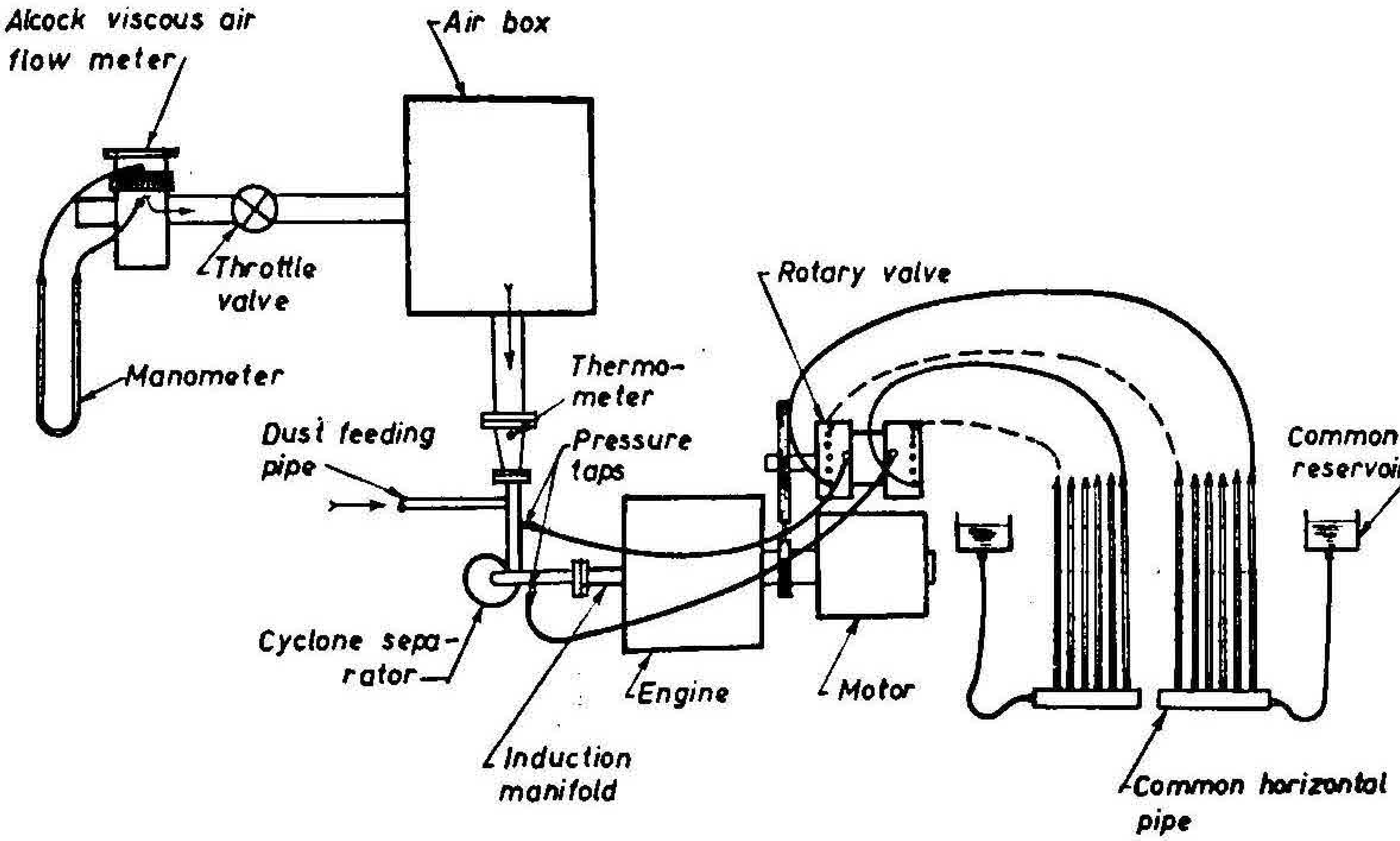


FIG. 1 *b*. Schematic diagram of the test rig for pulsating flow.

controlled the rate of admission. The airflow was recorded by an Alcock's viscous airflow meter.

In order to determine the pressure drop, across the separator, under oscillating flow conditions, a rotary valve which was run at half the speed of the engine was used. It is shown in Fig. 2 and the equipment used to record the pressure is photographed in Fig. 3. Seven taps at each end were used to lead from the rotary valve

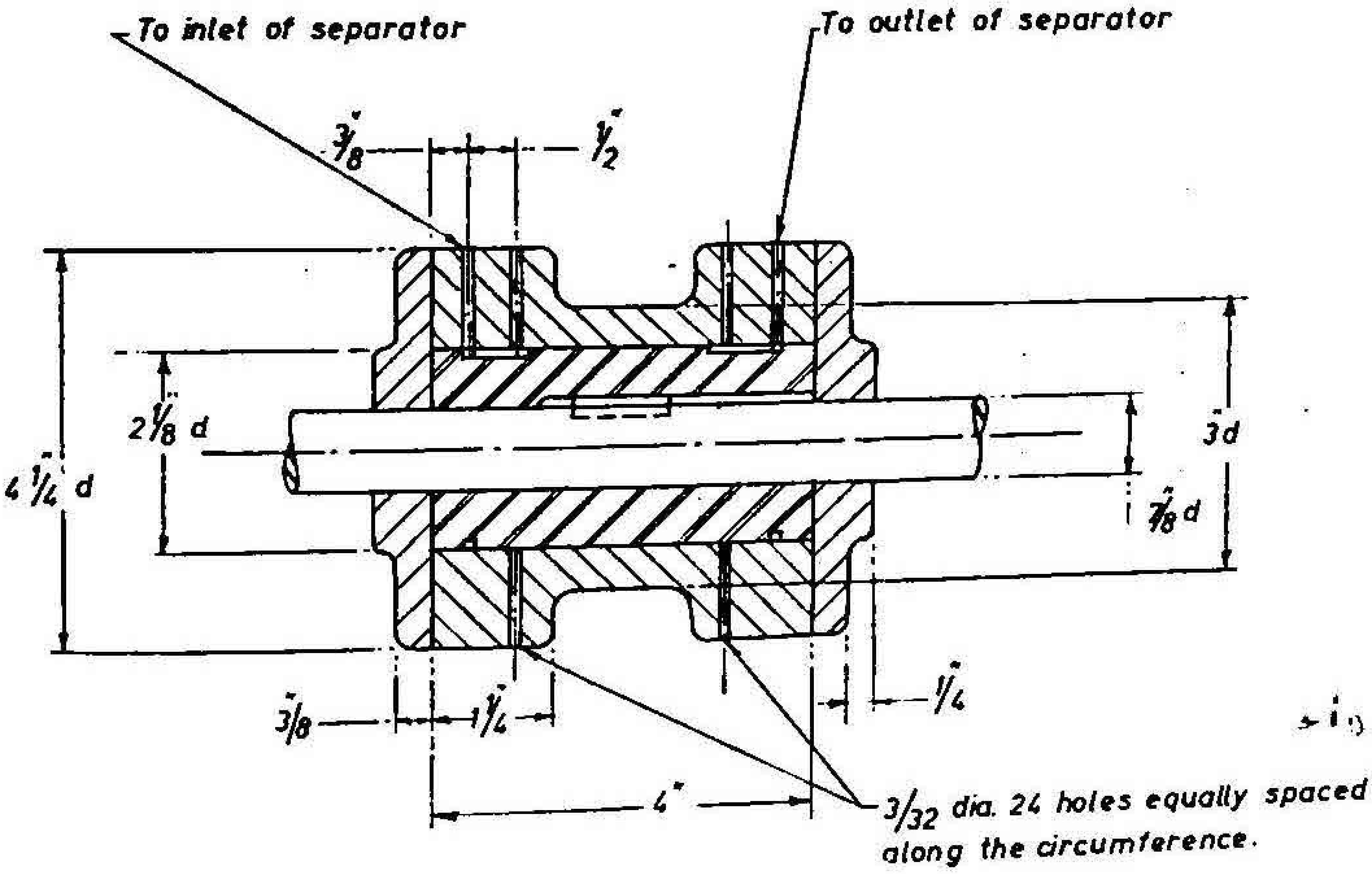
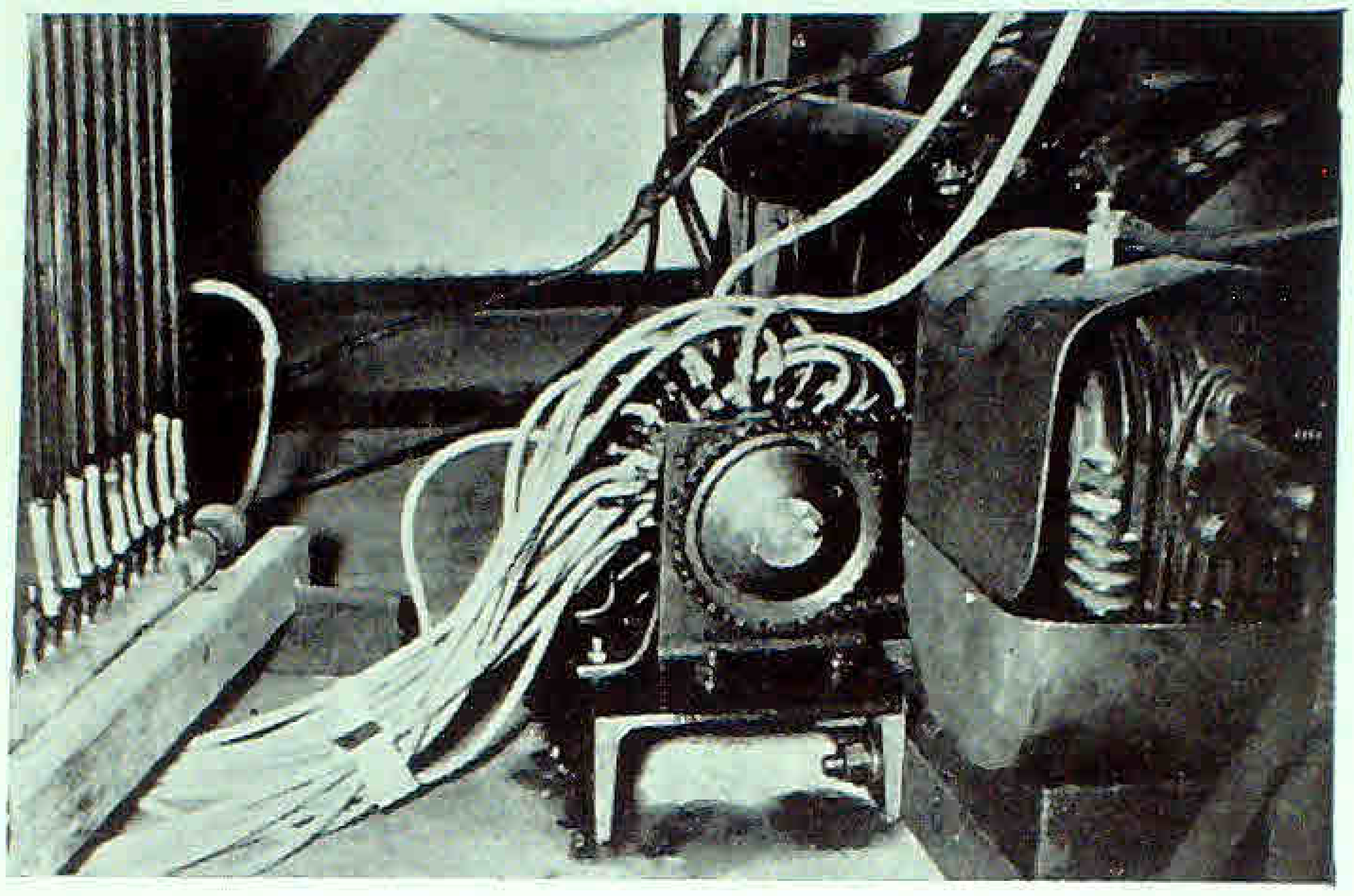
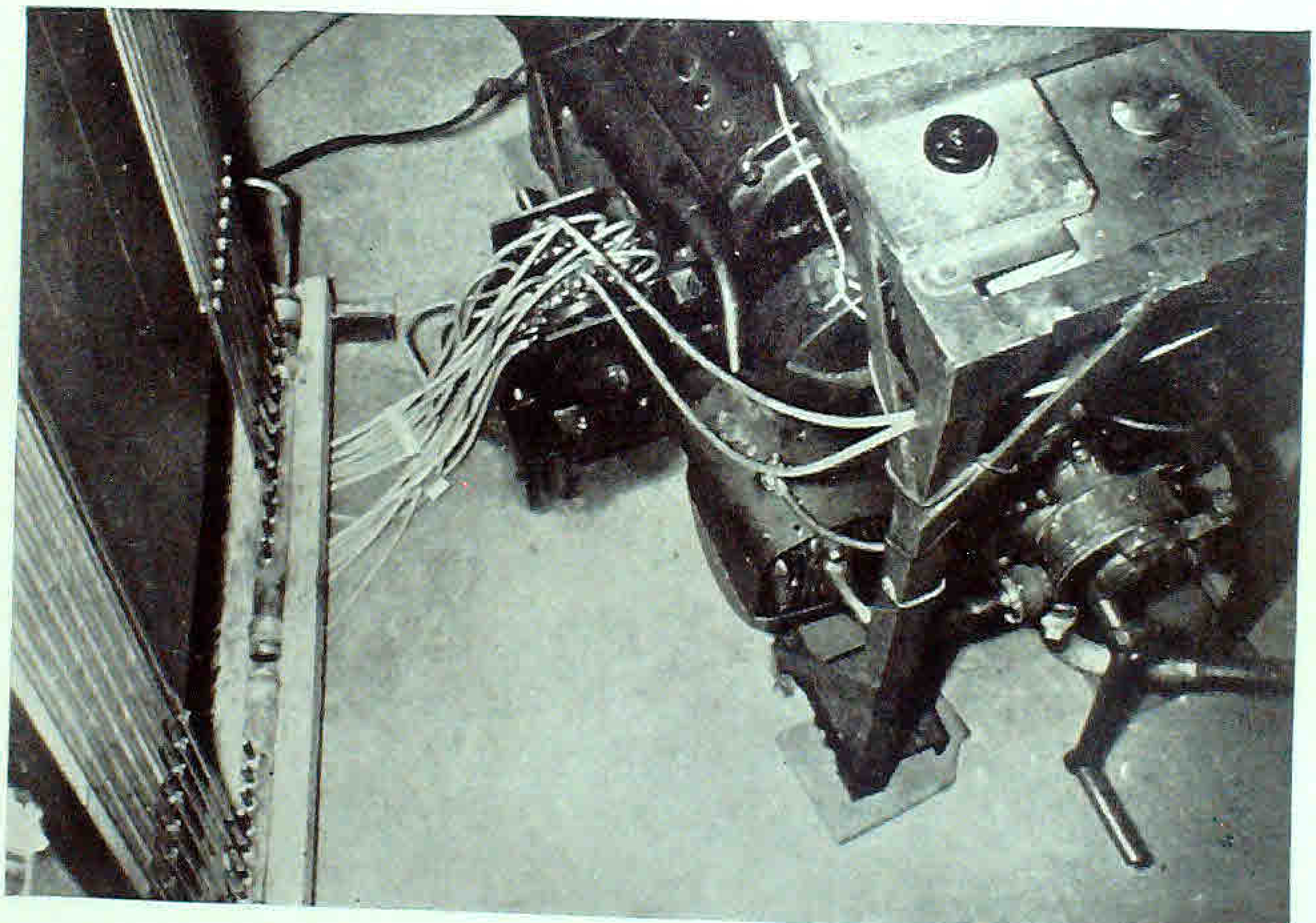


FIG. 2. View of rotary valve used to record the pressures.



Close-up of the Rotary Valve.



Details of the Rotary Valve and Manometers.

FIG. 3

to the bank of manometers. The spacing of the taps was adjusted so as to cover the engine suction period. The mean static pressure loss was computed from the average of the pressure wave shapes so obtained. Here and in the manometer working with the orifice meter alcohol of density 0·793 g./c.c. was used as indicator liquid.

For the investigation a single cylinder, four-stroke engine with a suction stroke of 207° crank angle was adopted.

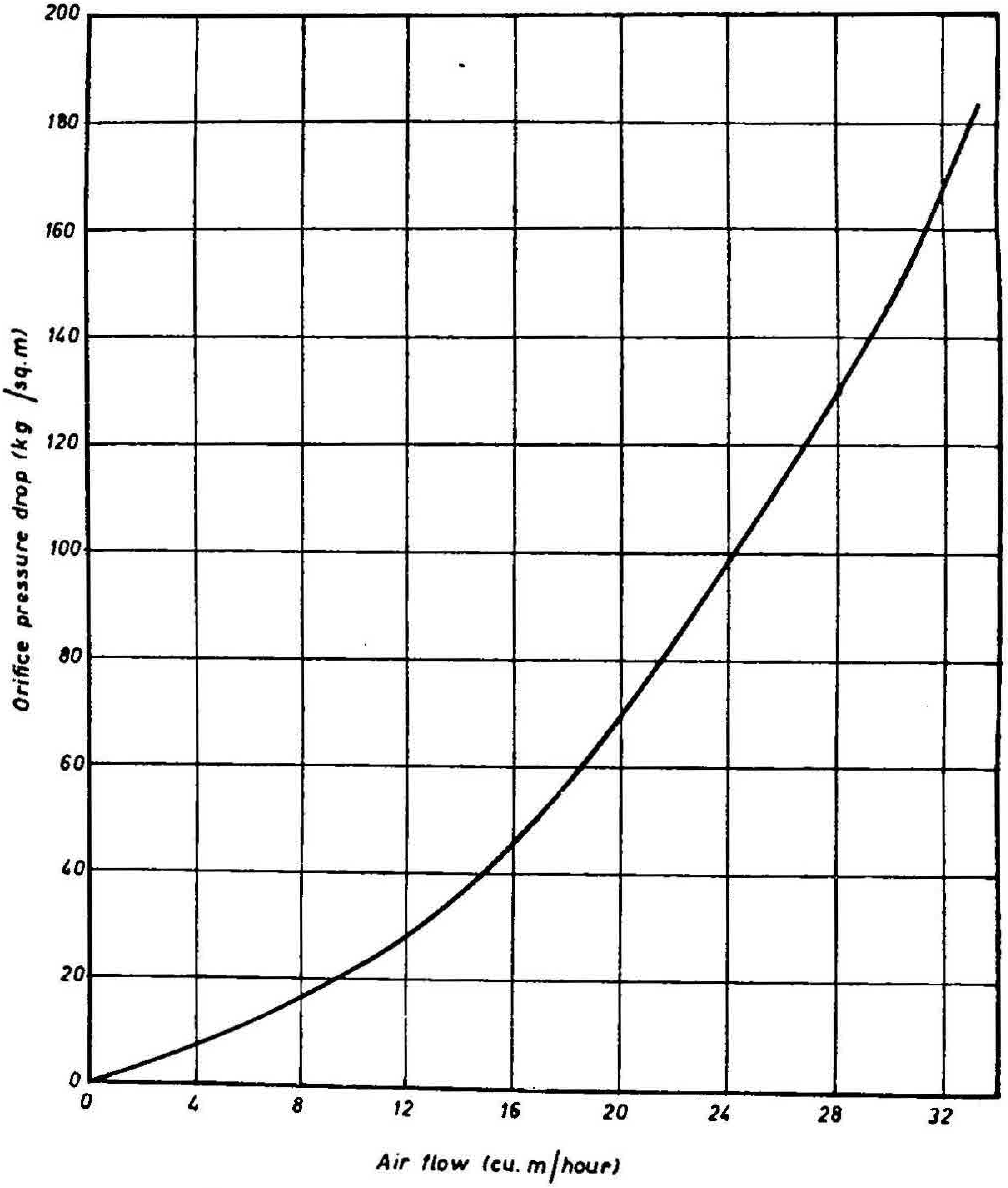


FIG. 4 Calibration curve for the orificemeter.

4.3. *Test procedure and evaluation*

4.31. *Calibration test.*—A number of preliminary experiments were made in order to check the instrumentation.

The orifice meter used for the measurement of the airflow was calibrated by using a gas meter. The calibration curve is given in Fig. 4.

4.32. *Collection efficiency.*—The collection efficiency was computed as follows:—

The amount of dried dust fed by the feeder and the amount of dust arrested by the separator were weighed on an analytical balance. The collection efficiency was then obtained from

$$\eta_{col.} = \frac{\text{Weight of dust collected, in grams}}{\text{Weight of dust fed, in grams}} \times 100.$$

It was found that the barometric pressure and room temperature did not vary appreciably for a particular series of experiments and hence corrections for mass-flow were neglected.

4.33. *Determination of particle size.*—Two types of dusts were used, namely dust A, consisting of light magnesium oxide, with a range of sizes from 0–12 micron and a specific gravity of ·10, and dust B, which was Fly ash, in the size range of 0–10 micron and a specific gravity of ·16. Micro-photographs and the corresponding scale taken with a Zeiss-Opton W. microscope are shown in Fig. 5. The size distribution is shown in Fig. 6.

This curve was obtained by taking a series of micro-photographs of a dust sample and by evaluating numbers and sizes of the particles (Table I).

4.34. *Experimental procedure.*—The regulating valve was adjusted to a particular airflow. Under steady state conditions the following data were observed:—

(1) Duration of experiment.

(2) Weight of dust fed to the airstream.

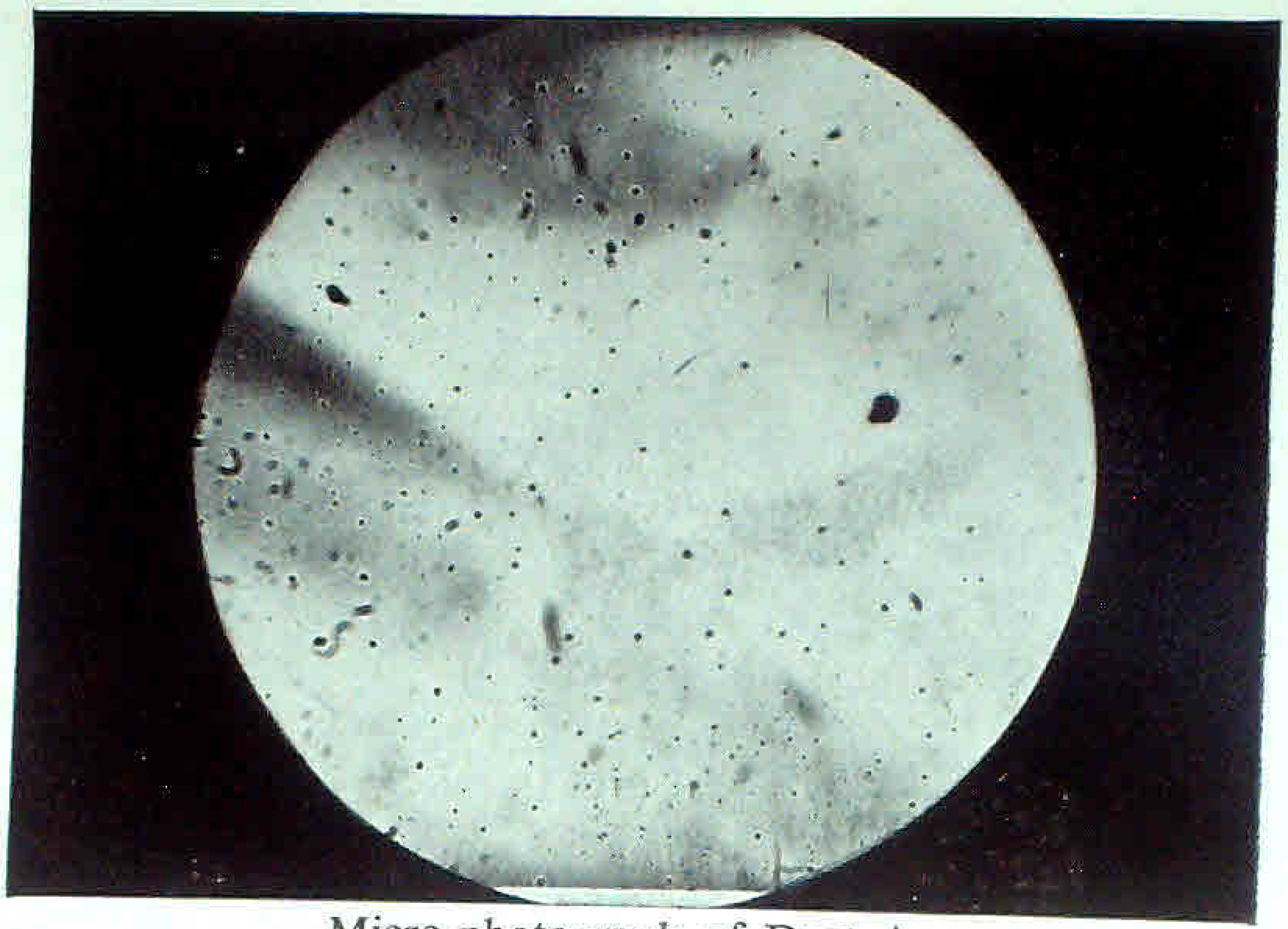
(3) Weight of dust arrested by the separator whereby precautions were taken to remove any dust clinging on the walls of the separator.

(4) Airflow.

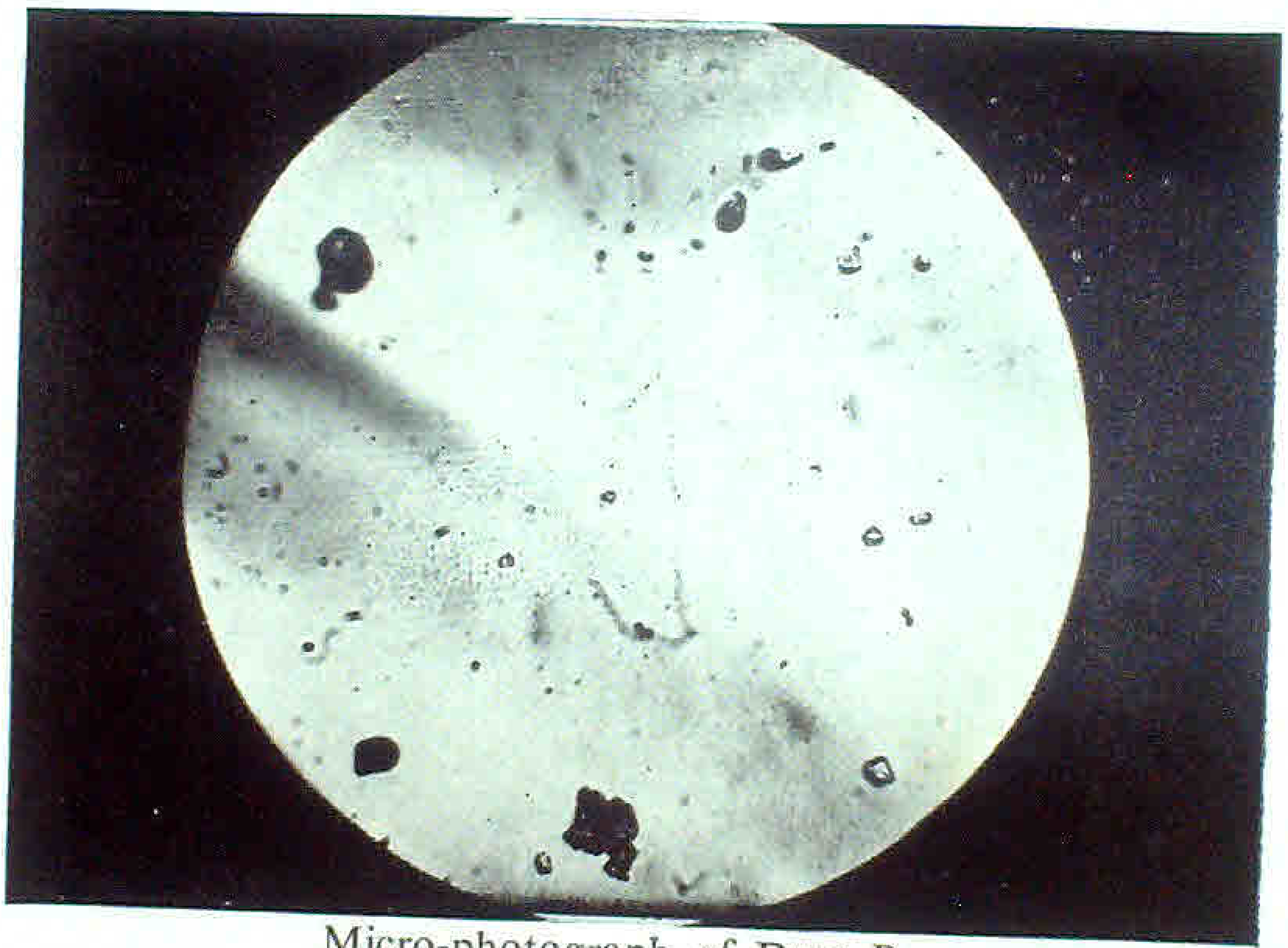
(5) Static pressure loss.

(6) Barometric pressure and room temperature.

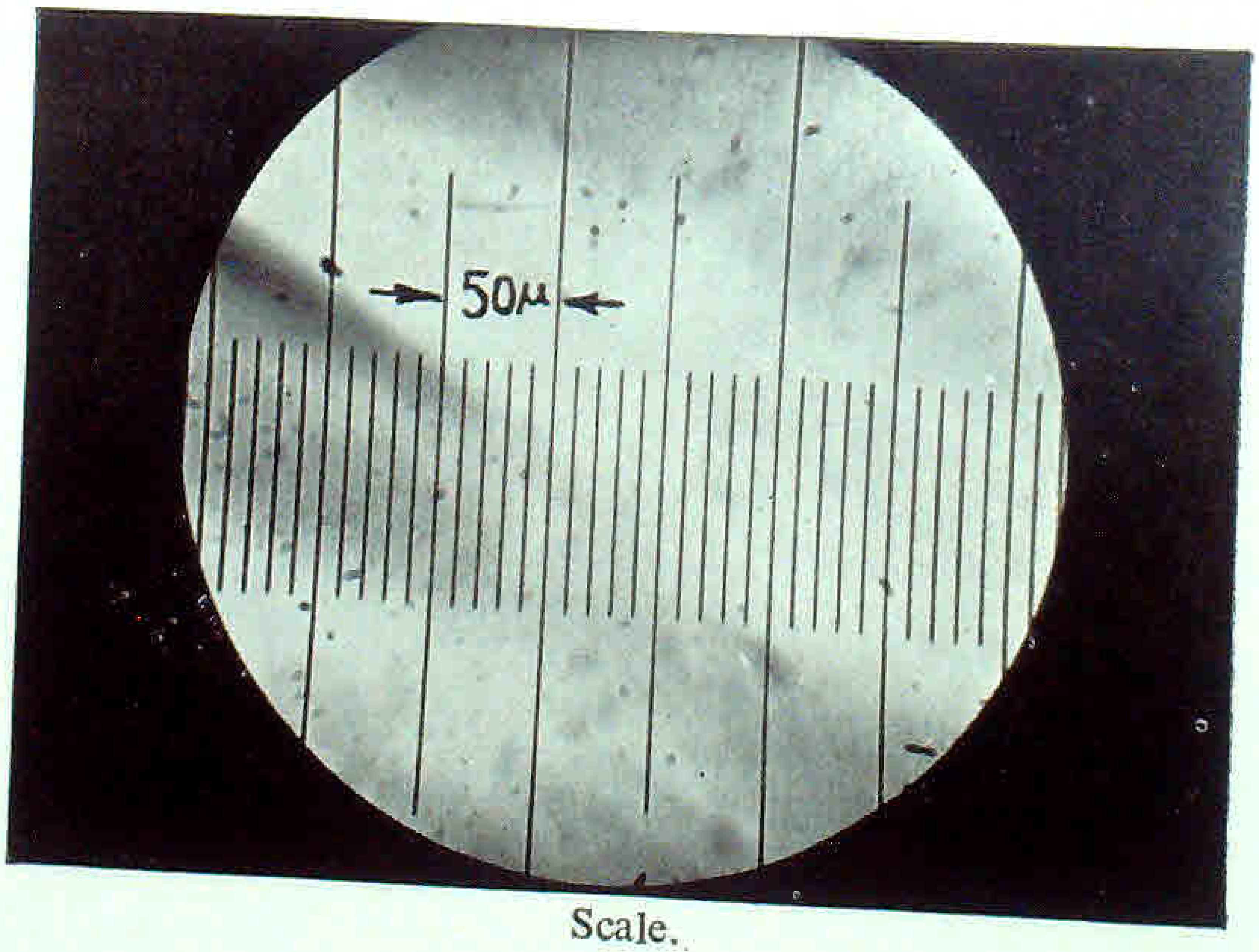
The same procedure was adopted for each modification of the original test model. The experiments were repeated twice for confirming the results obtained.



Micro-photograph of Dust A.



Micro-photograph of Dust B.



Scale.

FIG. 5.

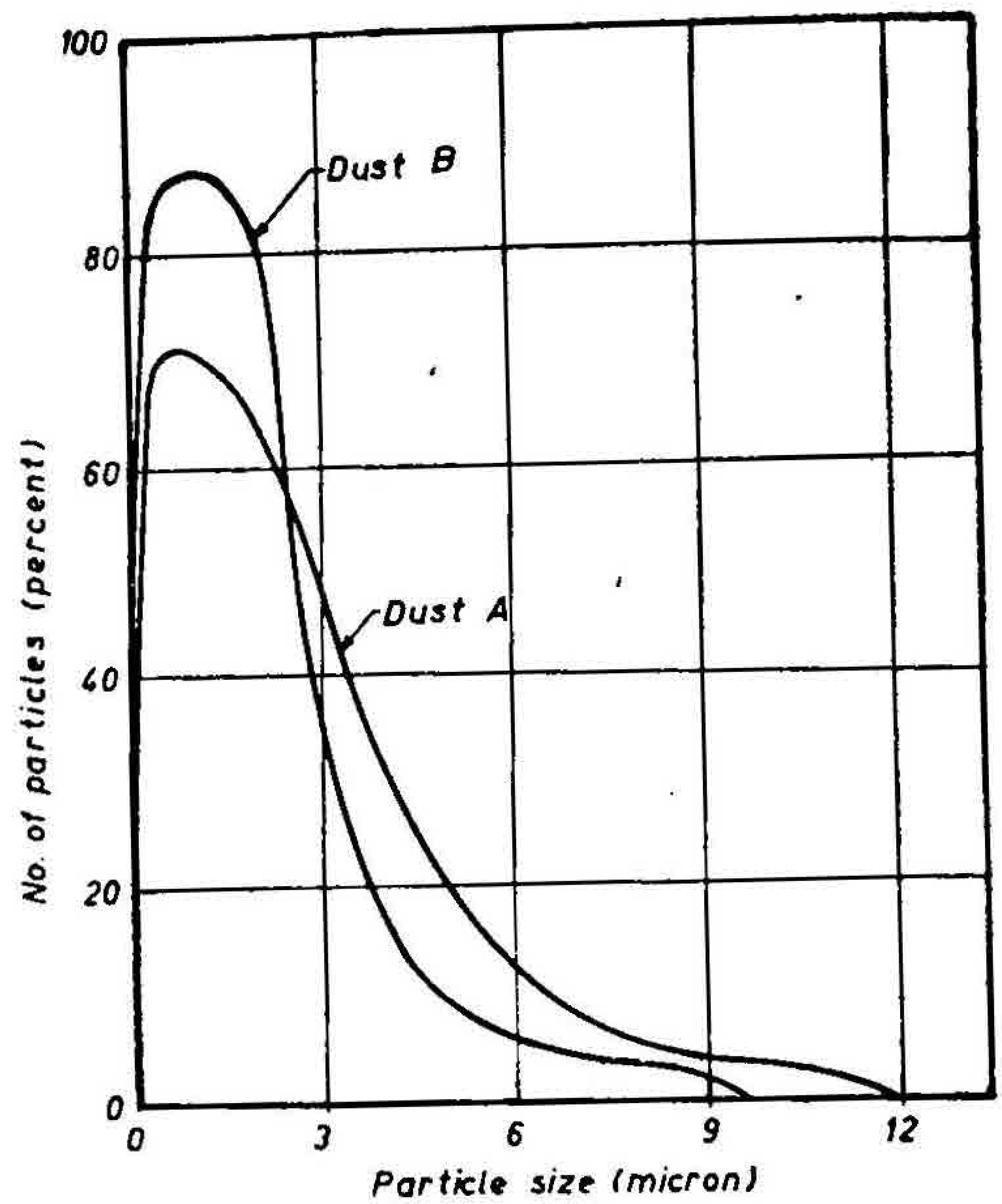


FIG. 6. Particle size distribution of dusts A and B.

4.4. *Course of development*

In Fig. 7 the principal features of the new separator are outlined: Dust-laden air is admitted tangentially and passes along the cylindrical walls to the lower parts of the separator body. There the co-axial conical insertion forms a circular gap through which the dust separated by centrifugal action and assisted by the insertion, enters the dust hopper. The clean gas, spiralling upwards, leaves the separator through the central exit tube.

The development of the separator was concerned with its dimensions and the inlet area and centred around the form and position of the conical insertion which originally had been supported from the cover of the hopper. Performance characteristics were ascertained, after having evolved with a continuous flow of air, what appeared to be an optimum design, which then was studied also under pulsating flow conditions.

5. TEST RESULTS

5.1. *The insertion*

5.11. *The position of the insertion.*—A marked improvement in collection efficiency was observed when the conical insertion was placed centrally above the

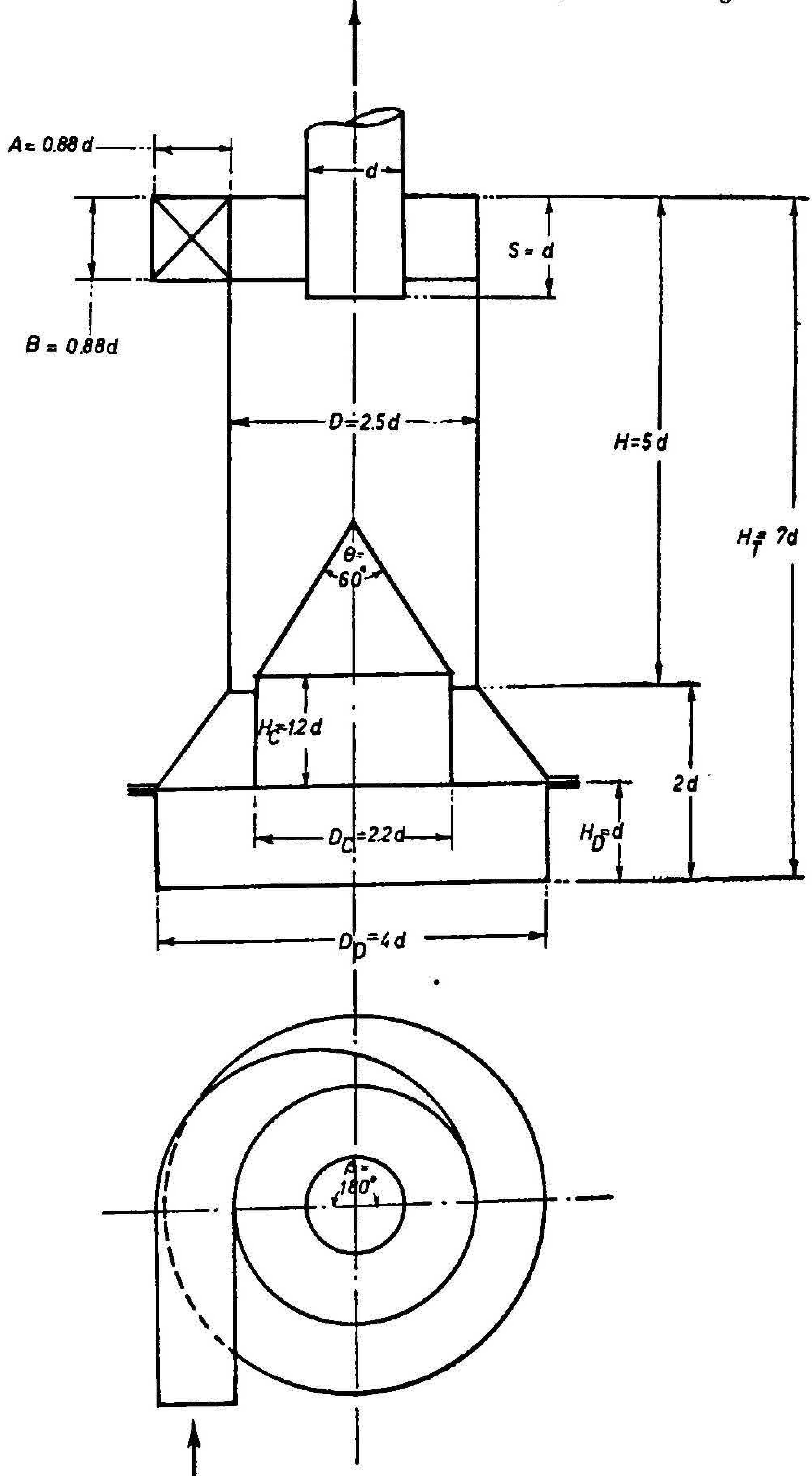


FIG. 7. Optimum proportions of new separator.

TABLE I

Particle size distribution of dust A

Photograph No. / Particle size range	1	2	3	4	5	6	7	Average %
0– 3 Microns	200	182	176	210	208	148	152	70
3– 6 ,,	50	42	46	80	64	71	72	23
6– 9 ,,	7	16	10	6	23	12	13	5
9–12 ,,	3	5	4	2	7	4	3	1·8
Total No. of particles	260	245	236	298	302	235	240	

dust bunker inside the cylindrical body of the separator. This may be due to the creation of a high vacuum inside the dust bunker which possibly helps in retaining impurities there. Details and the novel method of fixing the conical insertion are shown in Fig. 8.

5.12. *Vertical angle of cone.*—The results are collected in Table II and represented in Fig. 9. A vertical angle of 60° was found to lead to optimum operation.

5.13. *Cone height.*—The results are collected in Table III and shown in Fig. 10. The value of the collection efficiency showed an increase with increasing cone height upto a value equal to $1 \cdot 2d$ whereby d denotes the diameter of the exit pipe. The pressure loss thereby increased by a very small amount.

5.14. *Cone diameter.*—The results are collected in Table IV and drawn in Fig. 11. Changes of cone diameter affected the collection efficiency whilst the pressure loss remained almost constant. The optimum value was found to be $2 \cdot 5d$.

5.2. *The inlet area*

The results are collected in Table V and represented in Fig. 12. This result determines the average inlet velocity of the separator. There was a steep fall of the pressure loss as the inlet area was increased at constant massflow. Good performance was obtained when the inlet area was made equal to the outlet area.

5.3. *Dust characteristics*

5.31. *Dust concentration.*—The results are collected in Table VI. There was a slight increase in efficiency with higher dust concentrations.

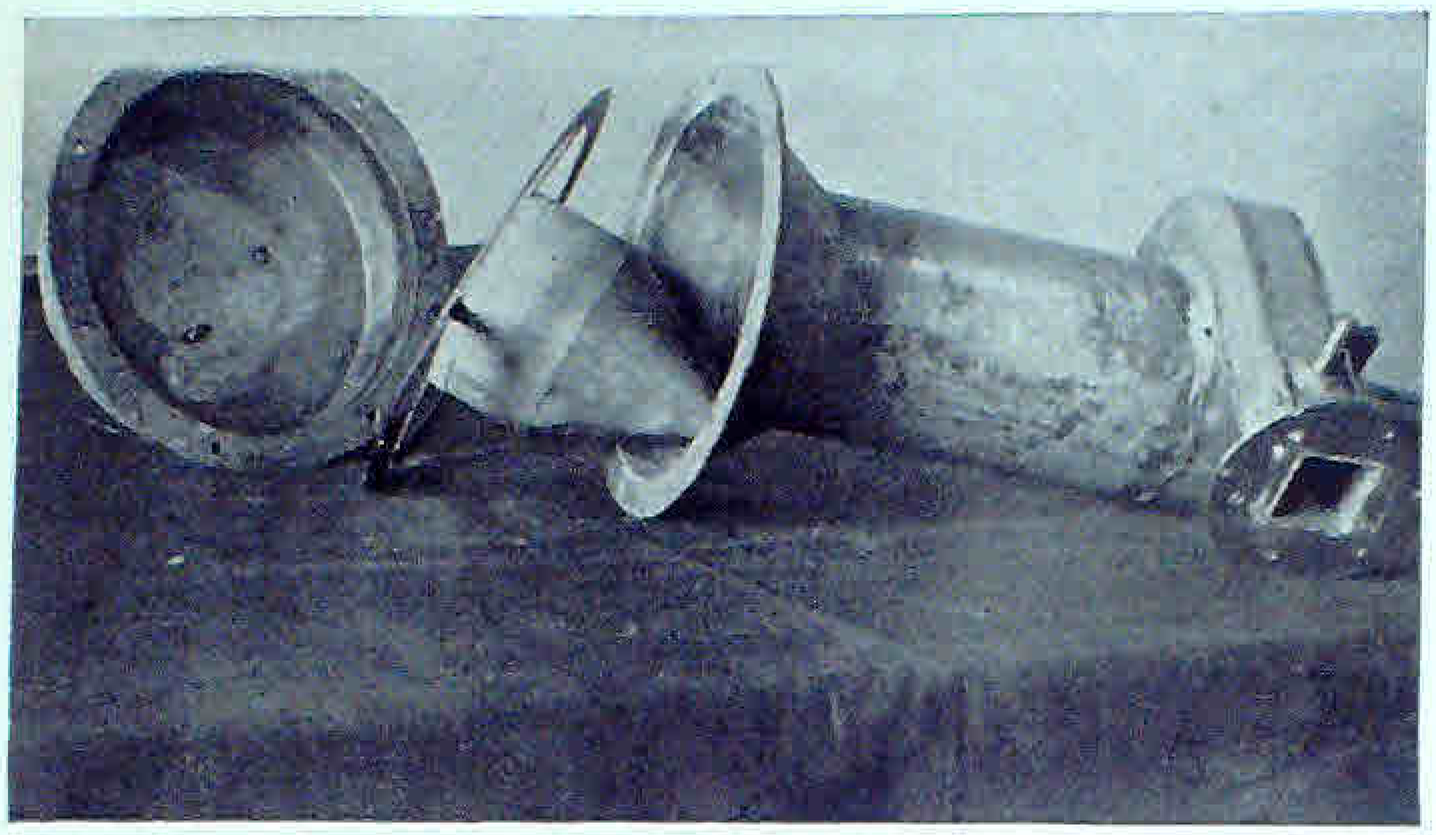
5.32. *Effect of density and size of dust.*—When operated under equal operating conditions the separator gave the same efficiency of 92% for both types of dust. Even though the particle size of dust B was smaller the equally good performance was due to its increased density.

5.4. *Effects of variations of airflow*

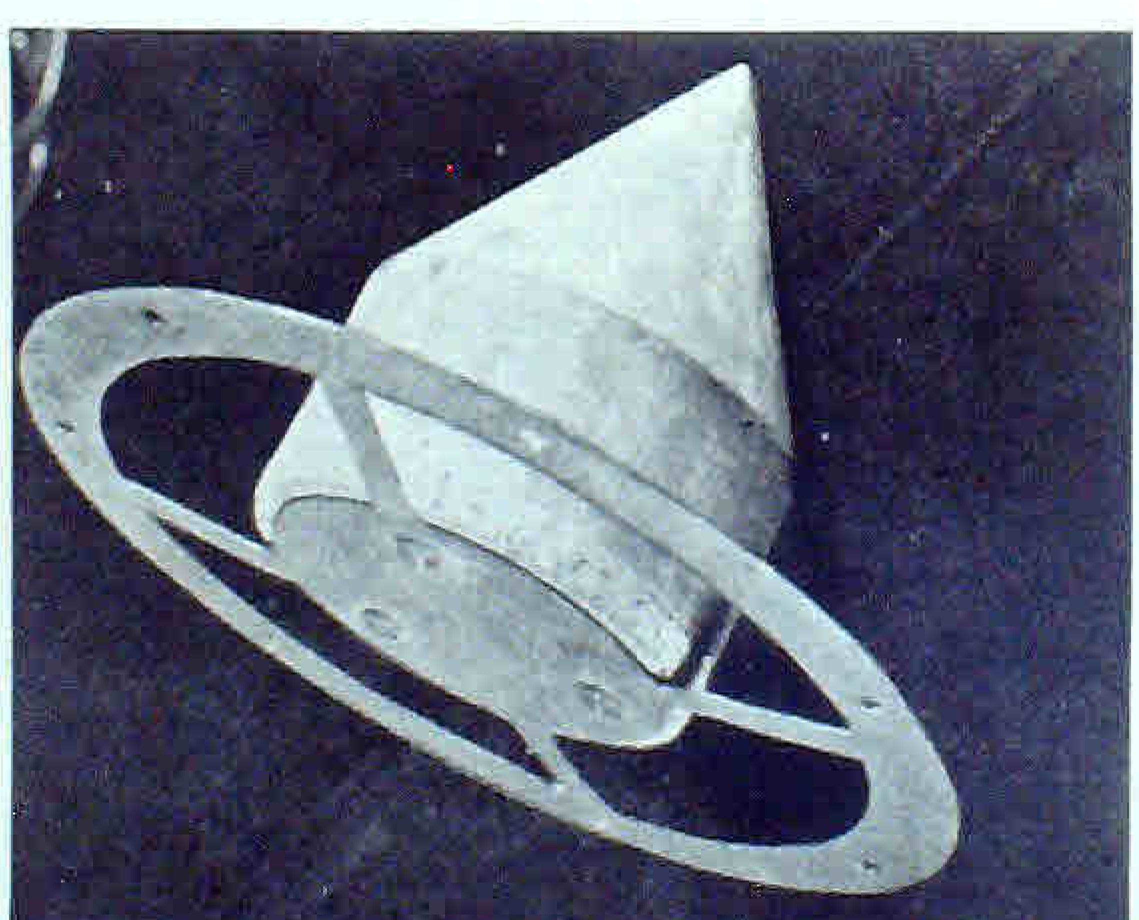
Two geometrically similar models one being a linear enlargement of the other, were tested at constant inlet velocities, with various airflow rates, each under continuous flow conditions. Irrespective of the massflow a separation efficiency of 93% was obtained for both models when the inlet velocity was maintained between 5 and 15 m/sec. (Table VII and Fig. 13).

5·5. *Pressure loss*

The results of pressure drop measurements have been evaluated in terms of multiples of the inlet velocity head and the relevant tables contain a quantity K, the pressure loss factor, which is defined in accordance with Ter Linden,[6] and which in the mean, has a value of 17·5 for average operating conditions, see relevant tables.



Parts of New Separator.



Details of the Insertion.

FIG. 8.

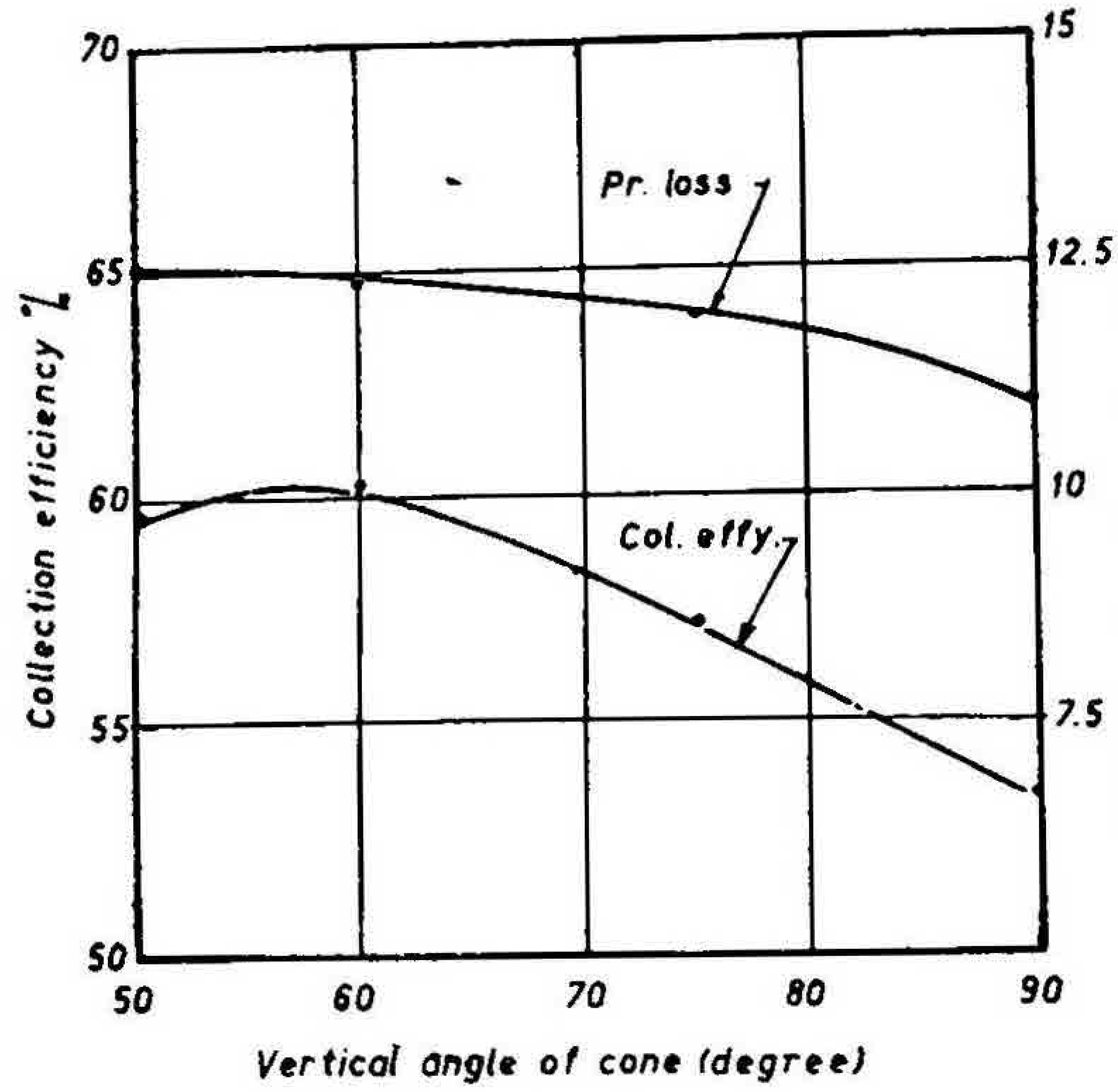


FIG. 9

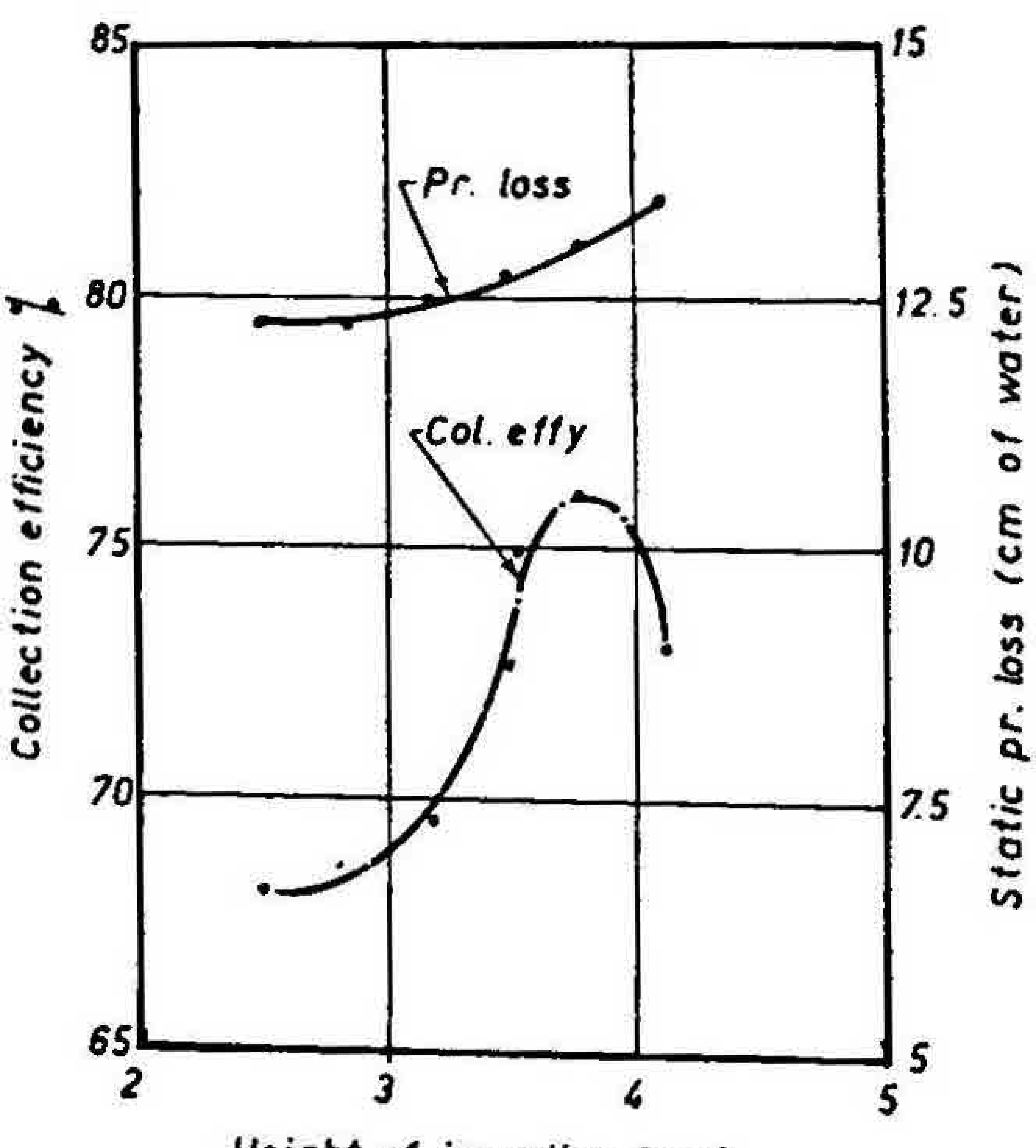


FIG. 10

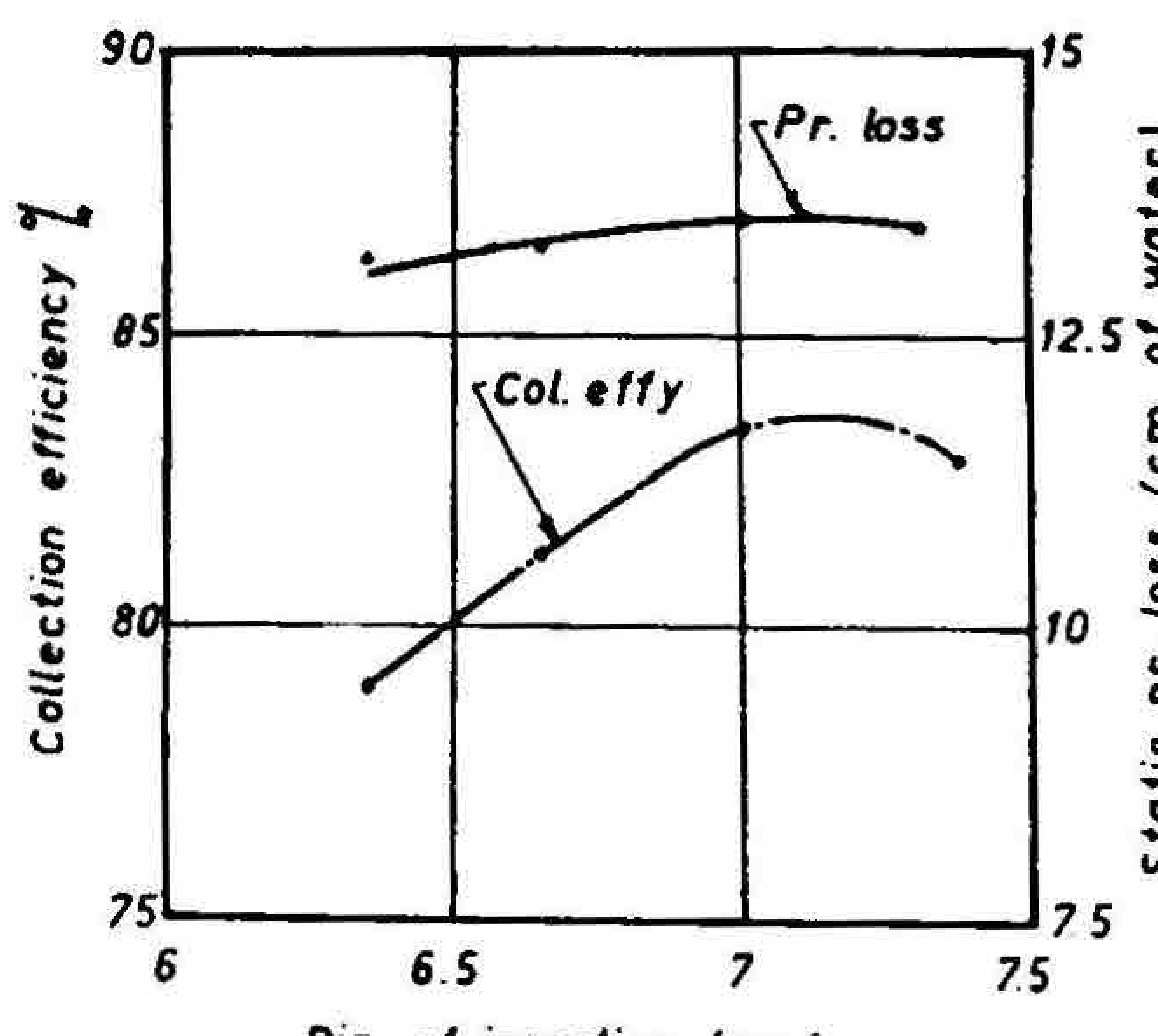


FIG. 11

FIGS. 9, 10 and 11. Performance characteristics with various shapes and sizes of the insertion.

TABLE II

Performance of 7·95 cm. test model for different vertical angles of the conical insertion

Details of Test: Test dust A.
Average dust concentration = 2·75 g./cu.m.
Air flow = 6,100 c.c./sec.
Inlet velocity = 14·3 m./sec.
Velocity head = 1·14 cm. of water

Test model: (Fig. 7)
A = B = 2·06 cm., d = 3·17 cm., D = 7·95 cm.
S = 3·17 cm., H_T = 22·2 cm., H = 15·9 cm.
H_D = 3·17 cm., D_C = 6·35 cm., H_C = 2·54 cm.
D_D = 12·7 cm.

Serial No.	Variable θ in degrees	Wt. of dust fed grams	Wt. of dust collected grams	Duration minutes	Collection efficiency %	Static pressure loss in cm. of water column	Static pressure loss in multiples of inlet velocity head
1	50	10	5·91	10	59·1	12·7	11·1
2	60	10	6·02	9·81	60·2	12·3	10·8
3	75	10	5·7	9·86	57·0	12·1	10·5
4	90	10	5·43	10·2	54·3	11·0	9·65

TABLE III

Performance of 7·95 cm. test model for different heights of the conical insertion

Details of Test: Test dust A
Average dust concentration = 2·75 g./cu.m.
Air flow = 6,100 c.c./sec.
Inlet velocity = 14·3 m./sec.
Velocity head = 1·14 cm. of water

Test model:
A = B = 2·06 cm., d = 3·17 cm., D = 7·95 cm.
S = 3·17 cm., H_T = 22·2 cm., H = 15·9 cm.
H_D = 3·17 cm., D_c = 6·35 cm., D_D = 12·7 cm.
θ = 60°.

Serial No.	Variable H_J in cm.	Wt. of dust fed grams	Wt. of dust collected grams	Duration minutes	Collection efficiency %	Static pressure loss	
						in cm. of water column	in multiples of inlet velocity head
1	2·54	10	6·8	9·62	68·0	12·2	10·8
2	2·86	10	6·83	9·47	68·3	12·2	10·8
3	3·17	10	6·95	10·0	69·5	12·4	10·9
4	3·5	10	7·52	9·8	75·2	12·55	11·0
5	3·8	10	8·1	10·1	81·0	12·95	11·3
6	4·13	10	7·35	9·89	73·5	13·45	11·8

TABLE IV

Performance of 7·95 cm. test model for different diameters of the conical insertion

Details of Test: Test dust A
Average dust concentration = 2·75 g./cu. m.
Air flow = 6,100 c.c./sec.
Inlet velocity = 14·3m./sec.
Velocity head = 1·14 cm. of water

Test model:
A = B = 2·06 cm., d = 3·17 cm., D = 7·95 cm.
S = 3·17 cm., H_T = 22·2 cm., H = 15·9 cm.
H_D = 3·17 cm., D_D = 12·7 cm., H_C = 3·8 cm.
θ = 60°.

Serial No.	Variable D_e in cm.	Wt. of dust fed grams	Wt. of dust collected grams	Duration minutes	Collection efficiency %	Static pressure loss	
						in cm. of water column	in multiples of inlet velocity head
1	6·35	10	7·90	9·82	79·0	13·2	11·5
2	6·67	10	8·13	10·2	81·3	13·3	11·65
3	7·0	10	8·35	10·31	83·5	13·7	12·0
4	7·3	10	8·30	9·76	83·0	13·7	12·0

TABLE V

Performance of 7·95 cm. Test model for different inlet areas

Details of Test: Test dust A
Average dust concentration = 2·75 g./cu.m.
Air flow = 6,100 c.c./sec.

Test model:

d = 3·17 cm., D = 7·95 cm., S = 3·17 cm.
H_T = 22·2 cm., H = 15·9 cm., H_D = 3·17 cm.
D_D = 12·7 cm., H_C = 3·8 cm., θ = 60°
D_C = 7 cm.

Serial No.	Variable inlet area sq. cm.	Inlet velocity m./sec.	Velocity head cm. of water	Wt. of dust fed grams	Wt. of dust collected grams	Duration minutes	Collection efficiency %	Static pressure loss	
								in cm. of water column	in multiples of inlet velocity head
1	4·25	14·3	1·14	10	8·31	10	83·0	13·7	12·0
2	6·45	9·45	0·5	10	9·13	9·82	91·3	7·65	15·3
3	7·85	7·8	0·336	10	9·32	10·03	93·2	5·85	17·5

TABLE VI

Performance of 7·95 cm. test model for various dust concentrations

Details of Test: Test dust A
Air flow = 6,100 c.c./sec.
Inlet velocity = 7·8 m./sec.
Velocity head = 0·336 cm. of water

Serial No.	Wt. of dust fed grams	Wt. of dust collected grams	Duration minutes	Dust concentration g./cu.m.	Collection efficiency %	Static pressure loss in cm. of water column	Static pressure loss in multiples of inlet velocity head
1	10	9·28	74·0	0·37	92·8	5·9	17·5
2	10	9·3	63·5	0·43	93·0	5·9	17·5
3	10	9·31	50·5	0·54	93·1	5·9	17·5
4	10	9·32	35·5	0·77	93·2	5·9	17·5
5	10	9·32	30·0	0·92	93·2	5·9	17·5
6	10	9·35	27·4	1·0	93·5	5·9	17·5
7	10	9·4	12·3	2·2	94·0	5·9	17·5

TABLE VII

Performance of two geometrically similar optimum models for various airflow rates

Test dust A

$\frac{\text{Size of model A}}{\text{Size of model B}} = 0\cdot77$

Temperature during all runs was 80–90° F.
Average value of K = 17·5

Serial No.	Airflow c.c./sec.	Inlet velocity m./sec.	Velocity head cm. of water	Wt. of dust fed grams	Wt. of dust collected grams	Duration minutes	Dust concentration g./cu.m.	Collection efficiency %	Static pressure loss: in cm. of water column	Static pressure loss: in multiples of inlet velocity head	K
						Model A					
1	3600	4·57	0·117	10	9·2	47·5	0·98	92·0	2·04	17·6	17·6
2	5400	6·76	0·260	10	9·25	32·0	0·97	92·5	4·62	17·7	17·7
3	6100	7·8	0·338	10	9·3	27·0	1·0	93·0	5·9	17·55	17·55
4	6400	8·01	0·358	10	9·35	25·3	1·05	93·5	6·05	17·5	17·5
5	7500	9·45	0·5	10	9·35	22·1	1·01	93·5	8·55	17·5	17·5
6	9600	12·2	0·83	10	9·32	18·2	0·96	93·2	14·2	17·2	17·2
7	1020	13·04	0·95	10	9·36	17·5	0·92	93·6	16·10	16·98	16·98
						Model B					
1	6100	4·57	0·117	10	9·25	26·5	1·08	92·5	2·04	17·6	17·6
2	9100	6·76	0·260	10	9·31	19·0	0·98	93·1	4·62	17·7	17·7
3	1020	7·8	0·338	10	9·34	16·83	1·04	93·4	5·9	17·55	17·55

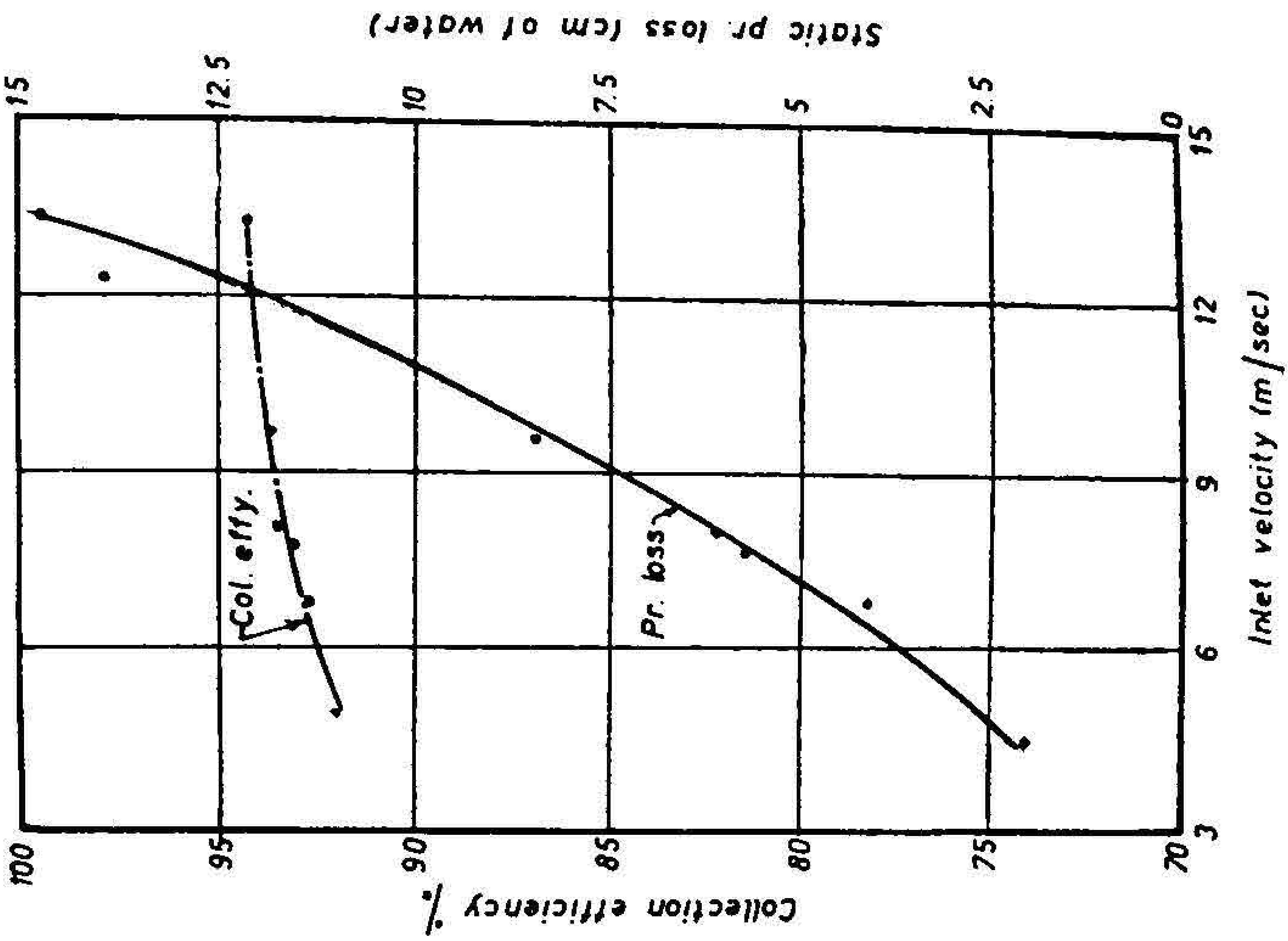


FIG. 13. Collection efficiency and pressure drop *vs.* inlet velocity (steady flow).

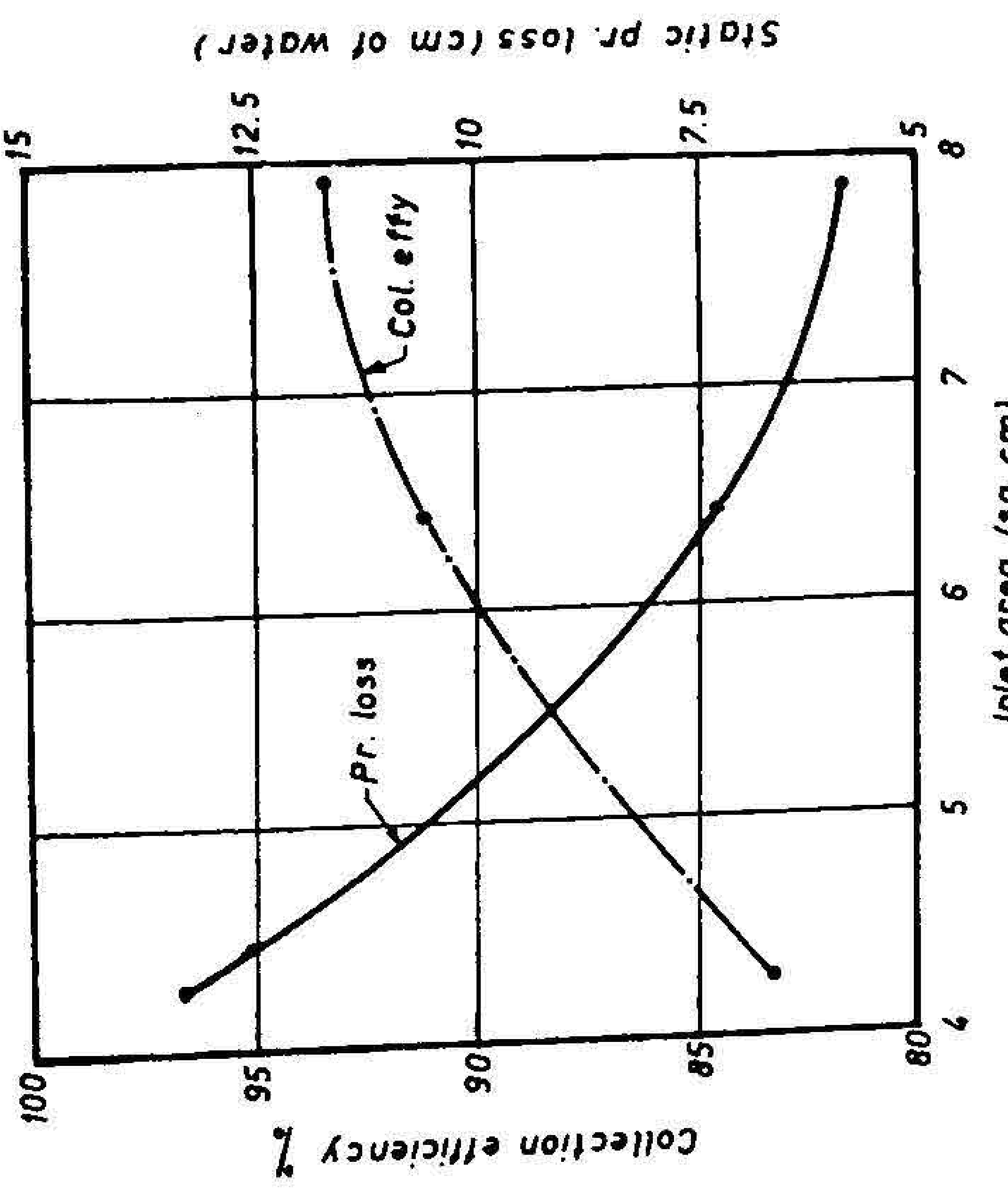


FIG. 12. Collection efficiency and pressure drop *vs.* inlet area of separator.

The pressure loss factor K is often considered as a measure of the quality of a separator with respect to its pressure loss. For a more thorough assessment of its operational qualities, however, it seems necessary to include the efficiency of separation, in conjunction with the average dimensions of the dust and its density for which the efficiency of separation was observed. These values can be grouped to define a quantity which can be denoted and construed as " equivalent pressure loss " with its appropriate dimension:—

$$K_{eq} = K \frac{1}{\eta_{col.}} X_D \gamma_D$$

Herein K is the pressure loss factor, $\eta_{col.}$ the collection efficiency, X_D the mean dust diameter—say in μ—and γ_D its weight density. The " equivalent pressure drop " is the lower the higher is the general effectiveness of the operation of the separator.

5.6. *Experiments with pulsating flow*

The engine was motored at speeds ranging from 200–2,000 r.p.m. Under these conditions, taking into account the results of tests under continuous flow conditions, the efficiency of separation was 83% over a range of mean inlet velocities from 8–15 m/sec. The results are given in Table VIII and represented in Fig. 14. It can be noted that now the two different separator models which gave identical values of pressure loss under continuous flow conditions, show a difference of pressure loss in favour of the smaller model although the same values of efficiency are achieved by both.

The effect of variation of frequency for a particular massflow was determined by inserting a suitable throttle valve into the gas inlet duct. The results are collected in Table IX and illustrated in Fig. 15. There was a marked decrease in pressure loss at higher frequencies with a general tendency to coincide after extrapolation for infinitely high frequencies with values for continuous flow.

5.7. *Experiments with oil in the dust bunker*

A marked improvement of the collection efficiency was obtained when the dust bunker was partially filled with oil. This may be due to the oil arresting and thereby preventing the recirculation of previously separated particles. A separation efficiency of 97% was obtained with steady as well as pulsating flow when model A was operated within the " critical " range of inlet velocities as well as frequencies mentioned above. The results are collected in Table X.

The presence of oil in the dust bunker thus appears to increase the efficiency of the separator.

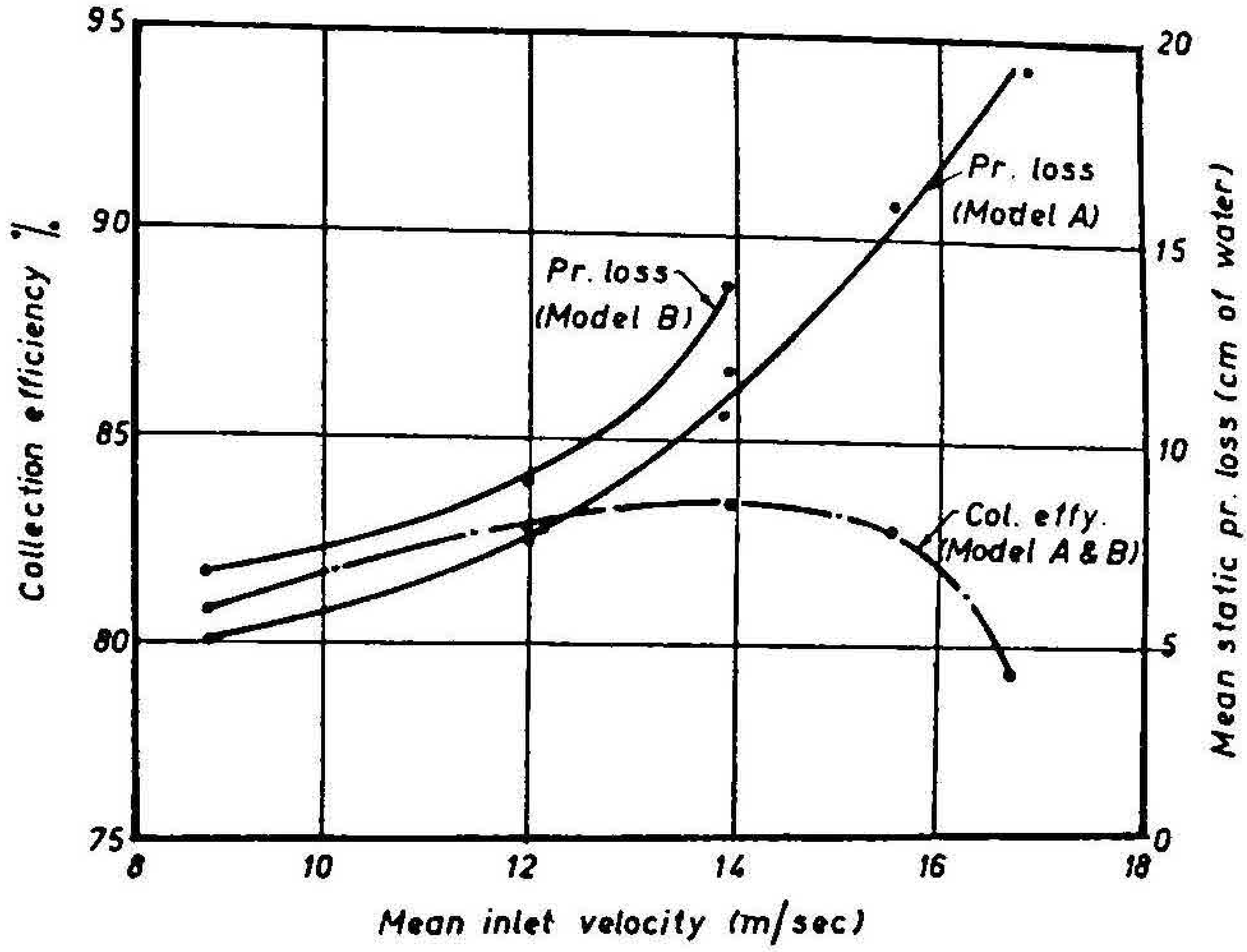


FIG. 14

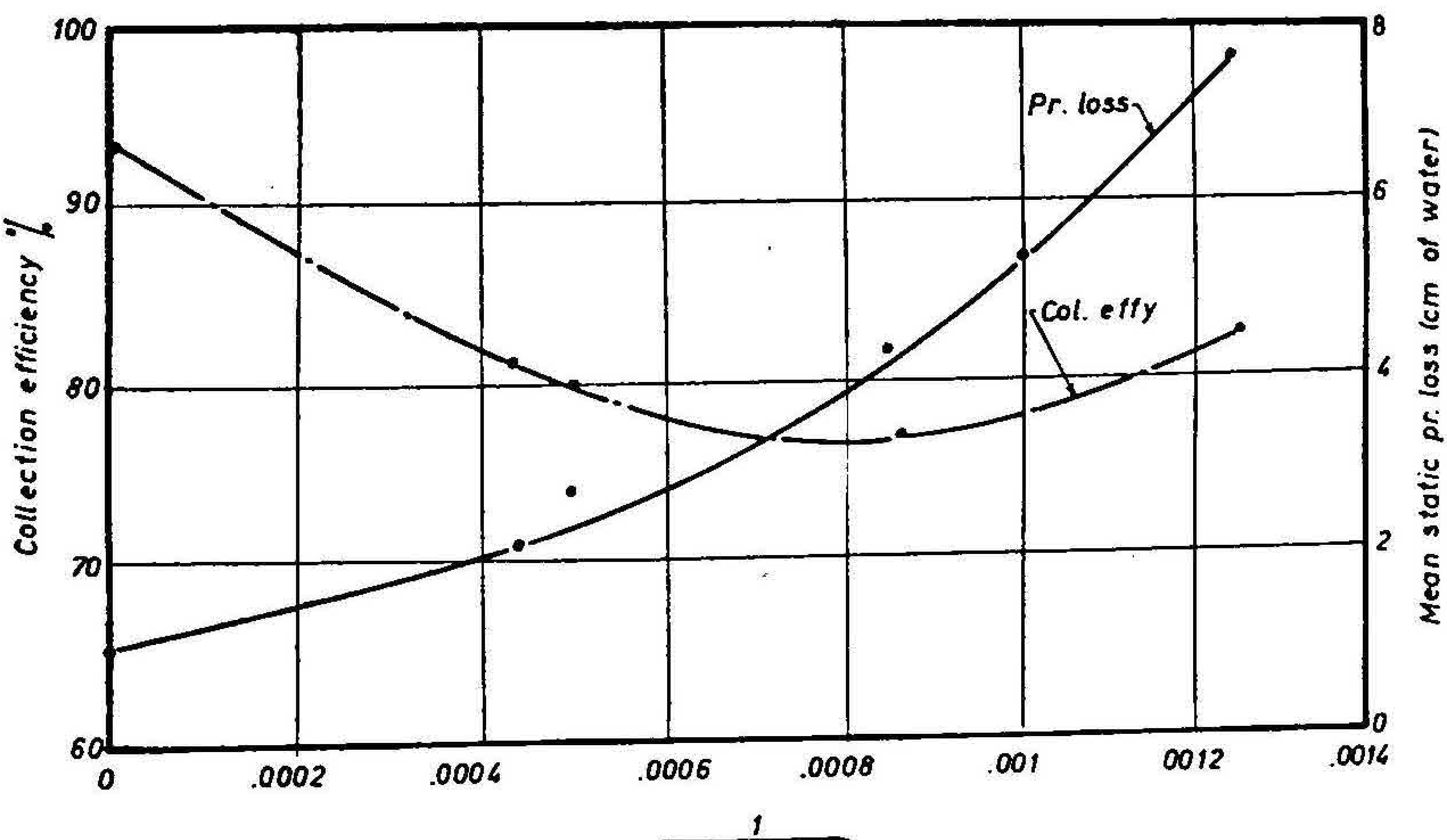


FIG. 15

FIGS. 14 and 15. Performance characteristics (Pulsating flow).

TABLE VIII

Pulsating flow. Performance tests on two similar models

Details: Engine used: 4 stroke single cylinder engine
Duration of suction stroke = 207° of crank angle
Dust used: Dust A

Serial No.	R.P.M.	Airflow c.c./sec.	Mean inlet velocity m/sec.	Wt. of dust fed grams	Wt. of dust collected grams	Duration minutes	Dust concentration g./cu.m.	Collection efficiency %	Mean static pressure loss cm. of water
					Model A				
1	270	1930	8·55	10	8·19	24	3·15	81·9	5·0
2	340	2660	11·75	10	8·23	19·98	3·08	82·3	7·6
3	440	3120	13·75	10	8·29	15·51	3·36	82·9	12·0
4	510	3520	15·5	10	8·30	14·50	3·32	83·0	16·0
5	600	3780	16·75	10	7·80	12·00	3·50	78·0	19·0
					Model B				
1	480	3300	8·55	10	8·20	15·5	3·0	82·0	6·0
2	680	4470	11·75	10	8·28	11·9	3·10	82·8	8·4
3	720	5250	13·75	10	8·31	11·1	2·87	83·1	14·5

TABLE IX

Pulsating flow. Performance of test model B at various frequencies

Average dust concentration = 2·95 g./cu.m.

Serial No.	Airflow c.c./sec.	R.P.M.	Wt. of dust fed grams	Wt. of dust collected grams	Collection efficiency %	Duration minutes	Static pressure loss cm. of water
1	4720	800	10	8·3	83	12·0	7·80
2	4720	1200	10	7·7	77	11·8	5·9
3	4720	1600	10	7·8	78	11·6	4·25
4	4720	2000	10	8·0	80	13·02	3·00
5	4720	2200	10	8·1	81	12·6	2·20

TABLE X

Performance of 7·95 cm. optimum test model with oil in the dust bunker

Details of test: Test dust A

Serial No.	Airflow c.c./sec.	Wt. of dust fed grams	Wt. of dust collected grams	Duration minutes	Dust concentration g./cu.m.	Collection efficiency %	Static pressure loss cm. of water
				Continuous flow			
1	6100	10	9·7	27	1	97	5·85
2	6400	10	9·72	25	1·07	97·2	6·00
3	7500	10	9·73	22	1·02	97·3	8·52
				Pulsating flow			
1	3120	10	9·71	15·5	3·35	97·1	10·2
2	3520	10	9·73	14·3	3·34	97·3	15·8

TABLE XI

Performance of 7·95 cm. optimum test model with different dust

Dust used: Fly-ash
Airflow = 6,100 c.c./sec.
Inlet velocity = 7·8 m/sec.
Velocity head = 0·336 cm. of water

Serial No.	Wt. of dust fed grams	Wt. of dust collected grams	Duration minutes	Dust concentration g./cu.m.	Collection efficiency %	Static pressure loss	
						in cm. of water column	in multiples of inlet velocity head
1	10	9·18	35	0·78	91·8	5·92	17·65
2	10	9·21	30	0·93	92·1	5·91	17·6
3	10	9·22	27	1·08	92·2	5·91	17·6

6. CONCLUSIONS, CONSEQUENCES AND COMPARISONS

6.1. *Dimensions*

According to the experiments the optimum dimensions of the insertion if placed in a separator body with dimensions in accordance with previous workers recommendations, appear to be:

Cone angle 60°,

Cone diameter 2·2*d*,

Cone height 1·2*d*,

where *d* denotes the diameter of the exit tube.

Besides, a square inlet of ·88*d* width and height was found to be superior to the original recommendation.

6.2. *Inlet velocities*

The optimum range of inlet velocities was 5–15 m/sec. for steady flow conditions as well as for pulsating flow conditions as occur in a single cylinder engine.

The effectiveness of the separator working in conjunction with a reciprocating engine depends thus on its speed range. The separator can be designed at the rated speed of the engine. If there is, however, a wide variation in speed during operation it cannot be avoided that the separator operates over part of the range beyond its optimum velocity whereby then its efficiency will also be somewhat reduced. This as well as considerations of servicing recommend the operation of the separator together with a filter: The considerable cleaning action of the separator will prevent for a long time the clogging of the filter and thus the increase of the pressure loss with its deleterious effects on the output of the engine.

6.3. *Comparisons*

For a comparison the conception of the "equivalent pressure loss" is used and if applied to the magnesium oxide dust $\gamma_D = 0\cdot 1$ g./c.c. results in a value

$$K_{eq} = 18\cdot 8$$

whereby a "mean" particle diameter of 10μ has been assumed. This, although the true mean diameter of the dust used in the experiments was smaller, serves the intended comparison better.

If the "equivalent pressure loss" is derived from another experiment reported earlier[8] the result is

$$K_{eq} = 220$$

whereby this is based on a separating efficiency of 0·70, a dust density of 2g./c.c. and a largest particle size of 10μ as given in the reference.

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