1/1/93

July, 1967

RB 65/49

D.M. 1276/65

SOUTH AUSTRALIAN GOVERNMENT DEPARTMENT OF MINES

THE ELECTRICITY TRUST OF SOUTH AUSTRALIA

RB 65/49

Amdel Report

No. 548

LEIGH CREEK COAL BURNER STUDIES

by

J.M. Clayton

Investigated by: Industrial Chemistry Section

Officer in Charge: R.E. Wilmshurst

P.A. Young. Director

THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES

Adelaide South Australia

CONTENTS

SUMMARY

Background

At the Thomas Playford Generating Station of the Electricity Trust of South Australia (ETSA) at Port Augusta, difficulty is experienced in maintaining maximum rated output for extended periods. Observations by ETSA staff and research conducted by CSIRO have defined reasons for these difficulties and indicated that the problem might be reduced if the combustion efficiency could be increased.

Objective

The Australian Mineral Development Laboratories undertook to study the operation of pulverised coal burners of the type used at Port Augusta and to suggest ways of increasing the combustion efficiency. The work involved an investigation of the operating characteristics of the burners and the construction of a cold model of one of the burners with which to study flow patterns and to test modifications. Following upon the investigation of the model, modifications were to have been made at the power station.

Summary of Work Done

Experiments conducted on No.1 boiler of the Port Augusta "B" Station showed that variations recorded in the oxygen level were probably due to variations in coal quality or quantity or stratification of the gas stream, rather than to variations in the air supply or a fault in the analyser. Analyses of the fuel supply indicated that crossflow between the two ends of the duplex pulveriser mills was not sufficiently serious as to warrant modifications to prevent it. The distribution of solids in the ducts leading to the burners was found to be asymmetrical. The tests revealed that there was no simple correlation between mill age and performance.

Work on the model burner showed the flow pattern probably existing in the burner tubes and allowed development of methods of improving the uniformity of solids distribution in the fuel-air mixture issuing from the burner mouth.

Conclusions

The performance of pulveriser mills is not as dependent on

time in service since overhaul as had been thought, and measurements have enabled the period between overhauls to be increased.

The distribution of solids in the gas stream leaving the burners was found to be very uneven. In the model the solids, which should be spread around the full circumference of the tube, a distance of 61 in., were confined largely to an arc of about 6 in. in length. This condition is unfavourable for combustion as air penetration to the centre of the band of coal will take some time, during which the particles will pass out of the hottest part of the flame. This could be at least partially responsible for the unburnt carbon found in the ash box and the precipitator dust. Extension of the band of solids as far as the furnace wall could lead to hot spots and the associated problems of corrosion and slag deposition.

Suggested modifications to burner design have not yet been adopted at the power station. Installation of narrow longitudinal baffles in the burner tube gave sufficient improvement in the cold model to warrant trial on at least one boiler in the "B" station.

Recommendations

It is recommended that a full study be made of the performance of one or more pulveriser mills over an extended period. The study should include product particle size analyses, assessment of coal hardness and maintenance of records of mill running time and feeder speeds. This could lead to a further useful increase in life of a mill between overhauls.

It is also recommended that modifications be made to the design of the burners in the Port Augusta "B" station. Some of the modifications tested on the model offer a considerable improvement over the existing design, and the use of multiple longitudinal baffles in the primary burner tube is recommended as a logical first step.

1. INTRODUCTION

Studies were initiated in June, 1965 for the Electricity Trust of South Australia (ETSA) with the general aim of improving the performance of the boilers at the Thomas Playford Power Station. The following programme of work, to be carried out on one of the boilers in the "B" Section, was drawn up by officers of ETSA and Amdel:

1. Measurements of O_2 in flue gas in order to assess the causes of the cyclic O_2 variation usually encountered in all the flue-gas streams:
   a. continuous measurement of O_2 in function of total air flow,
   b. measurement of O_2 recorder probe position (normal position of probe; in gas path at lower drum level on centre line of boiler).
2. Measurements related to pulverised fuel and primary air flow in order to study means to equalise the flow of primary air and of coal to burners and to homogenise the pulverised fuel - primary air mix:
   a. measurement of air flow to each burner (or at least what proportion of primary air goes to each burner),
   b. measurement of coal flow to each burner (calibration of coal feeders and assessment of possible cross-flow between two halves of a duplex mill),
   c. measurement of pulverised fuel distribution (concentration) over a given cross-section of the fuel/air line to each burner,
   d. measurement of pulverised fuel particle size distribution for each mill.
3. Assessment of flame shape to determine quantitatively the effects of burner modifications, if these are planned for the future, i.e.:
   a. construction of contour lines of O_2 concentration in the combustion zone by means of O_2 traverses,

b. construction of contour lines of temperature in the combustion zone by means of temperature traverses possibly taken with a bare or shielded thermocouple, instead of a suction pyrometer, as it is thought that the former devices, although not capable of giving true temperature measurements, can give reliable relative values.

4. Assessment of burner modifications for the purpose of rendering uniform the distribution of pulverised fuel in the primary air stream in the burner tube, and for the purpose of optimising the primary air flow conditions when leaving the burner mouth. This entailed: construction and operation of a full scale cold air model of a "B" burner tube. (The model can be constructed by using a number of spare parts obtained from the power station).

The work described at points 1, 2 and 3 was to be carried out on one of the "B" Section boilers at Playford Generating Station. Model work was to be carried out at the Thebarton section of Amdel.

Work has been done on Sections 1, 2 and 4.

All investigations at Port Augusta have been done on No.1 boiler, the most southerly of six boilers in the "B" station having a maximum continuous rating of 360,000 lb per hour of steam at 925^{o}F and 950 lb per sq in. each.

2. EQUIPMENT

Oxygen Analysis. Oxygen samples were collected in 40 ml glass bottles which previously had been filled with saturated sodium chloride brine and sealed with rubber surgical caps. Two hypodermic needles were used to pierce the self-sealing caps to allow the gas to flow in and displace the brine. A small vacuum pump was used to increase the gas flow rate.

Pulverised Coal Probe. A 1-inch bore probe was constructed for isokinetic sampling of the pulverised coal. Construction was based on the design of Toynbee and Parkes, (1962)[1]. The probe

1. Toynbee, P.A. and Parkes, W.J.S. (1962), "Isokinetic Sampler for Dust-Laden Gases", Int. J. Air Wat. Poll. 6, 113-120.

head consisted of a 1-inch nominal bore stainless steel pipe of 6 in. length and ¼ in. wall thickness, of which a 2½ in. length was tapered to give a sharp 1 in. diameter edge at the gas inlet. Within the pipe wall at 3 in. and 3-5/8 in. from the inlet end were two annular manifolds, with tappings to the inside and outside of the pipe respectively. Connections were taken from each of these manifolds along the outside of the probe. The probe head was attached to a 90 degree bend and 26 in. of straight pipe. A gate valve was also attached to facilitate operation of the ancillary equipment. The authors[1] predicted that the sampling velocity would be isokinetic when the pressure difference between the manifolds was zero. Suction was applied to the probe by means of two ejectors connected in parallel. The coal dust was removed from the gas stream by a small cyclone and was allowed to fall into a sealed drum. A 2-way slide valve allowed the coal dust to be diverted to obtain the samples. A sketch of the apparatus is shown in Figure 8.

Model Burner. Because of the problems associated with scale-up and of high temperature work, it was decided to construct a full-scale cold model of the primary section of a burner. The plan and elevation of this model are shown in Figures 1 and 2. The burner tube was modelled from ¼ in. thick perspex in two sections, one of which was removable to allow access for modifications. The elbow joining the tube to the fuel supply pipe was also constructed from ¼ in. perspex, to enable the flow pattern to be seen immediately before and at the elbow when sawdust was added to the gas stream. The model was situated on a scaffold 16 ft above ground level with 12 ft of straight vertical pipe leading into the perspex elbow. This arrangement was intended to simulate the pulverised fuel ducts rising from the mills to the burners in the Port Augusta "B" Section boilers. The burner tube vented into a perspex box, 4 ft 6 in. long and 4 ft square to permit observation of the flow patterns and photographic recording of these in selected cases. Gas and solid passed from the box into a cyclone in which the solids were separated. Air

---

1. Loc cit.

was supplied by a Chicago Design 16 Industrial Fan of rated capacity 6000 cfm against 6 in. water gauge (wg).

Sawdust was chosen for the flow studies because it was readily available. Mixed sawdust from a local furniture manufacturer was passed through a No.8 mesh sieve before use in the model. It was intended that the sawdust collected by the cyclone should be returned by means of high pressure air to the circuit at the branch near to the cyclone. Unfortunately the volume of compressed air required to achieve a high throughput of sawdust against the pressure in the pipe was excessive. It was therefore decided to pass the sawdust through the fan, a high throughput thus being achieved. Some air was bled back through the branch to blow the sawdust from the bottom of the cyclone and prevent blocking.

Attempts to produce smoke for studying the air flow, by using burning sawdust or liquid titanium tetrachloride were not entirely successful and this procedure was abandoned.

Photography. Photographs of the solid distribution in the gas stream were taken by an Asahi Pentax reflex camera using 400 ASA film. Lighting was provided by six suitably arranged 100 W floodlights, or flash bulbs, the former being more successful.

3. EXPERIMENTAL PROCEDURE AND RESULTS

3.1 Airflow and Oxygen Measurements

The studies began with an investigation of the supply of air to the boiler and the related oxygen analyser and recorder. A series of pitot traverses was made in the two primary and the two secondary air ducts. Velocity contours were then drawn for each duct as shown in Figures 3-6. From these the mean velocity and hence the airflow were calculated. The primary airflow was calculated as 136,000 lb per hour, i.e. 38.3% of the total, and the secondary airflow was calculated as 219,000 lb per hour, (61.7%), giving a total calculated airflow of 355,000 lb per hour. The primary and secondary air temperatures were measured as 759°F and 650°F respectively. At this time, the total airflow indicated by the instrument on the boiler control panel was

321,000 lb per hour, about 10% lower.

The percentage of oxygen in the flue gas of each boiler is measured and recorded continuously. The recorder trace commonly oscillated widely and the instrument was therefore checked against samples analysed in the laboratory to determine whether the fluctuations were both real and accurately recorded. Samples were extracted from a point in the gas sampling line just preceding the analyser over intervals of 30 seconds using the apparatus described in Section 2. The oxygen content of the gas in the bottles was then determined by gas chromatography and compared with that indicated by the continuous recording instrument, as shown in Table 1 and Figure 7. The instrument read consistently about 1.5% below the analysed value, and had a response lag of 1-1½ minutes.

In an attempt to define the cause of the fluctuations in the percentage of oxygen in the flue gas, the readings of the instrument were compared with a continuous recording of air velocity, as measured by a pitot tube in the south primary air duct. The pitot tube was left for 15 minutes in each of the positions used in the earlier traverse, except for the centre row, which was inaccessible. The airflow was too steady to give any significant changes in the recording, and during this period the oxygen level also stayed within fairly close limits.

3.2 Pulverised Coal Sampling

The next stage in the study was an investigation of the flow in the six 18-in. diameter ducts connecting the pulverising mills to the burners. Access was achieved by attaching short lengths of 4-in. bore pipe to holes cut in the western side of each duct, about 12 ft above the operating floor. The branch pipes are normally sealed by a blank flange. Some difficulty was encountered in preventing leakage from the duct during sampling. The final solution involved the use of a rubber sleeve constructed as a bellows, which was sealed to the probe and the access hole, whilst allowing the probe to be freely positioned. Insertion and removal of the probe involved stopping the appropriate mill for about 5 minutes. The apparatus used for the sampling is described in Section 2.

The six ducts are connected to the mills and the burners as shown in Figure 9, which also shows the numerical identification used at the power station. An attempt was made to sample each pipe at the nine points shown in Figure 10, but failure of the bellows during some of the experiments prevented full traverses from being achieved. Three timed samples were taken at each point and were weighed to determine the solids flowrates, the samples being kept for later size analyses. The distributions of the coal mass flow rates are shown in Figure 11 which was constructed from the values tabulated in Table 2. The diagram shows that in each pipe there was an uneven flow distribution across the section sampled. By obtaining the mean flow rate for each pipe from the values given in Table 2, a comparison of the total throughput in each pipe was obtained, and hence a comparison between the two halves of each mill (Table 3).

A full sizing analysis was performed on the samples from each point in pipes 4 and 6, the details being shown in Appendix A. The distribution of the various size fractions is shown in Figure 12 as percentages of each size fraction. Comparison of Figures 11 and 12 shows that the plus 200-mesh particles were unevenly distributed in the pipes, in a pattern corresponding with the mass flow distribution, whereas the minus 200-mesh particles are fairly evenly distributed. Size analyses were also performed on a composite sample from each of the other 4 pipes (Appendix B). A comparison of the sizing analyses from all six pipes is given in Table 4.

At the time of the experiments the south mill was two thirds through its normal period between overhauls, the centre mill was newly overhauled and the north mill was about to be overhauled. During the tests the low rating dampers on both pipes from the mill which was being tested were set fully open and the appropriate feeder was kept at a constant speed by manual control.

3.3 Model Burner

The model burner was constructed as described in Section 2. A coal spinner and spreader of the kind used in the "B" station burners were supplied by ETSA and fitted inside the tube in positions corresponding to those at Port Augusta. The spinner was a heavy casting having 12 vanes and was positioned at the end of the horizontal tube nearest the elbow. It was designed to give the coal and air mixture an initial swirl. The spreader was constructed from stainless steel and had 28 vanes. These extended from the surface of the burner tube to within 3 in. of the 4 in.-diameter sleeve in the centre of the tube to which the spinner and spreader were attached. The vanes were set at 45°, their function being to spread the coal/air mixture in a diverging jet into the secondary air stream.

On operation of the model with the spinner and spreader in these positions it was observed that the sawdust was unevenly distributed in the vertical pipe. At the elbow, it tended to be thrown out of the air stream to form a very highly concentrated band at the top of the elbow. This band or "rope" then passed through the spinner and, after about 1¼ revolutions in the tube, out through the spreader. The swirl imparted by the spinner tended to throw the sawdust to the circumference of the tube and it was observed that nearly all of the sawdust passed through the tube within 2-3 in. of the surface. The deflection imparted by the spinner was such that the sawdust reached the spreader at the same angle as the vanes, which therefore had very little effect on the flow pattern. Sawdust passing through adjacent spinner vanes tended to join the band, which became denser and more compact on its path to the spreader. It was estimated that about 70-80% of the total sawdust in the stream was condensed into the single "rope". This observation was corroborated by visual observation of old spinner/spreader units discarded from the burners, as these were very badly eroded over an area of 2 or 3 adjacent vanes, the remainder being comparatively unaffected. The assessment of the flow distribution of the sawdust was made visually by comparing the flow between each pair of vanes as seen from the outlet side of the perspex box. This estimate is shown diagrammatically in Figure 13 (R.1). A photograph of the distribution is reproduced in Figure 14.

A literature search revealed that a similar problem had been encountered by an American boiler manufacturer.[1] Although the geometry of their system was somewhat different, it was decided to try their modification to see if it was applicable to the problem. The first modification tried consisted of a single ½-in. square wooden baffle 36 in. long, which was fixed longitudinally at the top of the tube between the spinner and the spreader. This position was chosen so as to cut the band of sawdust about half way along the tube. On operating the model part of the band was deflected along the side of the baffle, distributing the sawdust over twice the area of R.1 as shown in Figure 13 (R.2).

The baffle was then replaced by a slightly larger baffle, 5/8-in. square. This appeared to be slightly too large, as most of the sawdust was deflected by the baffle, leaving an area of low concentration just behind it as shown in Figure 13 (R.3).

The next modification consisted of 8 equally spaced baffles ½-in. deep, ¾-in. wide, and 24 in. long extending from just behind the spinner. This arrangement produced a series of bands of sawdust running along the baffles. The bands continued from the ends of the baffles to the spreader, being only slightly deflected by the air swirl in the tube and spreading out only slightly as shown in Figure 13 (R.4). They could probably have been spread out more evenly by gradually tapering the baffles to allow the sawdust to "spill" over.

The next modification involved the removal of the spinner and its replacement by the spreader. The 8 baffles were left in position. This arrangement (R.5) gave a fairly good distribution of the sawdust, but as the photographic technique was not then in use, no record is available for comparative purposes. The arrangement was followed by one in which the spreader was removed

1. Whitney, G.C., (1959), "Use of Models for Studying Pulverised Coal Burner Performance", Transactions A.S.M.E. October 1958, 380-2.

and the spinner replaced (R.6). The rectangular baffles were replaced by 8 equilateral triangular section baffles of 1 in. face. This also gave a fairly good distribution, but the swirl was considerably less than that for R.5. As an extension of R.5, the spinner was again replaced by the spreader and the baffles were removed. The arrangement (R.7) produced two broad bands of sawdust on opposite sides of the tube, covering about 60% of the circumference. There were still two fairly large segments separating the bands with little or no sawdust.

The next modification consisted of 2 spreaders of opposite pitch set at the ends of the tube (R.8). The swirl imparted by the first spreader was neutralised by the sawdust impinging normally onto the blades of the second, before emerging as a confused jet parallel to the tube axis. The distribution of the sawdust was poor, about 80% passing through 2-3 vanes. The arrangement produced also a very high pressure drop across the model, with a correspondingly low fluid velocity.

As none of these modifications had been particularly successful, the spinner and spreader were returned to their original positions and the 8 triangular baffles were fitted. Some pronounced back eddies were noted in the elbow, originating from the end plate and the area of transition from vertical to horizontal pipe. A flat baffle was fitted into the tube elbow at an angle of about 30 degrees to the end plate. This was found to cut out most of the eddies but it had no significant effect on the pattern of the sawdust inside the burner tube. It was replaced by a second baffle, inserted at about 45 degrees, which had a slightly better effect. Some of the sawdust was deflected by the baffle into the lower half of the spinner. The bands of sawdust appeared to be slightly more evenly spread out as is shown in the photograph reproduced in Figure 15 (R.9).

An attempt was made to photograph the flow distribution in the tube using six 100 W floodlights positioned so as to illuminate thin transverse sections of the gas stream. The experiment proved to be abortive due to the lack of light intensity and it was repeated using flash bulbs. The resultant photographs were difficult to interpret. The distribution of sawdust leaving the tube was eventually photographed using the six 100 W floodlights positioned around three sides of the perspex box about 4 in. downstream from the tube outlet. Photographs were taken from the outlet side of the perspex box. Figures 14 to 21 were taken by this method.

One further modification involved the replacement of the spinner, spreader and support sleeve by a 1½ in. shaft on which was mounted an 8-bladed fan with variable pitch blades. The triangular baffles and the end baffle were also removed. The shaft was mounted on bearings at each end and was capable of being driven at variable speeds. After a preliminary trial the end baffle was replaced at 45 degrees and the spreader was replaced in its original position, this giving slightly improved performance.

With the shaft locked and the blades set at a 45 degree pitch with the fan fixed near the elbow, the distribution was similar to that in the original arrangement (Figure 16). When the fan was free-spinning under the action of the air flow, the bend of sawdust was broadened to cover almost half of the tube circumference, with some sawdust around the centre of the tube (Figure 17). Driving the shaft at 180 and 380 rpm did not significantly improve the distribution.

With the fan blades reset at 15 degrees to the tube axis the sawdust was distributed over about 60% of the tube circumference when the shaft was locked (Figure 18). When the fan was free-spinning the distribution was poorer, a high density band again forming (Figure 19). The effect of driving the fan at 130 rpm was to spread the band out only slightly. At 260 rpm the sawdust was distributed fairly evenly over about 70% of the circumference. Increasing the speed to 400 rpm did not improve this distribution.

The fan was then repositioned in the centre of the burner tube, the blades having the same pitch as before. When the shaft was locked, the sawdust was distributed over about 60% of the tube perimeter (Figure 21).

In conjunction with the various modifications tested a check was kept on the pressure drop across the model to ascertain whether any particular modification was within the capacity of the fans at the power station. Two holes were cut into the model, one in the vertical pipe about 3 ft below the burner tube, and the other in the outlet pipe from the perspex box, about 2 ft from the box. The pressure drop across the model was measured between these two points. The pressure drop for the original arrangement (R.1) was 1.54 in. wg and with the spinner removed (R.7) it was 1.17 in. wg. For the two opposing spreaders (R.8) it was 2.47 in. wg and for the original geometry with the addition of 8 triangular baffles and a baffle at 45 degrees in the elbow (R.9) it was 1.81 in. wg. Corresponding velocities for these modifications were R.1 - 41 ft per second, R.7 - 43 ft per second, R.8 - 31 ft per second and R.9 - 40.7 ft per second. The velocities were measured at the centre of the pipe.

A pitot traverse was made over an area equal to the area of the burner tube outlet at a distance of 3 in. downstream from the spreader. It was not possible to obtain reproducible values and no quantitative data were obtained except for confirmation that there was a band of air of high velocity, about 55 ft per second, near the circumference of the tube. The velocity then gradually tapered off to a value of zero at the annulus immediately surrounding the central 4 in.-diameter sleeve pipe. This showed that in general, the sawdust followed the air flow, the greatest concentration of sawdust being in the area of greatest air velocity.

4. DISCUSSION

The location of the pitot traverse stations used in determining the gas velocities plotted in Figures 3, 4, 5 and 6 were not in accordance with the appropriate British Standard[a], due to difficulties of access and some misunderstanding between Amdel and ETSA personnel. However, this should not greatly affect the validity of the results obtained.

The velocity contours drawn for the four air ducts show a

(a) British Standard 1042, (1943), Flow Measurement.

velocity differential across the ducts which can be related to the geometry of the ducts. A projection of the velocity differentials in the air ducts to the secondary wind box indicates that the supply of air to the 6 burners is uneven. This may be compensated for, however, by slight differences in the settings of the secondary air vanes. It would be very difficult to arrange for a controlled secondary air supply to each burner without substantial alteration of present layout. Any proposals to modify the secondary air system should bear in mind the possibility of slag formation in reducing zones of the furnace.

The percentage of oxygen in the flue gas is a direct indication of the quantity of excess air supplied to the combustion chamber. For the most efficient combustion the level of oxygen should be within the range 3.5-4.0% which corresponds to an excess air level of 17-20%. By continuously recording the oxygen level the efficiency of combustion can be determined. At the station a water-cooled probe is inserted into the boiler at about the lower drum level, and this continuously withdraws a sample of the flue gas which is cleaned and piped to a paramagnetic type oxygen analyser. This instrument actuates a large indicator near the control panel and also a circular chart recorder. Early observations showed that the indicated oxygen level fluctuated quite widely between 1.5 and 7% corresponding to excess air variations of 7.5 to 35%. The samples taken for separate analysis were taken at a time of relative stability but showed clearly that the analyser was responding to true variations in oxygen level and was following the fluctuations reasonably well. The comparison of the oxygen level with the air flow in the primary air-duct south was also made during a relatively stable period. There were, however, several sudden changes in oxygen level corresponding to variations of the order of 4% in the excess air level. As these were not accompanied by corresponding changes in primary air flow it seems valid to conclude that variations in air flow are probably not the cause of the fluctuations in oxygen level. It also does not seem feasible for the output of the forced draught fans to vary by up to 30%.

The fluctuations are therefore probably related to local variations in the flue gas caused by stratification and also to variations in the quality or the rate of the coal feed. It should be possible to define this by observing the indicator during a period when the boiler is oil-fired.

The uneven distribution of the coal particles in the fuel pipes is probably due to the geometry of the pipes, together with the centrifuging action of the mill fans. The momentum of the coal particles would tend to carry them to the outside of any bend in the pipe, the effect being greater for larger particle sizes. A symmetrical flow pattern in a pipe is not achieved for at least 20 diameters after a change in section. This length will be increased further in the case of two-phase flow. The maximum available length of straight pipe before the burners is 20 ft and this is reduced by the presence of the low rating dampers about 10 ft below the sampling section. It is therefore unlikely that a uniform distribution of coal entering the burner elbow is attained. This is verified by the data presented in Figure 12, which shows that the distribution of the large particles is still uneven 6 ft from the lower burner bank. The variation of the distribution from that predicted from the geometry is probably caused by some swirling.

The difference in throughput between the two pipes from each mill as shown in Table 2 is thought to be due to crossflow from one half of the mill to the other, although some of it may be attributed to fluctuations in the throughput of the coal feeders, or to different moisture content or solids density.

The most significant fact to emerge from the experiment lies in the size distribution figures (Table 3). These show no apparent correlation between mill age and performance. If the efficiency of a mill is assessed on its ability to produce minus 200-mesh particles, then the north mill, which was shut down for overhaul within 2 days following the experiment, was the most efficient. The centre mill, which had just been over-hauled was the next most efficient, and the south mill, which was two thirds through its estimated life, was the least efficient. These figures show that the present method used for determining the operating life of a mill may be conservative. It is understood that the cycle for overhauling the mills has now been reviewed. The life between overhauls might be still further increased if a periodic check were to be kept on the output from each mill using isokinetic sampling techniques. There seems to be a good chance that mechanical factors rather than pulverising performance will set the limit of safe operating time.

Operation of the model burner showed that the flow distribution can be improved by the use of a series of baffles placed longitudinally at the surface of the burner tube. This distribution is still further improved by the use of a baffle sloping across the elbow. The use of such baffles would probably give a very good distribution if the solids could be introduced evenly to the spinner. This cannot be achieved, as the momentum of the particles in the vertical direction carries them to the upper half of the tube before a horizontal velocity component can move them to the spinner. A set of turning vanes such as are commonly used in elbows in air conditioning networks, would probably improve the flow pattern, but their use has been considered undesirable on the grounds that they would necessarily be of relatively thin section and would be subject to severe erosion. There would therefore be the danger of eroded fragments falling into the low rating damper, or even into the mill.

The use of the baffles mentioned above would give a flow of solids distributed over about 60% of the circumference of the burner outlet. Whilst this is far from perfect, it is still a vast improvement on the present arrangement with a distribution over about 10% (See Figures 13 and 14).

5. CONCLUSIONS AND RECOMMENDATIONS

The performance of pulveriser mills is not so highly dependent on time since overhaul as had been thought, and measurements have enabled the period between overhauls to be increased.

From model studies it was apparent that the distribution of solids in the gas stream leaving the burners was extremely uneven. The solids, which should be spread around the full circumference of the tube, a distance of 61 in. were, in fact, confined largely to an arc of about 6 in. in length. This condition is very unfavourable for combustion as air penetration to the centre of the band of coal will take some time, during which the particles will pass out of the hottest part of the flame. This could be at least partially responsible for the unburnt carbon found in the ash box and the precipitator refuse. Extension of the band of solids as far as the furnace wall could lead to hot spots and the associated problems of corrosion and slag deposition.

Suggested modifications to burner design have not yet been adopted at the power station. Installation of narrow longitudinal baffles in the burner tube gave sufficient improvement in the cold model to warrant trial on at least one boiler in the "B" station. It is therefore recommended that this modification should be made and evaluated at the earliest available opportunity.

It is also recommended that a full study be made of the performance of one or more pulveriser mills over an extended period. The study should include product particle size analyses, assessment of coal hardness and maintenance of records of mill running time and feeder speeds. This could lead to a further useful increase in life of a mill between overhauls.

6. ACKNOWLEDGEMENTS

The author wishes to thank Dr M. Bosio of ETSA for his assistance throughout the project, and the staff at the power station for their assistance in carrying out experimental work. Thanks are also due to Mr R.M. Ball, who assisted with the experimental work.

APPENDIX A

SIZING ANALYSIS OF SAMPLES TAKEN FROM DUCTS 4 AND 6

REPORT ML396/67

MATERIAL:	Pulverised Coal
LOCALITY:	Port Augusta
IDENTIFICATION:	Samples D4.P1 - D4.P9 and D6.P1 - D6.P8
DATE RECEIVED:	10/8/66
WORK REQUIRED:	Sizing analysis

Investigation and Report by: S. Armstrong, C.V. Agate

Officer in Charge, Metallurgy Section: P.K. Hosking

TABLE A-1: SIZING ANALYSIS OF SAMPLES TAKEN FROM DUCTS 4 AND 6
Cumulative weight retained per cent[(a)]

Sample No.	Nominal Screen Aperture microns							
	+850	-850 +600	-600 +420	-420 +300	-300 +210	-210 +150	-150 +105	-105 + 75
D4.P1	0.1	0.5	1.4	3.3	7.8	16.0	28.5	37.1
D4.P2	0.2	1.1	2.7	5.1	8.8	16.4	24.3	29.4
D4.P3	0.2	1.0	2.7	6.3	13.1	28.0	44.5	50.5
D4.P4	0.1	0.7	2.2	5.0	10.0	16.0	23.4	28.5
D4.P5	-	0.6	2.6	5.8	12.7	21.9	32.6	38.6
D4.P6	-	0.7	2.4	5.8	12.3	24.2	35.6	41.9
D4.P7	-	0.5	1.5	3.7	7.8	17.6	28.2	33.8
D4.P8	0.1	0.9	2.5	5.1	9.6	14.9	24.1	29.3
D4.P9	-	0.9	2.2	3.9	6.6	9.5	13.0	16.0
D6.P1	-	0.4	1.1	2.0	3.2	5.3	13.3	18.8
D6.P2	-	0.4	1.2	2.5	4.2	6.1	9.3	12.6
D6.P3	0.2	0.8	2.3	5.2	11.0	19.2	29.6	35.7
D6.P4	-	0.6	1.9	4.5	10.1	18.4	29.1	36.8
D6.P5	-	0.4	1.4	3.4	7.4	13.3	21.6	27.4
D6.P6	-	0.5	1.2	2.3	4.5	7.5	12.4	16.6
D6.P7	-	0.5	1.2	2.1	3.4	5.4	9.4	13.4
D6.P8	-	0.4	1.3	3.1	7.3	15.0	33.5	39.5

(a) Screen sizings were conducted using a Ro-tap machine for 30 minutes.

APPENDIX B

SIZING ANALYSIS OF SAMPLES TAKEN FROM DUCTS 1, 2, 3 AND 5
REPORT ML499/67

MATERIAL:	Pulverised Coal
IDENTIFICATION:	Sample Nos. D2.P1 - P7 and D5.P1 - P9
DATE RECEIVED:	22/8/66
WORK REQUIRED:	Size analysis

Investigation and Report by: S. Armstrong and C.V. Agate

Officer in Charge, Metallurgy Section: P.K. Hosking

TABLE B-1: SIZING ANALYSIS OF SAMPLES TAKEN FROM DUCTS 1, 2, 3 AND 5

Nominal Screen Aperture microns	Mesh BSS	Cumulative Weight Retained %[(a)]			
		D.1	D.2	D.3	D.5
+850	+ 18	-	-	-	-
-850 +600	- 18 + 25	0.5	0.2	0.5	0.2
-600 +420	- 25 + 36	1.9	0.5	1.7	0.9
-420 +300	- 36 + 52	5.0	1.3	4.0	2.4
-300 +210	- 52 + 72	12.3	3.3	8.5	5.6
-210 +150	- 72 +100	26.7	10.1	17.2	15.8
-150 +105	-100 +150	42.9	29.0	33.2	28.0
-105 + 75	-150 +200	48.3	35.0	39.6	32.7

(a) Screen sizings were conducted on a Ro-tap machine for 30 minutes.

Note: At the request of Mr J.M. Clayton the sizing analysis of sample No. D2.P1-P7 and D5.P1-P9 were cancelled, and substituted for a size analysis of representative samples from bulks D1, D2, D3 and D5. The remainder of each bulk sample was passed through an 18-mesh BSS screen and the plus 18-mesh fraction retained

TABLES 1 TO 4

FIGURES 1 TO 21

TABLE 1: FREE OXYGEN ANALYSES ON BOILER NO.1
Sampling Period 30 Seconds

Manual Control			Automatic Control					
Sample No.	Instrument Reading %	Laboratory Analysis %	Sample No.	Instrument Reading %	Laboratory Analysis %		Instrument Reading %	Laboratory Analysis %
1	3.0	4.45	1	2.6	4.15	35	2.1	3.40
2	3.0	4.50	2	2.7	3.85	36	2.1	3.70
3	3.2	4.50	3	2.5	4.00	37	2.5	4.80
4	3.1	4.35	4	2.5	3.95	38	2.8	5.20
5	3.0	4.40	5	2.6	3.95	39	2.9	4.10
6	2.9	4.90	6	2.5	3.90	40	3.0	5.40
7	3.1	4.30	7	2.2	3.65	41	3.1	4.40
8	3.0	4.60	8	2.2	3.75	42	3.2	4.20
9	3.1	4.30	9	2.4	3.75	43	3.1	4.25
10	3.0	4.30	10	2.4	4.15	44	2.9	4.20
11	2.8	4.50	11	3.0	4.80	45	3.1	4.20
12	2.9	4.60	12	3.0	4.12	46	2.8	3.90
13	2.9	4.65	13	3.2	4.35	47	2.6	3.70
14	2.8	4.35	14	3.1	4.05	48	2.4	3.75
15	2.9	4.50	15	2.8	3.90	49	2.5	3.65
16	2.9	4.50	16	2.6	3.70	50	2.6	3.75
17	2.9	4.40	17	2.6	3.70	51	2.4	4.70
18	2.7	4.30	18	2.6	3.60	52	2.9	3.90
19	2.6	4.35	19	2.5	3.65	53	3.1	3.85
20	2.8	4.45	20	2.6	3.80	54	2.8	4.20
21	2.9	4.50	21	2.7	3.75	55	3.0	5.50
22	2.8	4.50	22	2.6	3.70	56	3.3	4.35
23	2.9	4.30	23	2.6	3.95	57	3.3	4.40
24	2.7	4.50	24	2.6	3.90	58	3.2	3.75
25	2.6	4.50	25	2.2	3.60	59	2.7	3.40
26	2.6	4.30	26	2.1	3.20	60	2.3	3.55
27	2.8	4.41	27	2.1	5.40	61	2.1	3.20
28	2.9	4.35	28	2.8	4.45	62	2.1	3.85
29	2.9	4.15	29	3.1	4.15	63	2.65	4.10
30	2.9	4.35	30	3.2	4.95	64	3.0	4.35
			31	3.0	4.05	65	3.2	4.60
			32	2.6	3.85			
			33	2.6	4.65			
			34	2.3	3.40			

TABLE 2: PULVERISED COAL FLOW RATES

Probe Position	Pipe 1 Sample weight g	Pipe 1 Collection time sec	Pipe 1 Flow rate g/sec	Pipe 1 Mean Flow Rate	Pipe 3 Sample weight g	Pipe 3 Collection time sec	Pipe 3 Flow rate g/sec	Pipe 3 Mean Flow Rate
1	88.9	23.3	3.81	3.52	62.6	20.5	3.05	3.07
	135.8	37.4	3.63		79.3	25.1	3.15	
	84.4	27.0	3.12		84.6	28.0	3.02	
2	54.6	28.6	1.90 (b)	3.28	ns (a)			4.91
	82.3	25.0	3.29		93.5	19.0	4.92	
	99.4	30.2	3.28		106.0	21.6	4.90	
3	117.1	25.2	4.64	4.57	104.3	26.7	3.90	3.67
	114.1	25.2	4.52		104.9	29.5	3.55	
	117.4	25.8	4.54		102.9	28.8	3.57	
4	125.7	25.1	5.00	5.02	ns			4.05
	109.6	21.7	5.04		ns			
	112.5	28.4	3.96 (b)		68.9	17.0	4.05	
5	ns				96.5	22.4	4.30	4.15
	ns				111.7	26.9	4.15	
	ns				107.9	26.9	4.01	
6	110.9	28.4	3.90	3.43	ns			4.77
	93.5	29.2	3.20		ns			
	98.3	30.8	3.19		99.3	20.8	4.77	
7	ns				91.9	24.9	3.68	3.76
	ns				98.6	26.1	3.77	
	ns				99.4	25.4	3.83	
8	ns				94.1	26.1	3.60	3.52
	ns				ns			
	ns				96.2	27.9	3.44	
9	ns				84.9	26.8	3.16	3.14
	ns				91.4	29.1	3.14	
	ns				87.7	28.0	3.13	

Continued

TABLE 2: CONTINUED

Probe Position	Pipe 2 Sample weight g	Pipe 2 Collection time sec	Pipe 2 Flow rate g/sec	Pipe 2 Mean Flow Rate	Pipe 5 Sample weight g	Pipe 5 Collection time sec	Pipe 5 Flow rate g/sec	Pipe 5 Mean Flow Rate
	93.7	25.4	3.68		ns			
1	95.0	25.4	3.74	3.68	ns			2.73
	97.1	26.8	3.62		72.0	26.3	2.73	
	81.0	27.5	2.94		87.6	22.4	3.91	
2	91.6	31.2	2.93	2.93	83.6	21.7	3.85	3.88
	90.5	31.0	2.91		ns			
	96.7	25.2	3.83		114.3	17.0	6.72	
3	108.1	28.0	3.86	3.85	112.9	17.2	6.56	6.42
	92.8	24.0	3.86		120.8	20.1	6.00	
	88.3	22.0	4.01		91.9	18.8	4.88	
4	90.8	24.0	3.78	3.90	94.8	21.0	4.51	4.57
	89.2	34.4	2.59(b)		69.2	16.0	4.32	
	86.3	24.9	3.46		98.5	16.5	5.97	
5	86.1	25.5	3.37	3.39	101.2	20.0	5.06	5.26
	91.5	27.4	3.34		100.3	21.0	4.77	
	86.6	26.0	3.33		ns			
6	91.3	25.7	3.55	3.50	ns			
	95.2	26.2	3.63		ns			
	83.2	32.6	2.55		72.1	23.6	3.05	
7	85.1	34.6	2.45	2.48	65.9	21.8	3.02	3.04
	86.6	35.6	2.43		76.7	25.0	3.06	
	ns				86.2	23.2	3.71	
8	ns				ns			3.71
	ns				ns			
	ns				74.5	30.6	2.43	
9	ns				72.1	28.6	2.52	2.46
	ns				66.9	27.4	2.44	

Continued

TABLE 2: CONTINUED

Probe Position	Pipe 4 Sample weight g	Pipe 4 Collection time sec	Pipe 4 Flow rate g/sec	Pipe 4 Mean Flow Rate	Pipe 6 Sample weight g	Pipe 6 Collection time sec	Pipe 6 Flow rate g/sec	Pipe 6 Mean Flow Rate
	ns				78.2	34.2	2.28	
1	75.5	22.2	3.40	3.40	76.7	32.0	2.39	2.36
	ns				88.0	36.4	2.41	
	85.5	35.2	2.42		81.3	34.6	2.34	
2	81.0	33.6	2.41	2.44	86.0	36.6	2.34	2.35
	89.0	35.6	2.49		73.6	30.8	2.38	
	ns				88.3	20.6	4.28	
3	105.9	22.3	4.74	4.74	105.3	24.9	4.22	4.25
	ns				ns			
	80.5	20.4	3.94		107.3	24.6	4.36	
4	93.1	24.1	3.86	3.89	103.7	25.3	4.09	4.20
	95.2	24.6	3.87		115.3	27.6	4.17	
	ns				88.8	25.4	3.49	
5	87.4	16.6	5.26	5.15	ns			3.47
	108.8	21.6	5.03		90.1	26.1	3.45	
	78.5	20.0	3.92		82.9	30.4	2.72	
6	89.3	23.0	3.88(b)	3.90	88.6	33.2	2.66	2.69
	95.2	25.0	3.80		91.7	33.8	2.71	
	83.3	28.2	2.95		84.6	36.2	2.33	
7	92.2	29.5	3.12	3.02	88.2	39.2	2.25	2.30
	91.8	30.6	2.99		80.0	34.2	2.33	
	ns				110.7	30.4	3.64	
8	81.0	23.5	3.44	3.33	113.8	30.0	3.79	3.75
	79.5	24.7	3.21		105.3	28.4	3.70	
	68.4	29.0	2.35		ns			
9	79.1	28.6	2.76	2.49	ns			
	81.1	34.2	2.37					

(a) ns = no sample.
(b) Experimentally incorrect and disregarded.

TABLE 3: OUTPUT OF MILLS

Mill Location	Pipe No.	Coal Flow lb/hr	Coal Flow %	Difference %
South	1	9200	48.3	
	3	9900	51.7	3.4
Centre	2	8400	46.6	
	5	9700	53.4	6.8
North	4	9400	54.1	
	6	7900	46.9	7.8

TABLE 4: SIZING ANALYSES OF COAL SAMPLES

Mesh BSS	Weight Retained, %						Mean
	South Mill		Centre Mill		North Mill		
	Pipe 1	Pipe 3	Pipe 2	Pipe 5	Pipe 4	Pipe 6	
+ 52	5.0	4.0	1.3	2.4	4.9	3.1	3.5
- 52 + 72	7.3	4.5	2.0	3.2	5.0	3.3	4.2
- 72 +100	14.4	8.7	6.8	10.2	8.4	5.0	8.9
-100 +200	21.6	22.4	24.9	16.9	15.7	13.7	19.2
-200	51.7	60.4	65.0	67.3	66.0	74.9	64.2

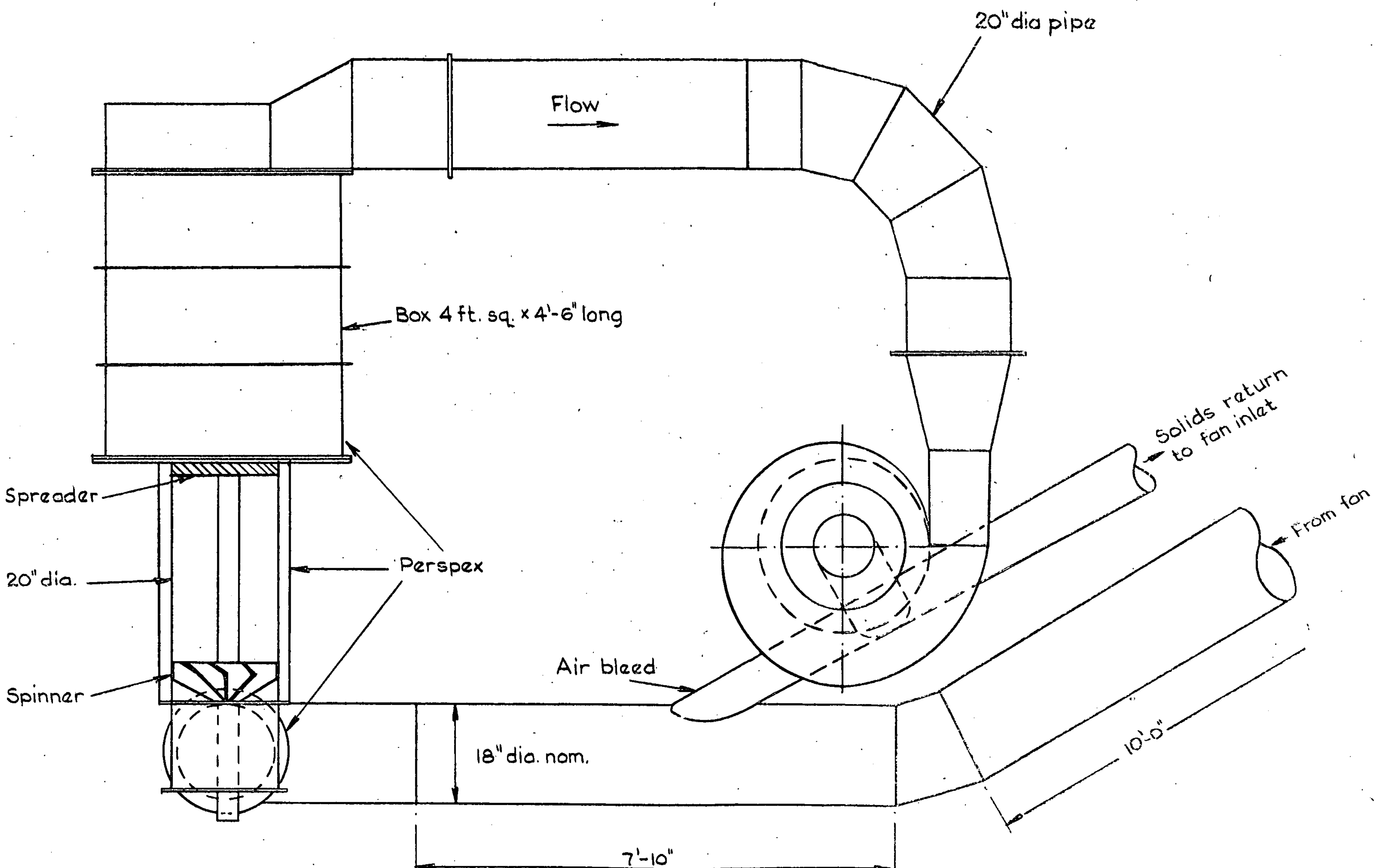


FIG. 1: PLAN OF MODEL FOR BURNER STUDIES

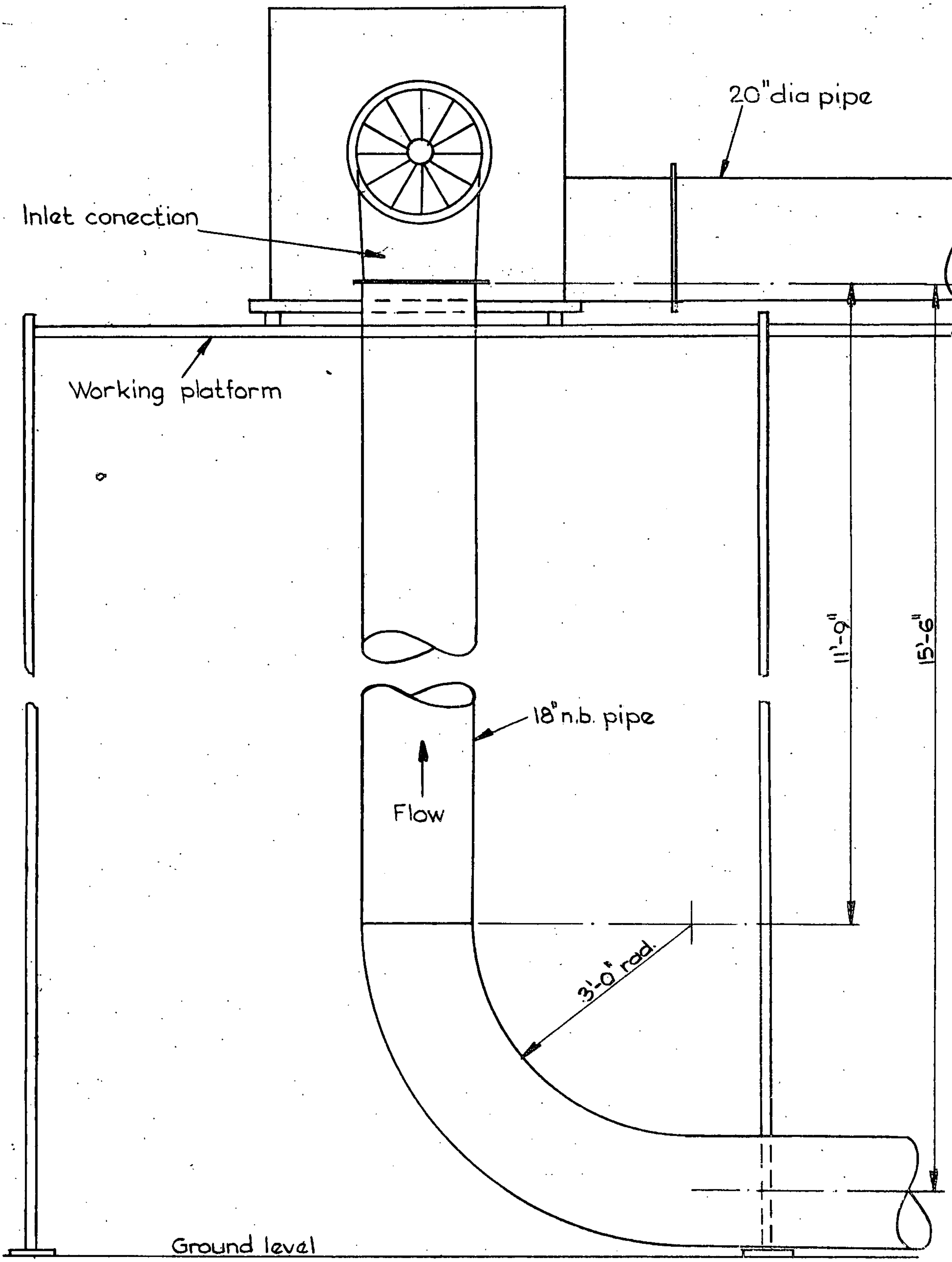


FIG.2 : ELEVATION OF MODEL FOR BURNER STUDIES

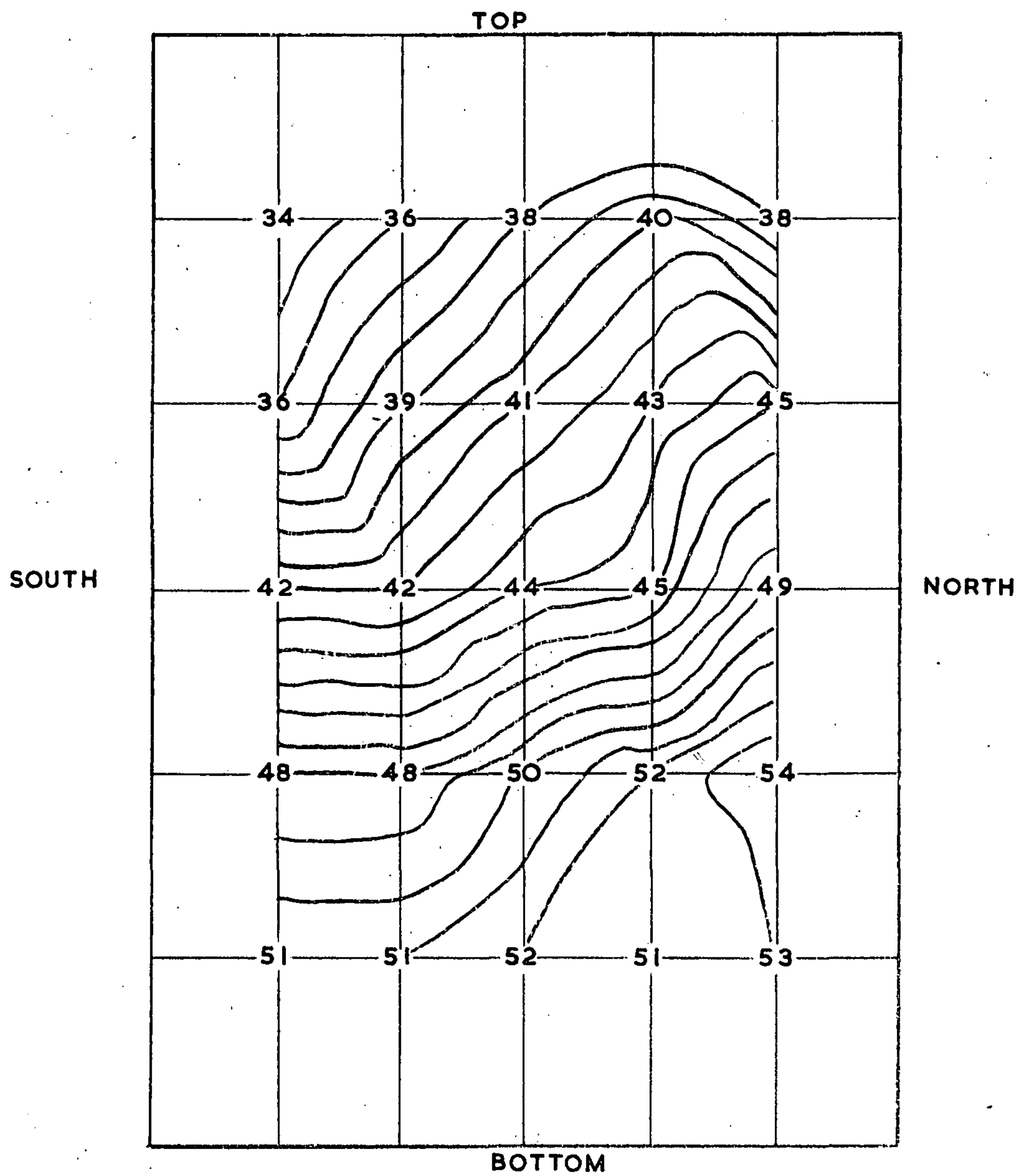


FIG. 3: PRIMARY AIR VELOCITY DISTRIBUTION
SOUTH DUCT - BOILER NO. 1

Velocities in ft/sec

Centre of section approx. 3 ft above operating floor level

Contours constructed by linear extrapolation between measured values

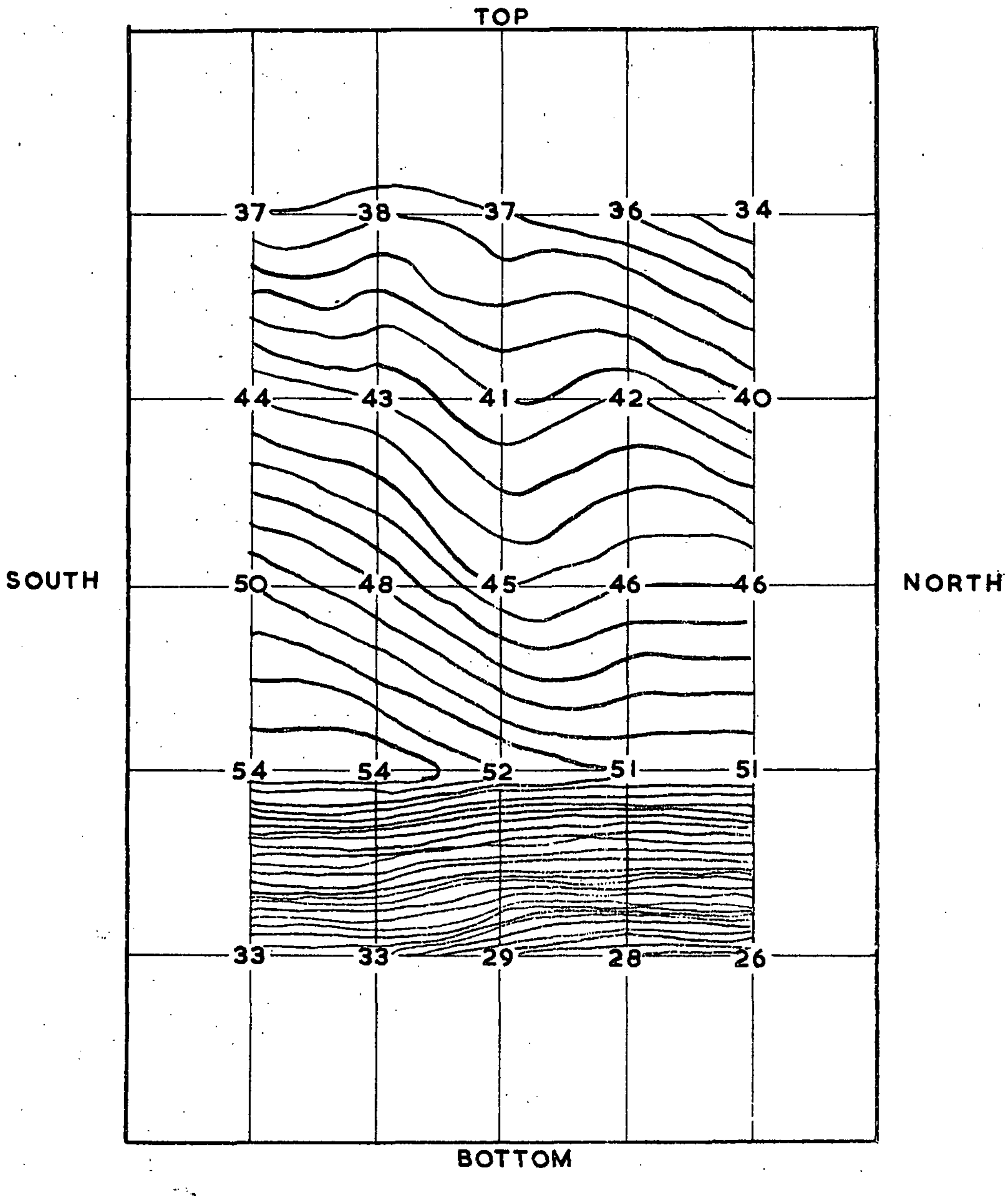


FIG. 4: PRIMARY AIR VELOCITY DISTRIBUTION
NORTH DUCT - BOILER NO. 1
Velocities in ft/sec
Centre of section approx. 3 ft above operating floor level
Contours constructed by linear extrapolation between measured values

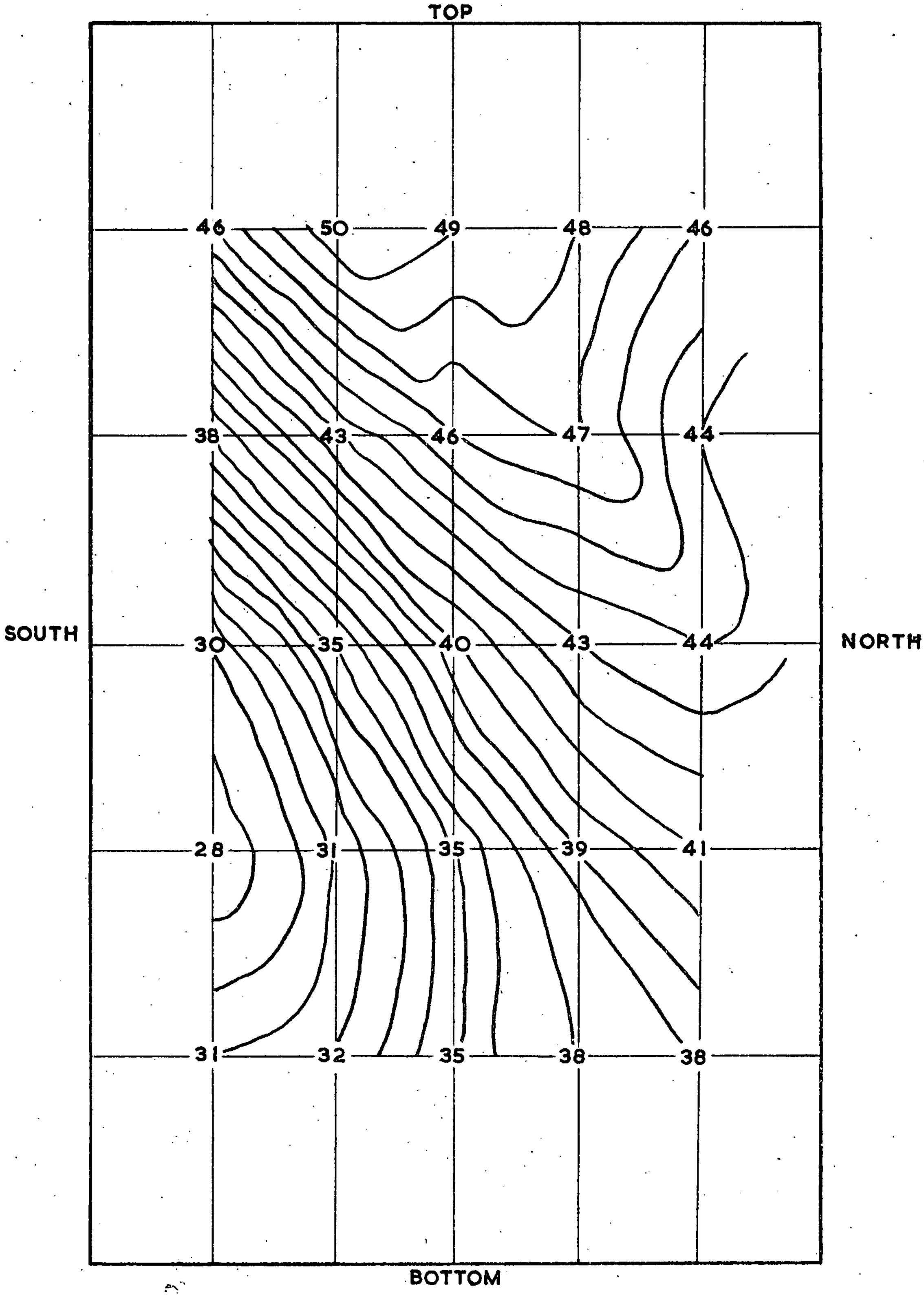


FIG. 5 SECONDARY AIR VELOCITY DISTRIBUTION
SOUTH DUCT - BOILER NO. 1
Velocities in ft/sec
Centre of section approx. 16 ft from windbow entrance
Contours constructed by linear extrapolation between measured values

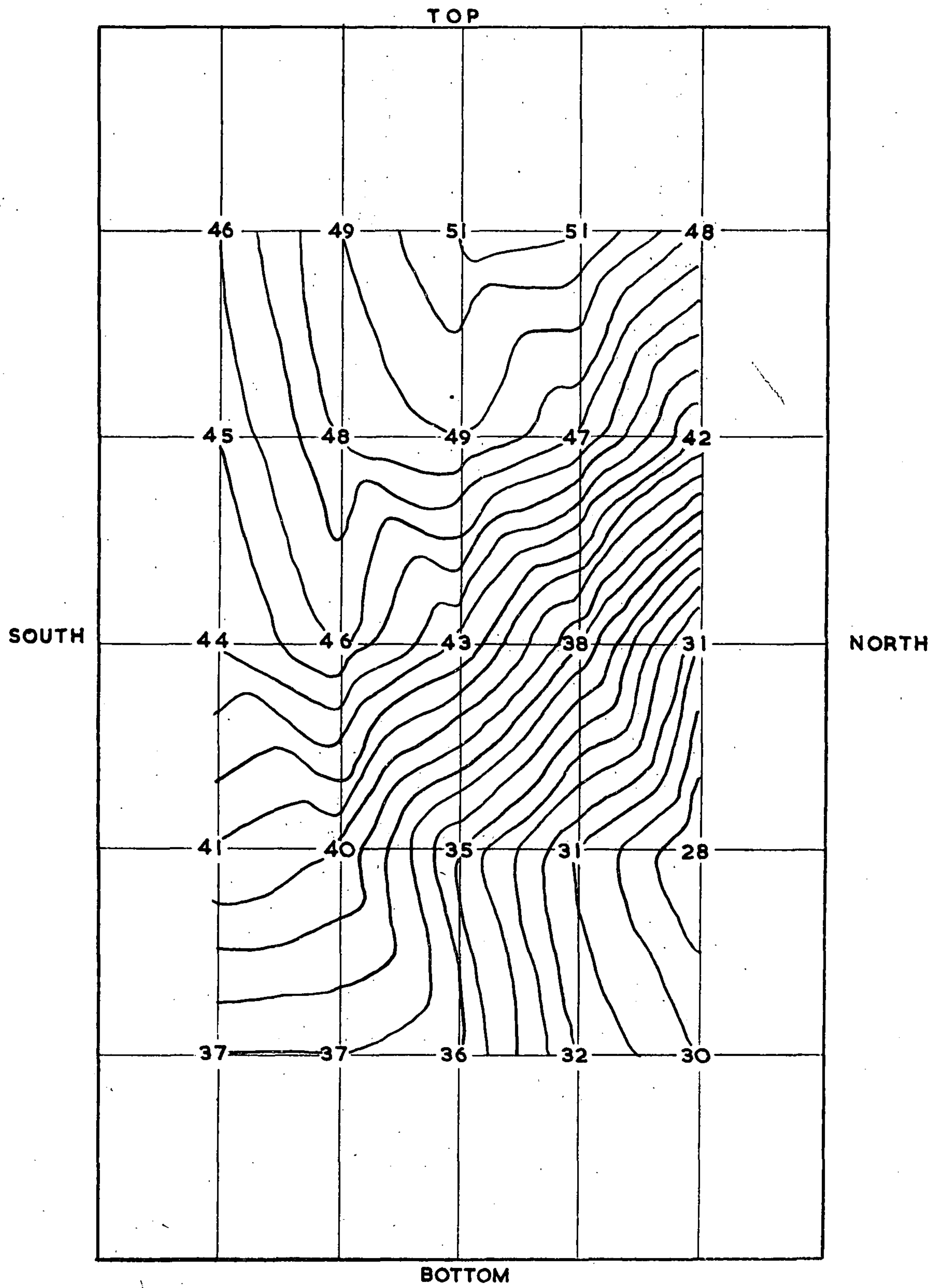


FIG. 6 : SECONDARY AIR VELOCITY DISTRIBUTION
NORTH DUCT - BOILER NO. 1
Velocities in ft/sec
Centre of section approx. 16 ft from windbox entrance
Contours constructed by linear extrapolation between measured values

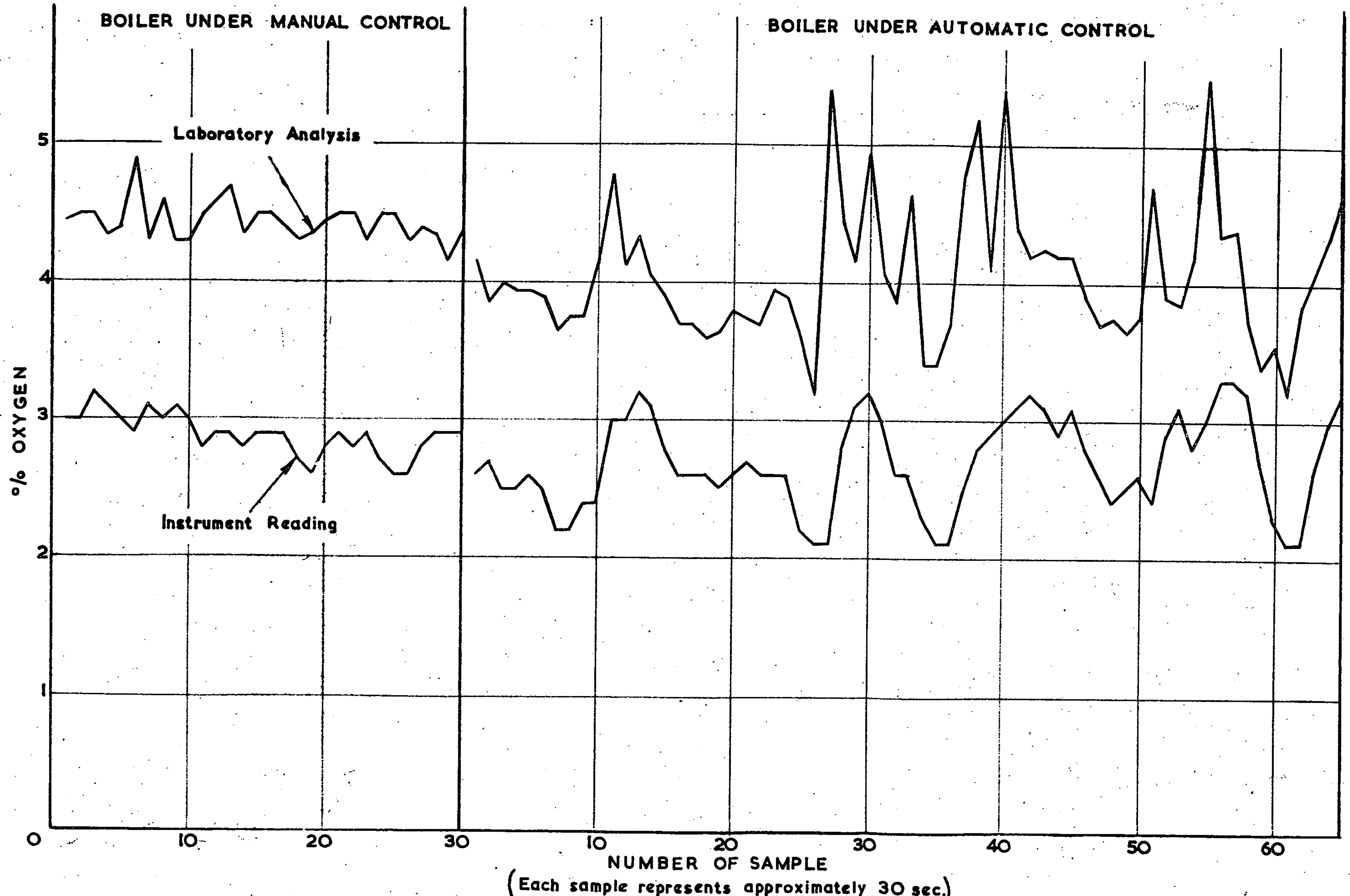


FIG. 7 : EXCESS OXYGEN ANALYSES - BOILER NO. 1

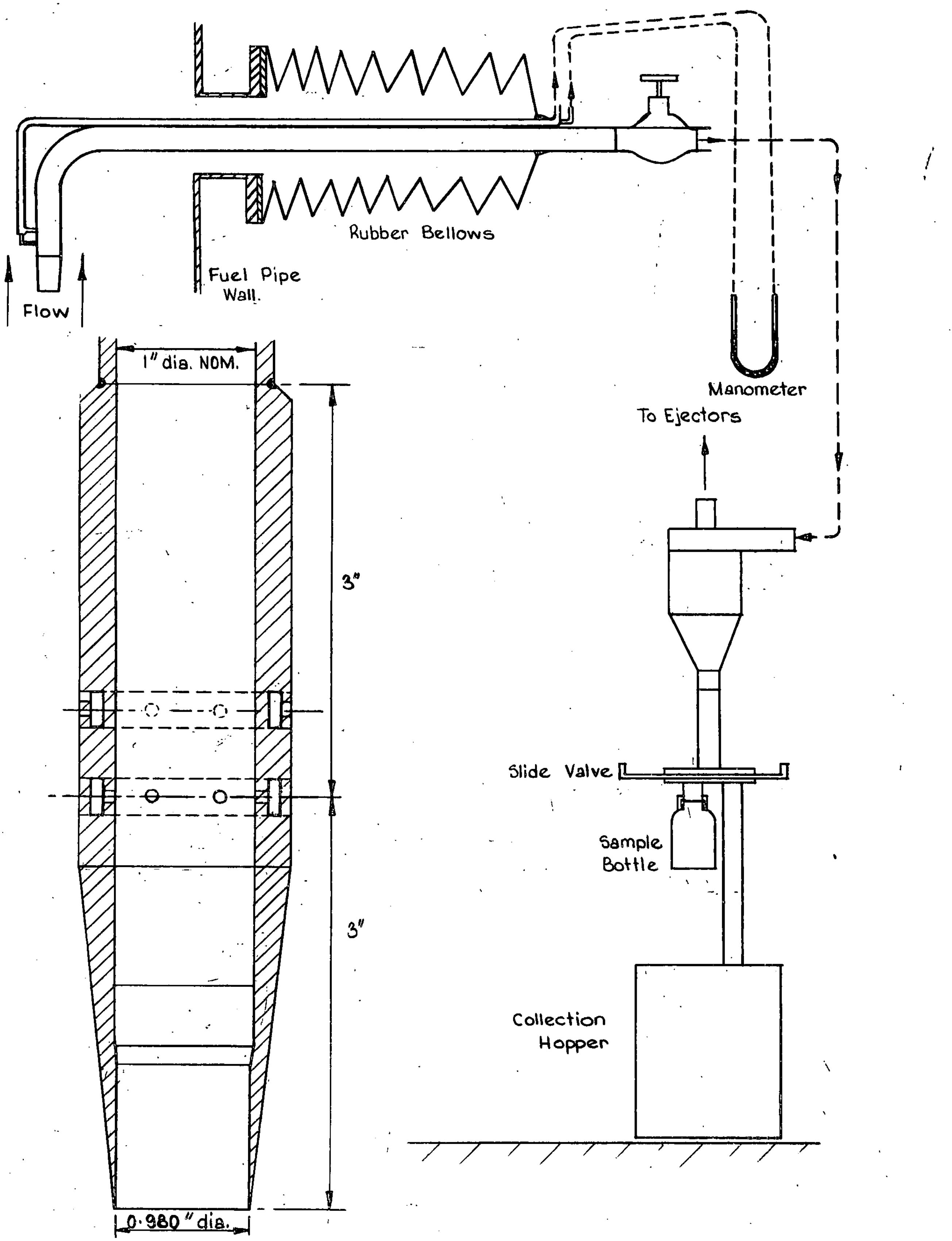


FIG. 8: SKETCH OF PULVERISED FUEL SAMPLING EQUIPMENT

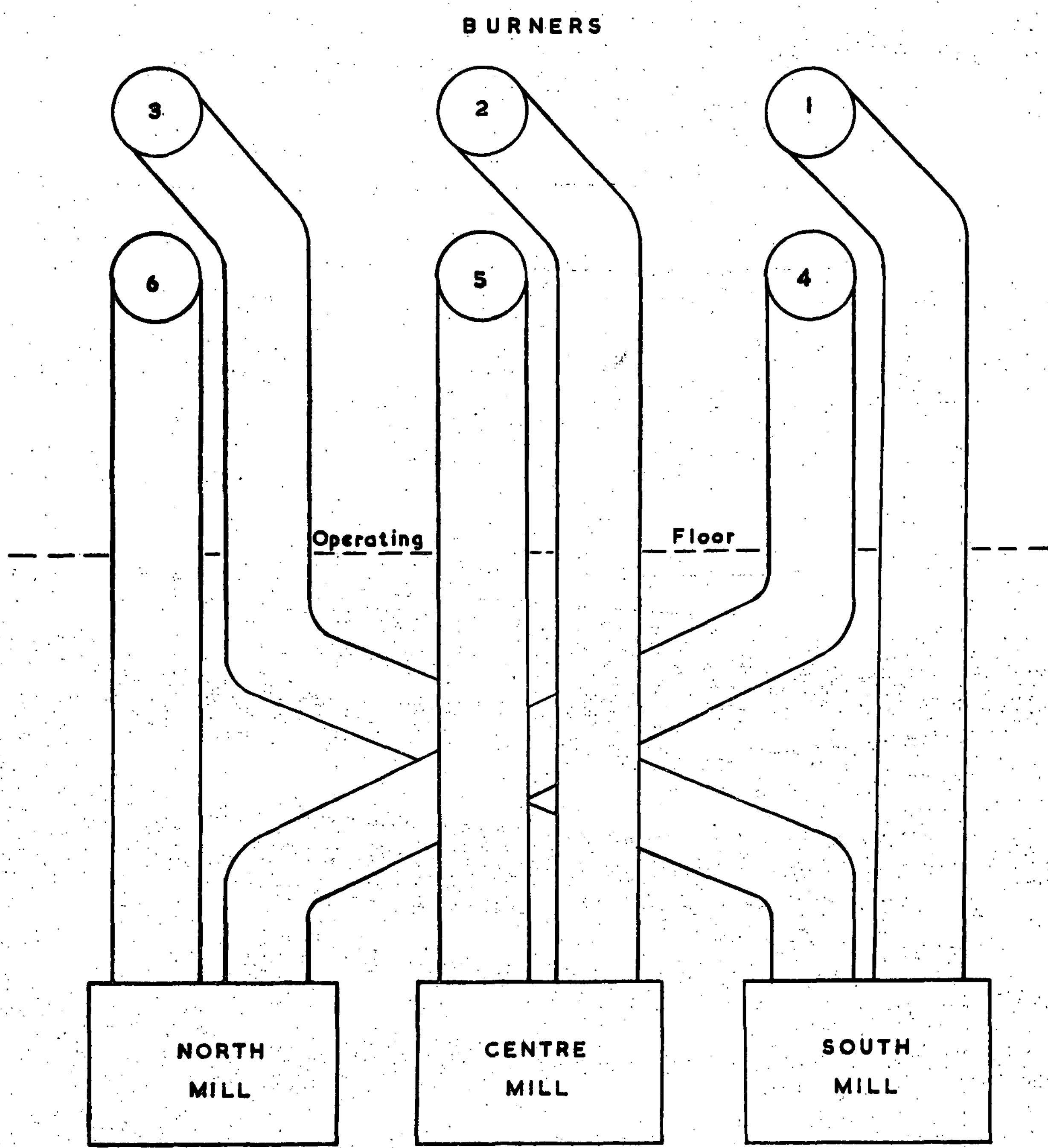


FIG.9 : SCHEMATIC ARRANGEMENT OF PULVERISED FUEL PIPES
Showing Numbering System

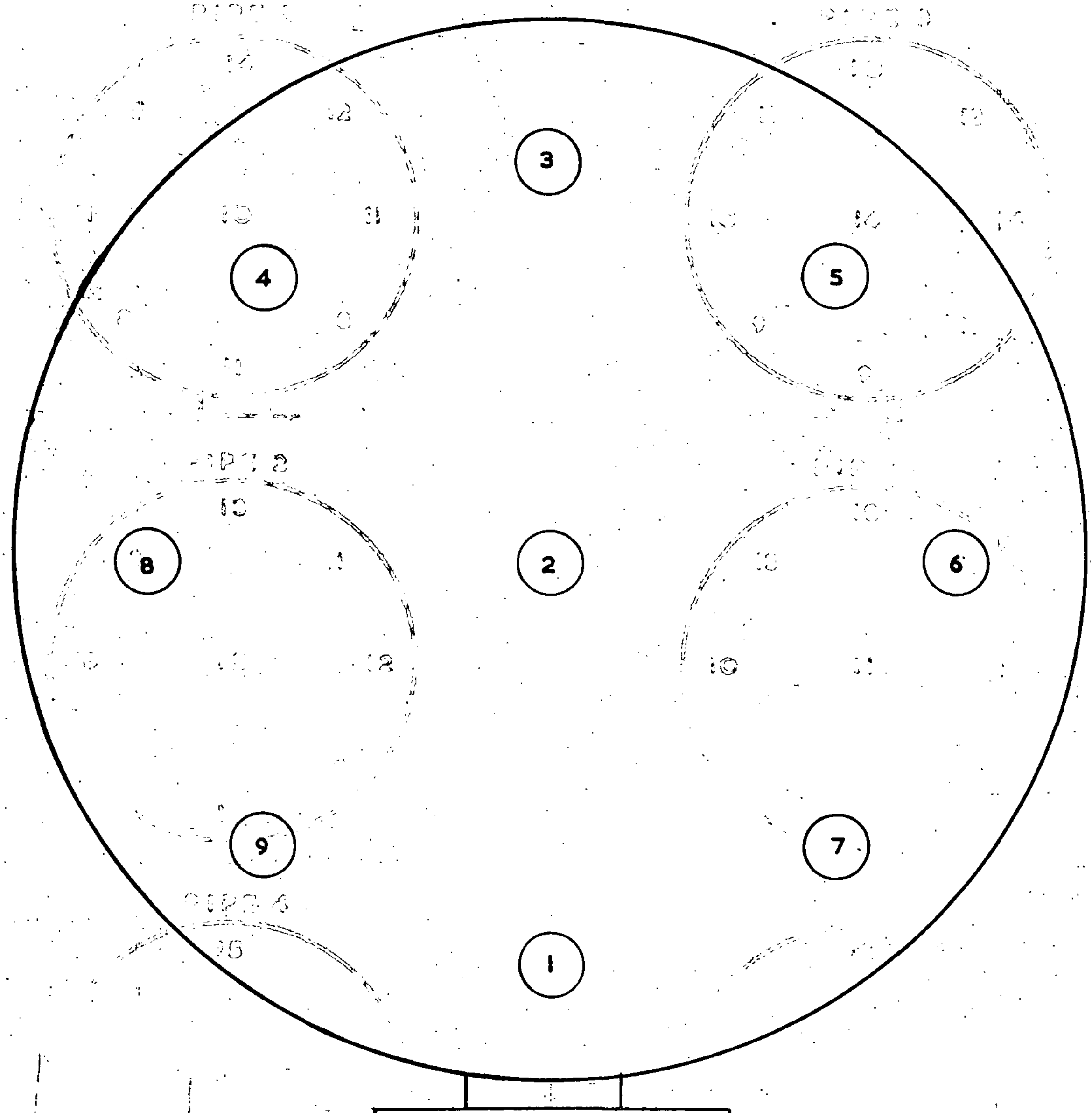
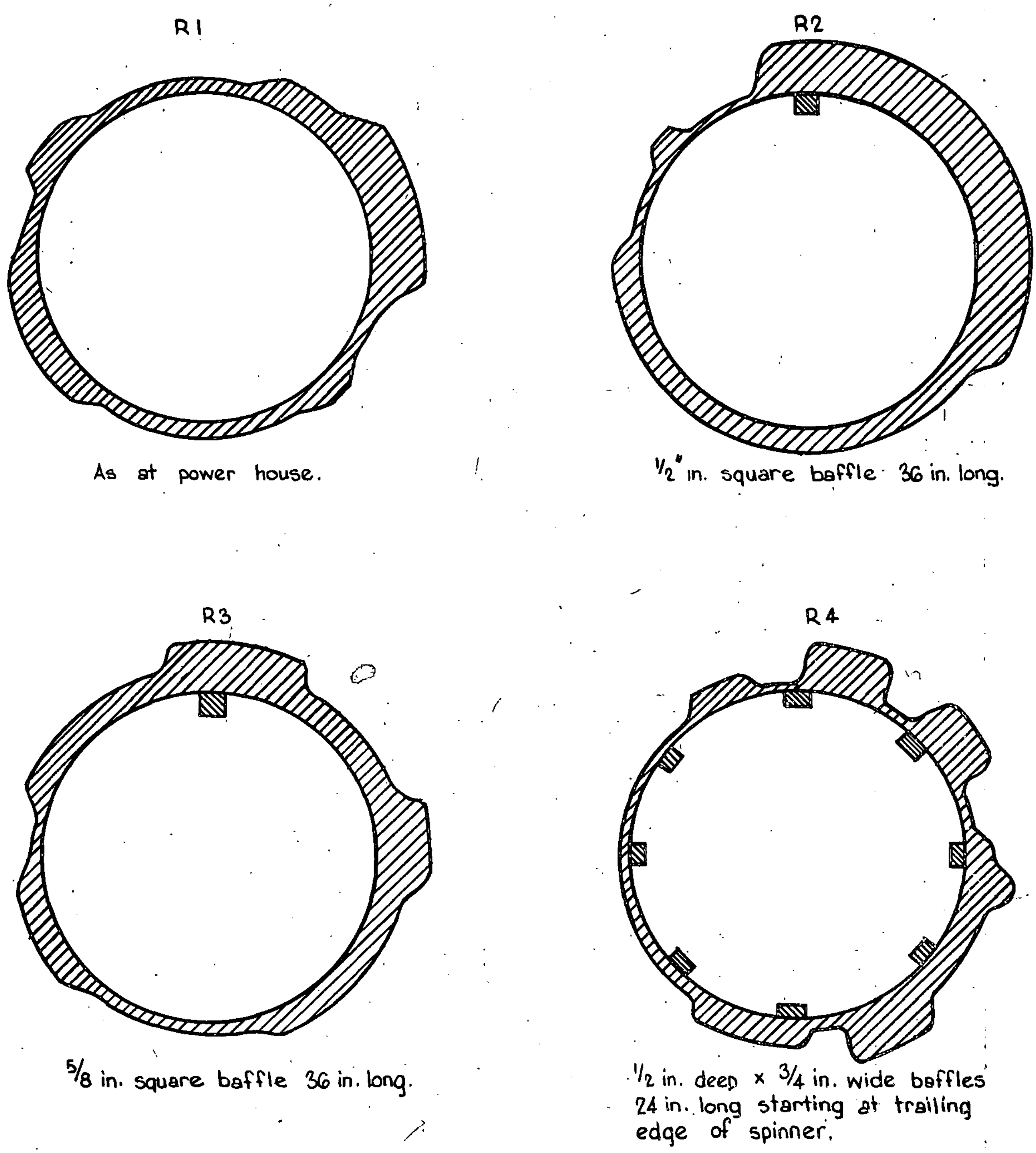


FIG.10: POSITIONS OF SAMPLING POINTS IN EACH PIPE
With Reference Numbers



Distance between Spinner (trailing edge) to Spreader (leading edge) 36 inches.

FIG. 13: DIAGRAMMATIC REPRESENTATION OF FLOW DISTRIBUTIONS AT BURNER OUTLET
Height of hatching represents quantity of solids emitted
(Not to scale)

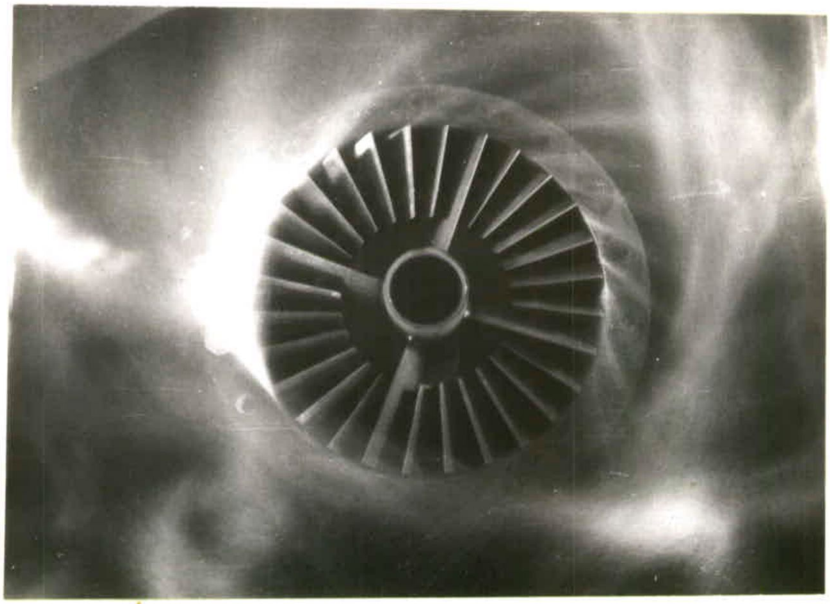


FIG. 14: ORIGINAL FLOW DISTRIBUTION

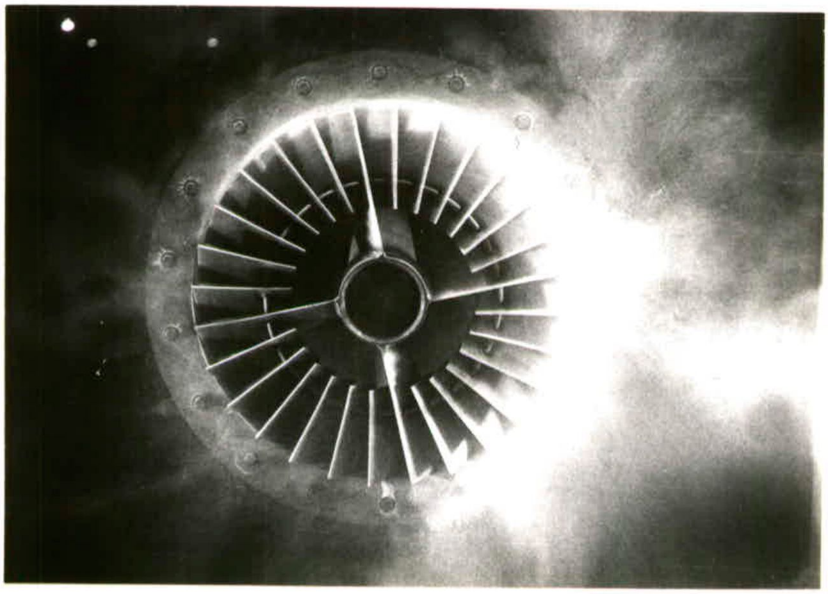


FIG. 15: EFFECT OF EIGHT TRIANGULAR BAFFLES

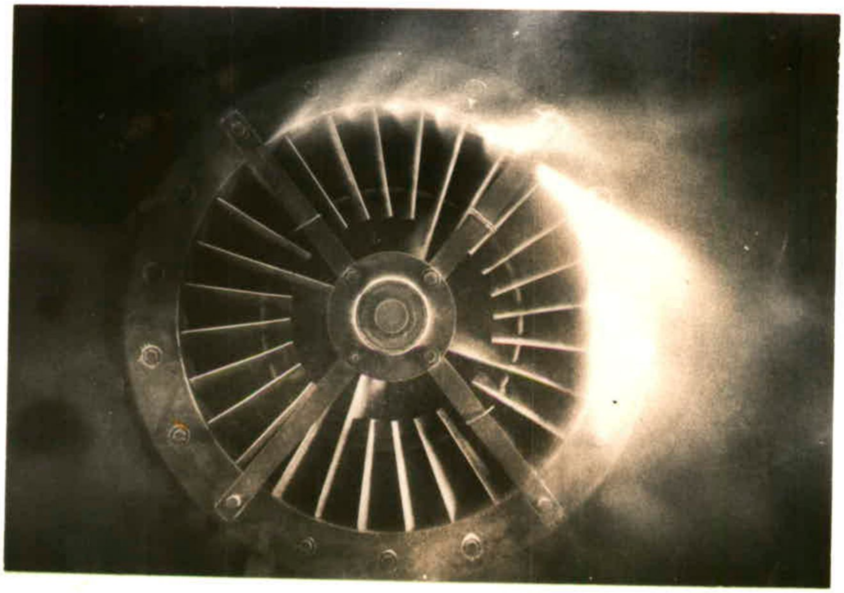


FIG. 16: EFFECT OF EIGHT-BLADED FIXED FAN WITH BLADES AT 45°

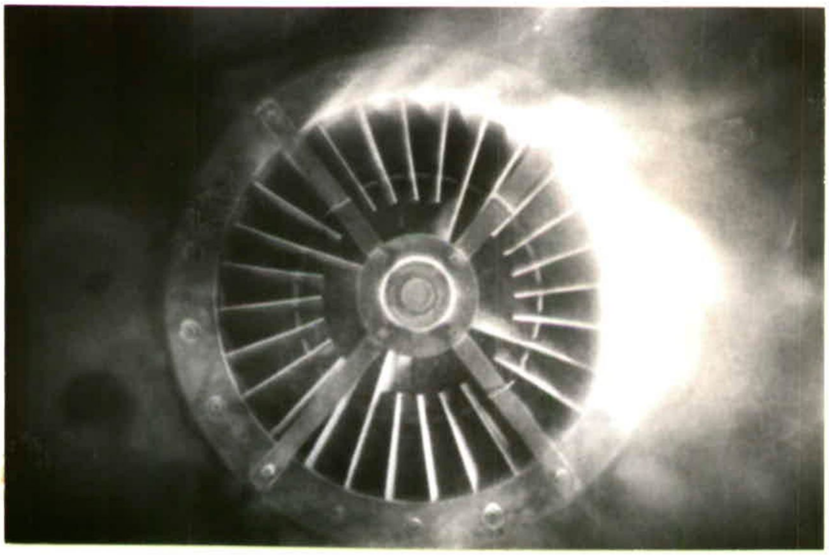


FIG. 17: EFFECT OF EIGHT-BLADED FREE-SPINNING FAN WITH BLADES AT 45°

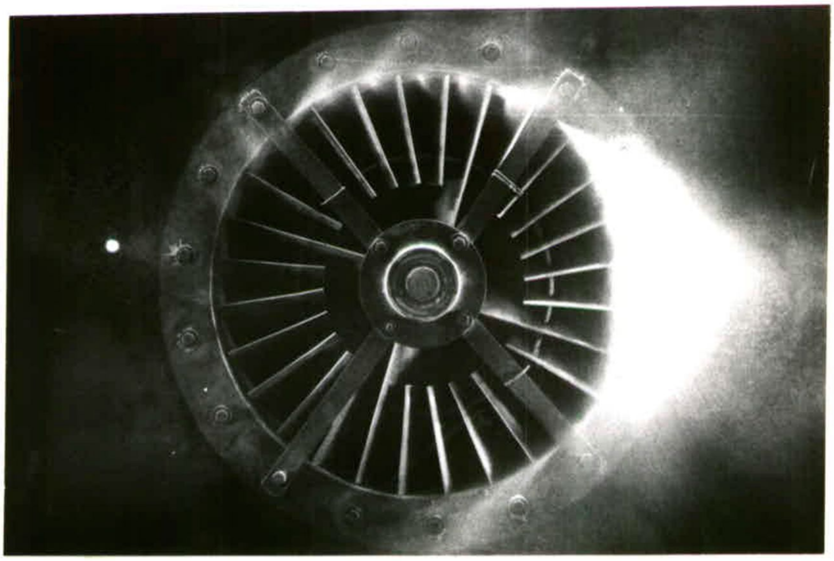


FIG. 18: EFFECT OF EIGHT-BLADED FIXED FAN WITH BLADES AT 15°

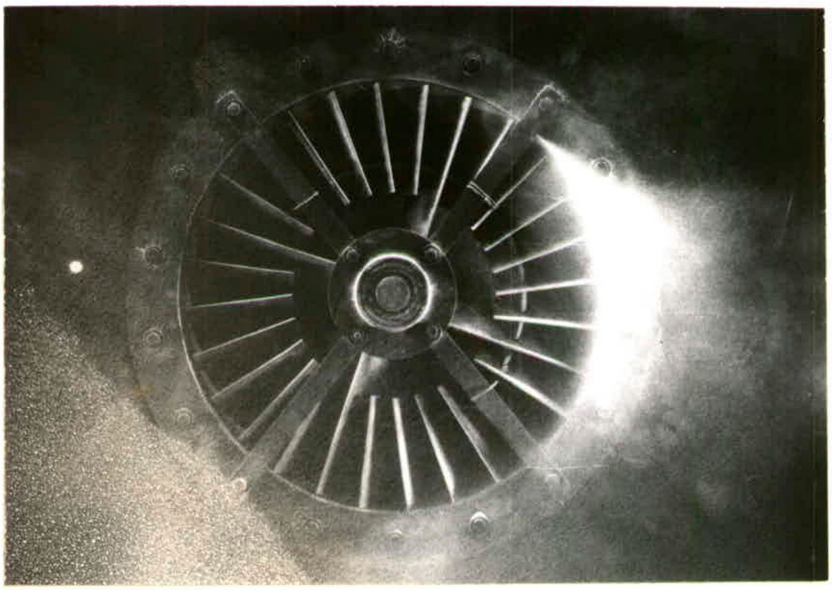


FIG. 19: EFFECT OF EIGHT-BLADED FREE-SPINNING FAN WITH BLADES AT 15°

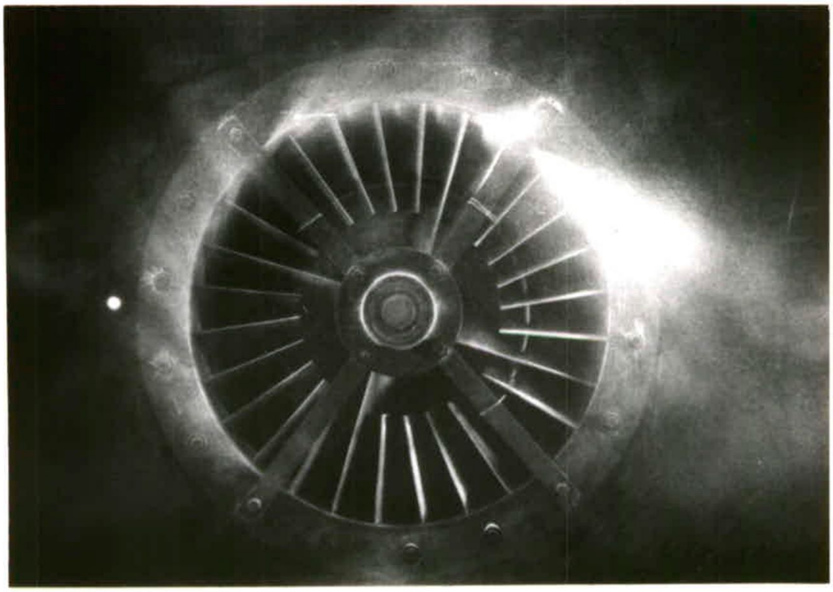


FIG. 20: EFFECT OF EIGHT-BLADED DRIVEN FAN WITH BLADES AT 15°

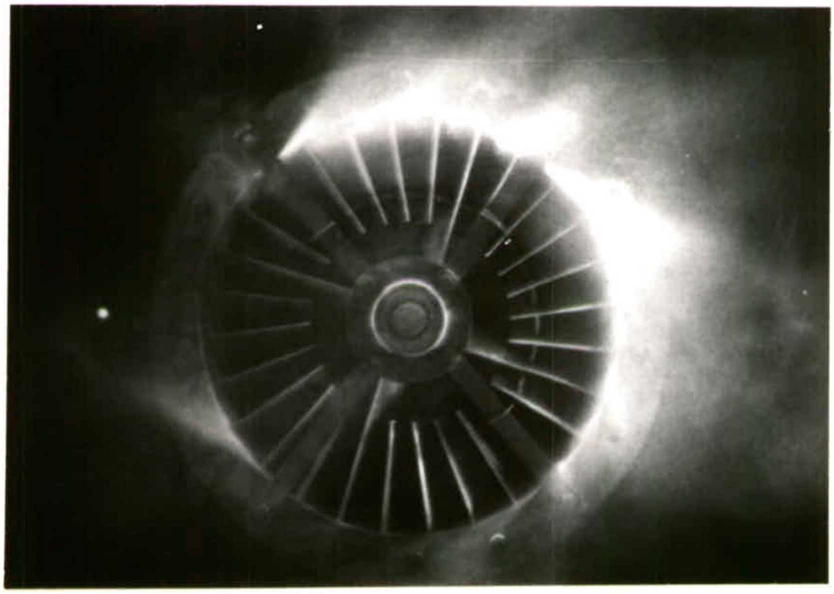


FIG. 21: EFFECT OF EIGHT-BLADED FIXED FAN WITH BLADES AT 15°
POSITIONED AT CENTRE OF BURNER TUBE