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FUEL RESEARCH INSTITUTE OF SOUTH AFRICA

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A REPORT ON THE DEVELOPMENT OF A CYCLONE BURNER

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1. INTRODUCTION:

Fundamentally the cyclone burner is a horizontal or slightly forwardly inclined cylinder in which a mixture of air and fine coal is blown and where complete gasification of the solid fuel takes place, followed by a complete combustion of a large part of the fuel. The gases and the finer fuel particles are completely burnt in a secondary furnace. In large installations the cylinder is provided with water cooling. The fuel, which has to be burnt is introduced tangentially at one end of the cylinder, mixed with approximately 15% of the necessary combustion air, which is blown in tangentially at a high velocity through inlet ports or nozzles situated in the roof of the cylinder. In the larger installations a small amount of tertiary air is blown in axially to impart a movement to the core of the vortex.

The temperature maintained inside the burner should be such that the ash in the fuel is converted into molten slag which adheres to the inner wall of the cylinder and forms a film of liquid slag. With the exception of the very fine particles of the fuel, which are burnt in suspension, the fuel particles are thrown on to the film of molten slag by centrifugal force, stick there, and are then completely gasified and burnt due to the scrubbing action of the high velocity secondary air. The ash from these particles is again liquidised and flows towards the front end of the cylinder due to a slight inclination and leaves the burner through a slag tap hole. Usually the burner is connected to a secondary furnace, for instance the combustion space of a boiler. The molten slag flows on to the bottom of this secondary furnace and leaves it through a second slag tap hole after which it may be collected in a water tank where the molten slag disintegrates into granulated slag which may be handled easily. This granulated slag is free from combustible matter.

It may/.........

It may be appreciated that the properties of the molten slag play a major rôle in the proper functioning of the burner. If the molten slag is not fluid enough it will not run freely out of the burner but will stick to the inner wall, eventually blocking up the whole burner. According to W.T.Reid and N.Cohen, in their paper, "The Flow Characteristics of Coal-ash Slags in the Solidification Range", molten coal-ash slags have a so-called "temperature of critical viscosity", T_{cv}.

Below T_{cv} the molten slag is plastic due to the presence of crystals in the molten mass, which have not yet been melted and increase the internal yield stress. At T_{cv} all crystals have disappeared and with further increase in temperature the viscosity of the slag gradually decreases. It is clear that for a proper functioning of the burner, the layer of molten slag adhering to the inner wall should have a temperature which lies well above its temperature of critical viscosity. Any cooling of the wall will cool down the part of the layer of slag which is directly in contact with the wall and the temperature on that side of the layer of molten slag might well become lower than its temperature of critical viscosity so that the layer of slag will consist of a plastic layer covered with a liquid layer. The more severe the cooling, the thicker the plastic layer. Therefore, in order to keep most of the layer in a liquid state, we must either operate the burner at a very high internal temperature, or restrict the cooling of the wall. On large burners where a much larger amount of heat is generated, cooling may be introduced, because then the heat absorbed by the cooling medium is a much smaller proportion of the total heat developed. On the burner developed at the Institute, water cooling caused an untimely freezing of the slag, and it was therefore decided to use refractory linings without water cooling.

Research work on the cyclone burner started in the United States, some 20 years ago. Most of this work has been conducted with a view to solving the fly-ash disposal problem, as one of the features of this burner is its excellent ash retention and the convenient form in which the ash is discharged. The first commercial installation in the United States was built at Calumet Power Station, in 1944.

In Britain/.......

In Britain no cyclone furnaces were in commercial operation up to 1956. However, a considerable amount of large scale experimental work had been carried out which was more directed to another feature of this burner, the efficient use of fuel, which is of prime importance in Britain.

In Germany, development of the cyclone burner started in 1949. The basic design details are the same as those used in the United States, but refinements had to be made to suit the requirements for German fuels. Many of the German coals are low in volatile matter and this, combined with their high geological age, requires a comparatively high ignition temperature.

In view of this, the German coals require finer grinding (70-90% through 0.5 mm), but the results were similarly successful in the elimination of fly ash.

At the beginning of 1954, one of the Engineering firms at the East Rand started the development of a cyclone burner with the object of determining its suitability as a chemical reactor. The design of the burner was practically the same as that of a burner which had been in operation in Sweden for a few years and was used to burn saw dust. It was agreed that the Institute would take over their design and carry on with the experiments.

2. OBJECTS OF THE EXPERIMENTS.

The experimental work on the cyclone burner at the Institute was carried out with the following objects:

(a) To develop a burner which could be used for as large a variety of South African coals as possible.
(b) To construct the burner in such a way that combustion of the coal would be as efficient as possible.
(c) To investigate the possibilities of the burner as a chemical reactor.

The experimental work in connection with the object (a) has almost been completed.

During the development of the burner, those factors which could influence the combustion efficiency of the burner were taken into account. However, tests to determine the efficiency were not undertaken, as that stage of the experiments could not be reached.

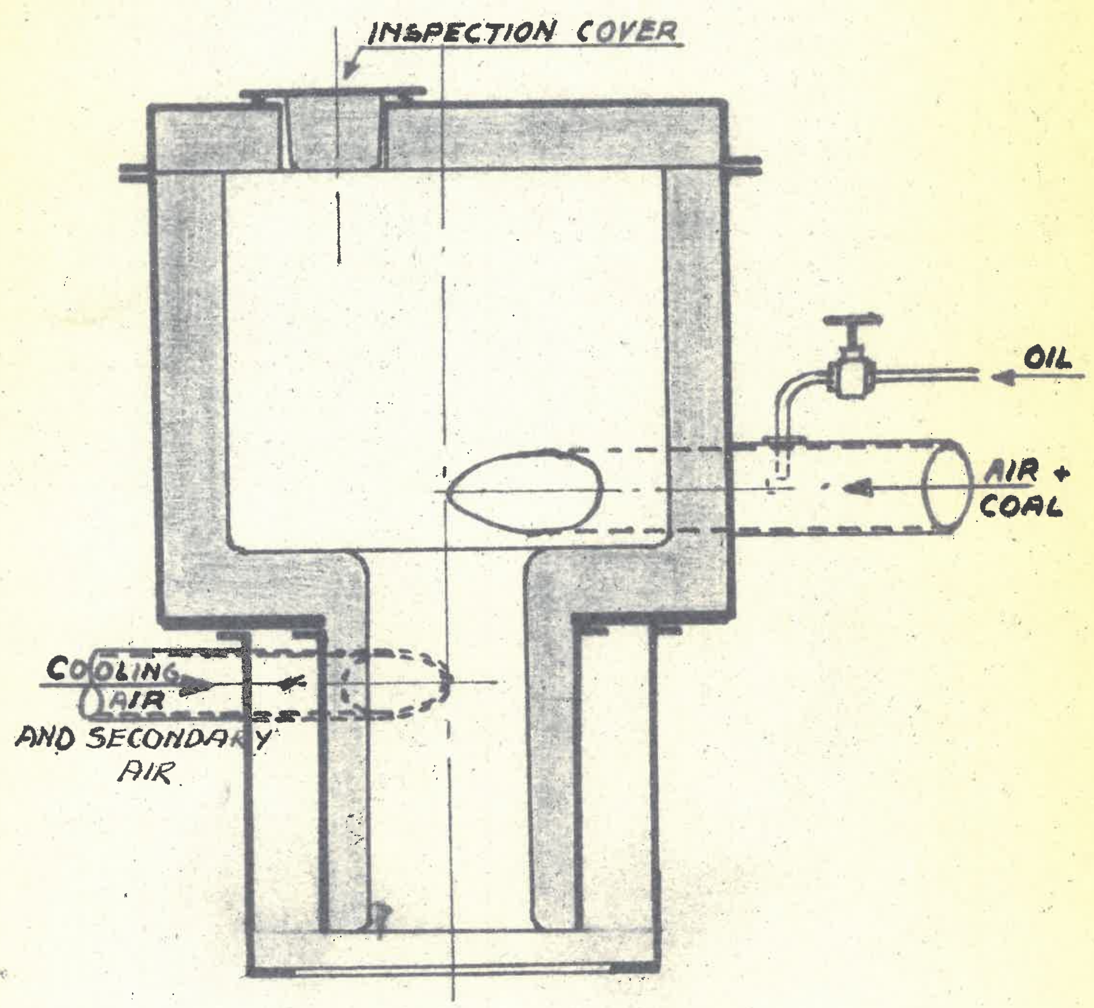

FIG. 1 : ORRIGINAL DESIGN OF CYCLONE BURNER.

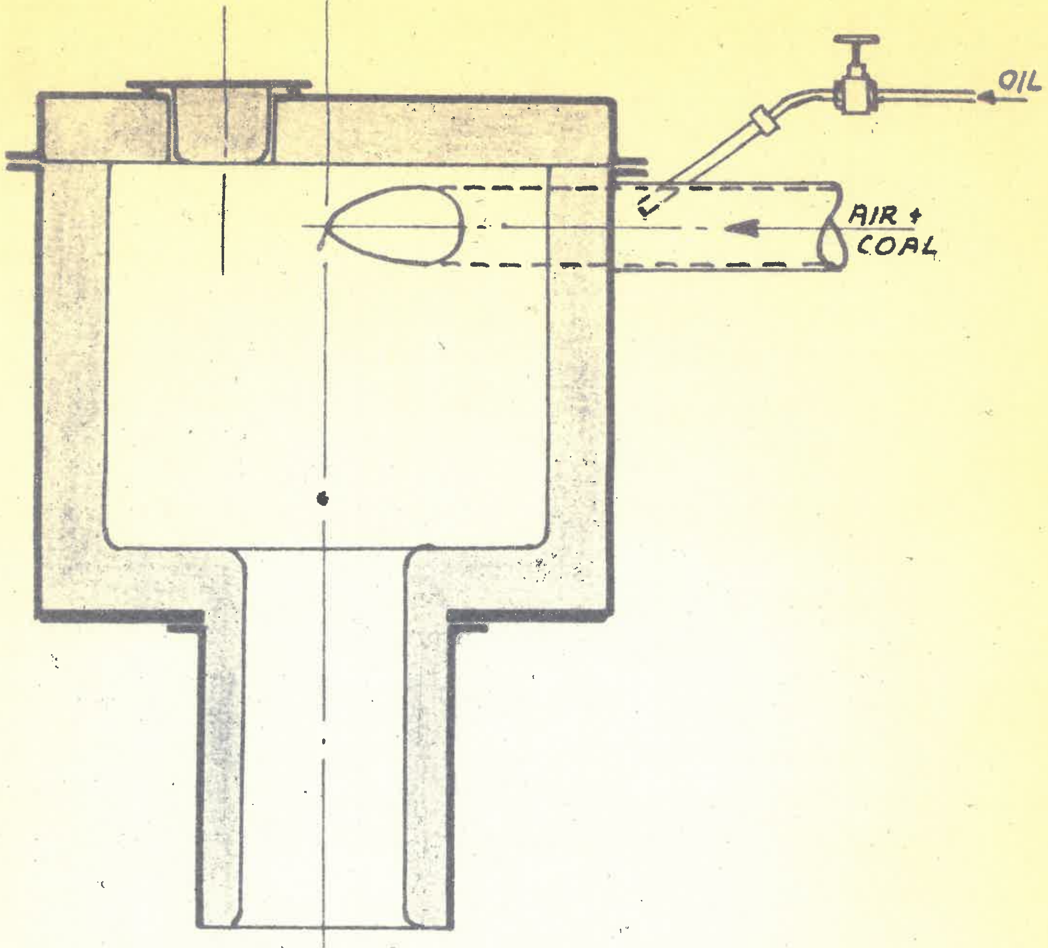

FIG. 2 : MODIFICATION "A"

3. DEVELOPMENT OF THE CYCLONE BURNER.

The construction of the above-mentioned burner is shown schematically in Figure 1. It was used in a vertical position as shown in the figure, which according to the designer, was necessary to prevent the burner from blocking up with coal. The air necessary for combustion and transport of the coal was supplied by a fan. The suction pipe of this fan was mounted over the retort of an underfeed stoker. While the stoker pushed the coal up in the retort it was carried away by the air suction and blown into the burner tangentially at the bottom end of the main body, just above its outlet nozzle. Secondary air was also provided and blown tangentially into a jacket provided around the outlet nozzle. This amount of air served mainly as cooling air for the outlet nozzle and reached the combustion gases emitted from the burner only at the bottom end of the nozzle. Its usefulness as secondary combustion air was thus very doubtful since the burner discharged its hot gases into the open.

To put this burner into operation, a wood fire had to be laid-on inside. This fire had to be ignited by opening the inspection cover. Oil was then sprayed into the primary air supply pipe and the burner was first operated on oil only till it was sufficiently heated up to achieve ignition of the coal. The coal used was ground to -1/16". It took more than one hour to reach the required ignition temperature. The object was to switch off the oil supply as soon as the burner could be operated on coal only, but, although several trials were made, it was never possible to switch off the oil supply completely. A small amount of oil was always necessary to keep the burner in operation.

It was observed that the main burning zone lay well inside the outlet nozzle, and that a large part of the coal supplied to the burner was blown out again in an almost unburnt state. Samples taken from this blown out coal contained more than 80% combustible matter, hence the difficulty to maintain a high temperature inside the burner. Oil also flowed out of the burner nozzle indicating that the oil was not properly atomised.

In order to improve the combustion of coal and oil, modification "A" was carried out, as shown in Figure 2. Primary air and coal were now blown in at the top end of the main burner body in an effort to push the main burning zone

back/......

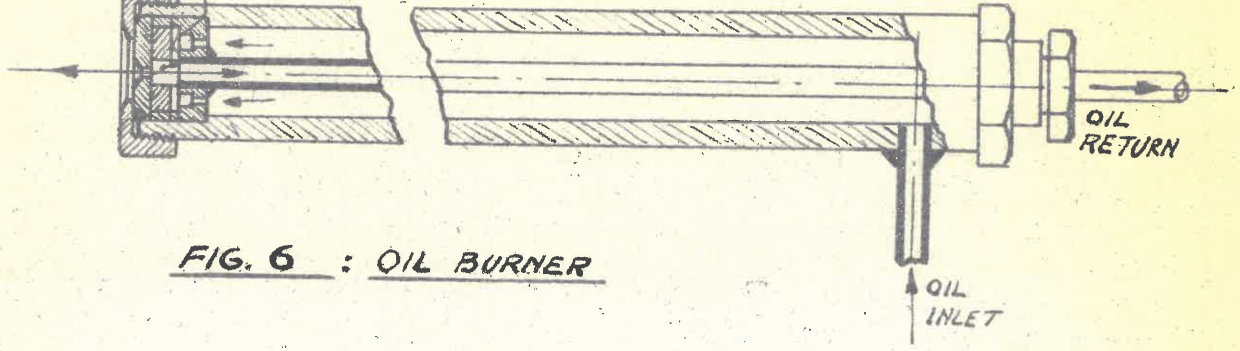

FIG. 6 : OIL BURNER

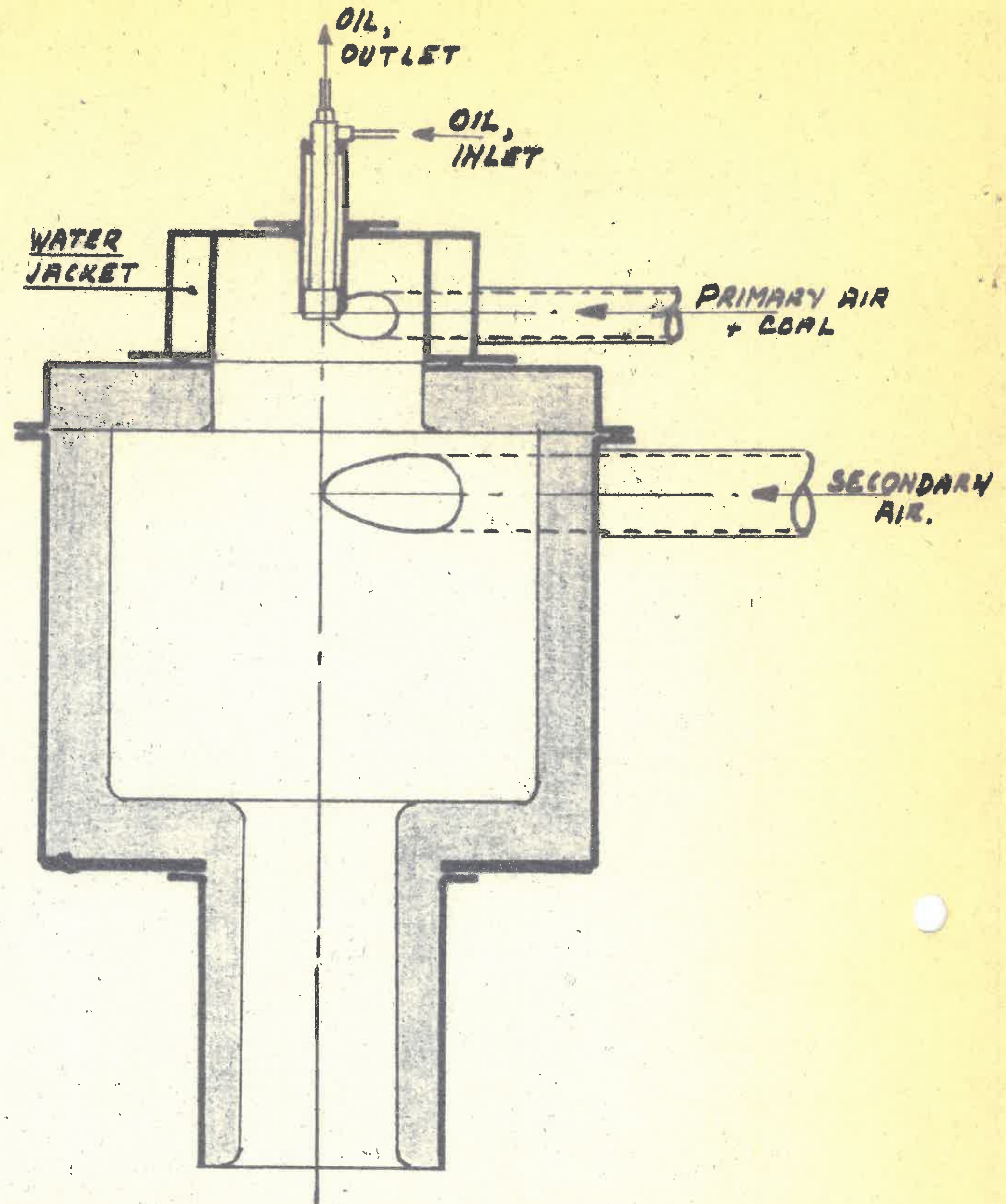

FIG. 3 : MODIFICATION "B"

back into the burner by increasing the time that the coal swirled around inside the burner, thus improving the conditions for more complete combustion of the coal. At the same time the oil supply nozzle was placed in such a position that the oil was sprayed in the direction of the air flow thus minimising the amount of oil sprayed against the wall of the air supply pipe and keeping it more in suspension and in direct contact with the combustion air.

The secondary air supply was discarded and the secondary air jacket around the outlet nozzle removed as being useless.

Subsequent trials showed that the main burning zone was still lying partly inside the outlet nozzle so it was considered necessary to push the coal supply still further backwards. The emission of black smoke indicated that the air supply was inadequate to achieve complete combustion. A small amount of oil was still flowing out of the outlet nozzle. Furthermore, it was noted that some erosion of the burner lining occurred just behind the air and coal supply pipe, in the direction of the flow. (The burner was lined with basicrete.)

For the above mentioned reasons, modification "B" as shown in Figure 3, was carried out.

The top of the burner was modified and provided with a water-cooled steel hood, which contained the primary air and coal supply pipe, feeding the air and coal tangentially into the burner. The impact of the high velocity air and coal stream was now taken up by the steel wall of the hood thus eliminating erosion of the burner lining at that spot.

The oil nozzle was also redesigned as shown in Figure 6. The disadvantage of the previous nozzle was that atomisation of the oil stopped as soon as the regulating valve was slightly closed, resulting in a pressure drop, and the oil spray changed into a solid jet. In order to achieve better atomisation over a larger pressure range a new nozzle was designed on the so-called return flow principle. A small vortex chamber was provided behind the nozzle plate in which the oil supplied by the oil pump with a pressure of 100 lbs/sq. inch, was introduced tangentially. A return flow pipe leads part of the oil via a regulating valve back to the oil storage tank. In this way the pressure of the oil and the amount of oil flowing tangentially into the vortex chamber, remain practically constant and constituted a strong vortex resulting in a good atomisation of the oil which was discharged through the hole in the nozzle plate. The amount of oil going through this nozzle plate is regulated by opening or closing the regulating valve in the return flow pipe. Tests with this oil nozzle showed that even with very small discharges, the atomisation was still reasonable.

The oil nozzle was mounted inside a pipe situated

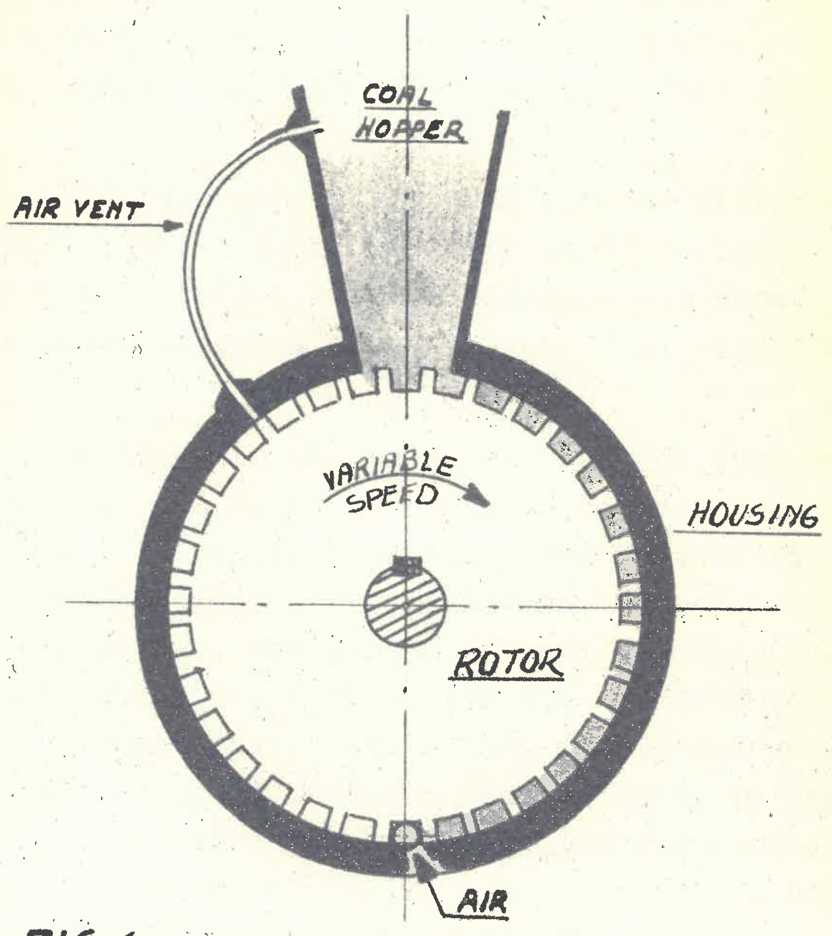

FIG.4: SCHEMATIC ARRANGEMENT OF COAL FEED REGULATOR

air, derived from the main fan and blown into a venturi tube located in the primary air supply pipe. Variation of the amount of coal supplied to the burner is achieved by varying the rotor speed. An air vent is provided to prevent the air leaking along the rotor from blowing back through the coal bunker.

Trials with the new coal supply system were very promising, but as a large amount of partly unburnt coal was still blown out of the burner, which was still in a vertical position, it was decided to put it in an almost horizontal position, with an inclination of 10° towards the outlet nozzle, thus eliminating the influence of the force of gravity on the fall out of the coal particles. This made

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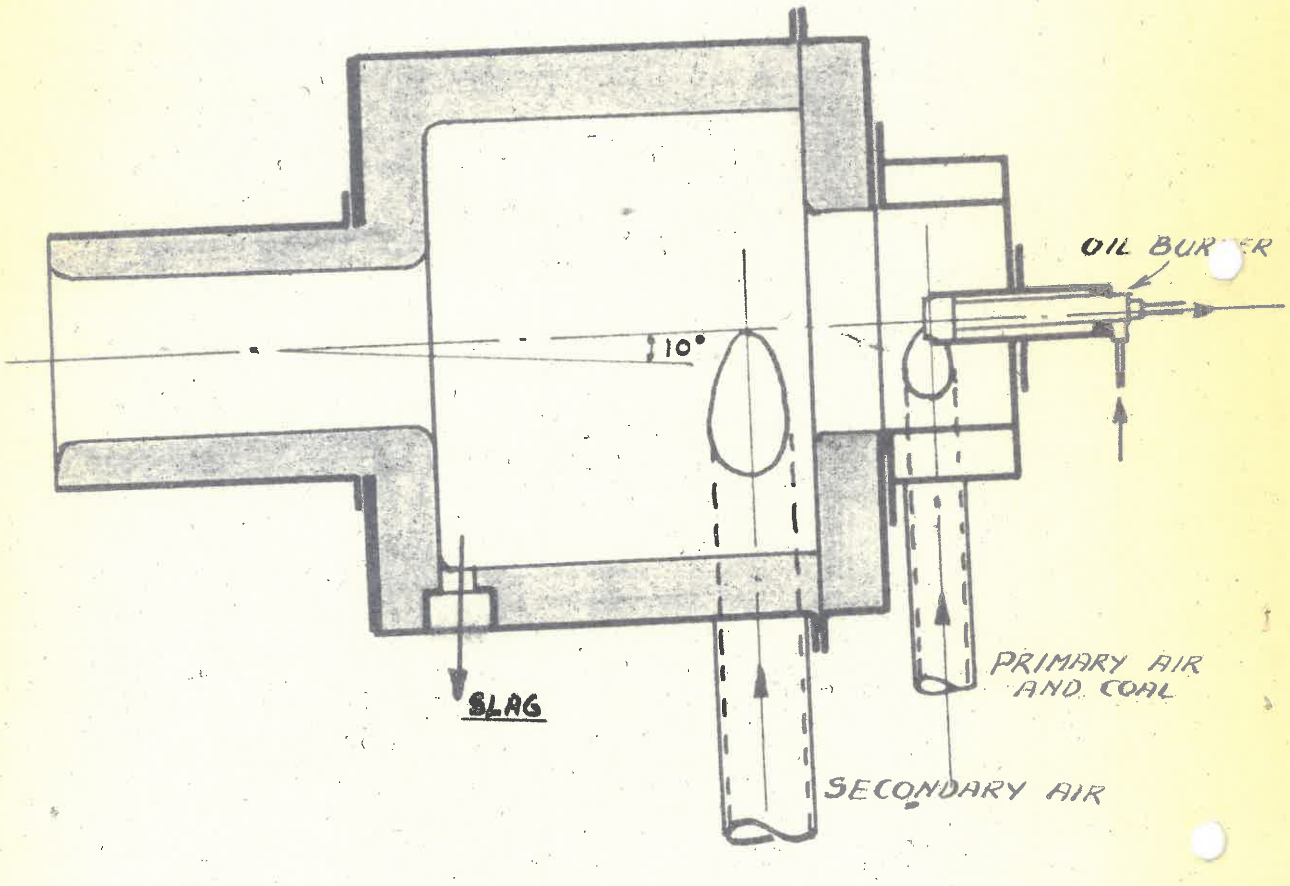


FIG. 5 : MODIFICATION 'C'

it necessary to provide the burner with a slag tapping hole at the lower end, just behind the outlet nozzle. This modification is shown in Figure 5.

During renewed trials slagging of the ash was again achieved while burning on coal only, but much trouble was encountered with the slag tapping hole. The temperature inside the burner was high enough to liquify the slag, but the slag's temperature dropped well below its temperature of critical viscosity during its flow through the tapping hole, so that the slag reached its plastic state and became too thick to flow freely. Its temperature quickly dropped further to below its freezing temperature, and the slag tap hole got blocked and had to be cleared continuously.

The amount of unburnt coal blown out of the outlet nozzle was much smaller, but a fair amount now came out of the slag tapping hole. Samples taken from this blow-out contained about 70% combustible matter.

A build-up of coarse coal occurred inside the burner, at the bottom of the cylinder, and after about two hour's operation almost the whole bottom half of the burner was filled with this coal. Slagging of the ash stopped completely due to the temperature drop inside the burner, and the test had to be discontinued. On inspection, it was found that the bottom half of the burner was filled up with a solid mass of slag covered by lumps of porous material which looked like coke. It was found necessary to re-line the burner, a time consuming operation due to the fact that basicrete has to be air dried for about four days after its application, before slow baking over a period of several hours, at increasing temperatures, can be started.

As it was felt that the settling down of the coarse coal particles along the bottom of the wall of the burner was due to the fact that the air velocities were too small, it was decided to replace the two existing primary air and secondary air fans by a two-stage fan which had ample capacity to supply both primary air and secondary air at such an initial pressure that the velocity with which the secondary air entered the burner was increased from its previous value of about 60 ft./sec. to about 150 ft./sec. The primary air velocity was kept at about 60 ft./sec. by throttling.

During/.......

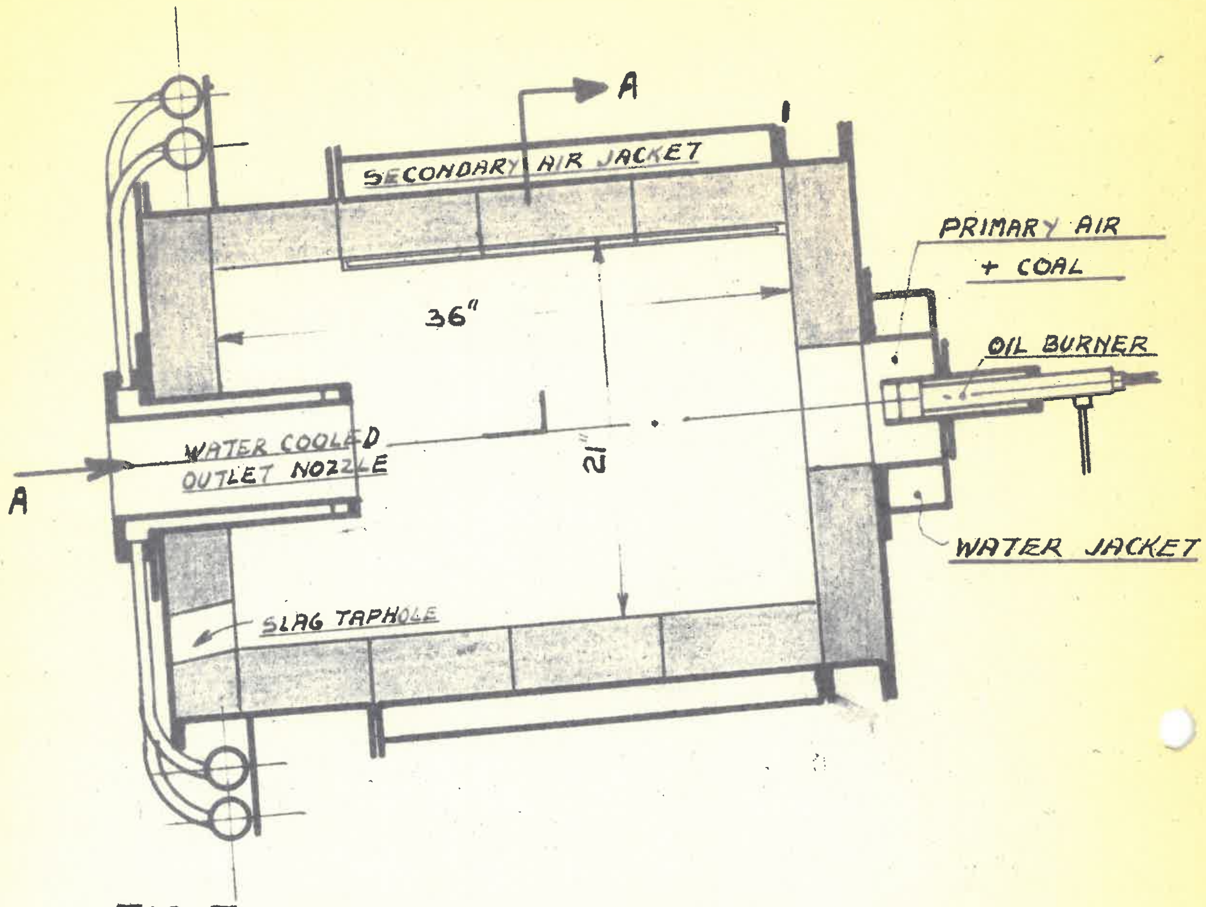
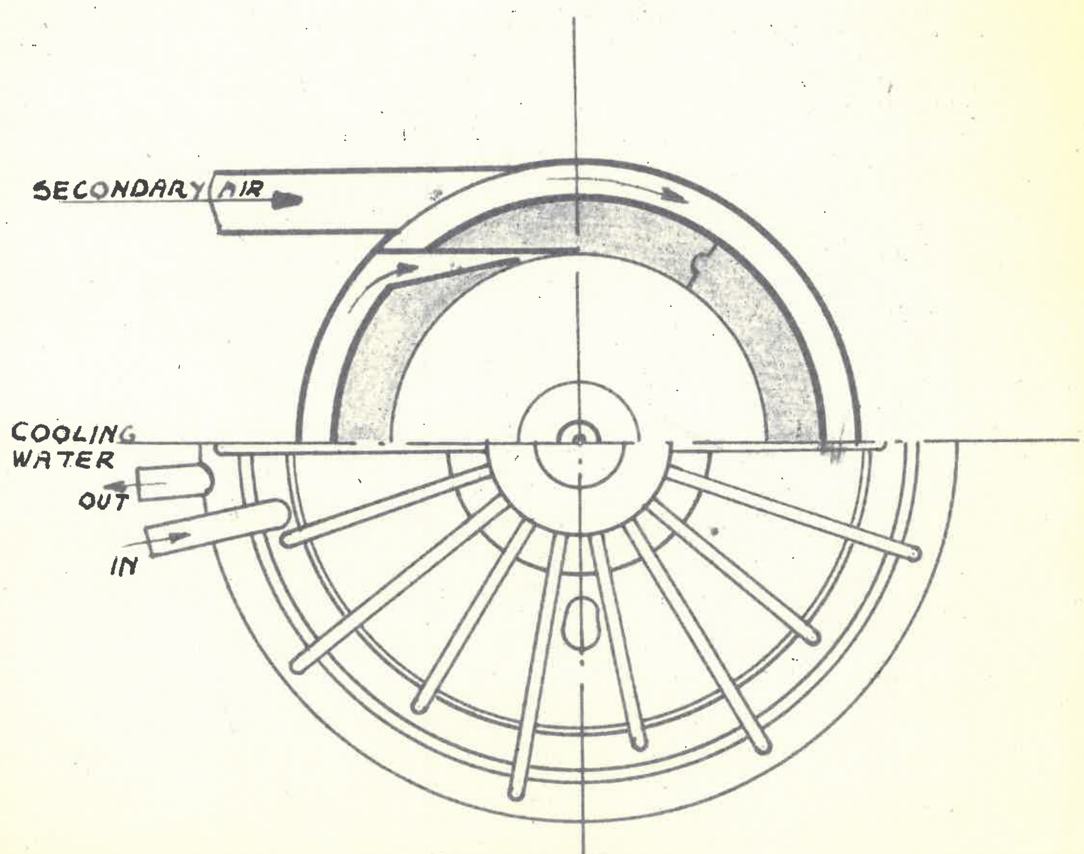


FIG. 7 : NEW DESIGN OF CYCLONE BURNER.



SECTION A-A

During the next trials, building up of the coarse coal no longer occurred, but after about three hour's operation, clouds of grey dust were emitted from the outlet nozzle. An inspection of the inside of the burner revealed that large parts of the lining close to the secondary air inlet ports had been eroded.

The lining used up to this stage was made of a plastic refractory, and this material apparently did not stand up to the higher velocities inside the burner. It had been observed previously that the surface of the lining was cracked, probably due to the severe temperature differences occurring in the burner during operation. The above mentioned erosion of the lining most probably started from these surface cracks. As soon as small parts of the upper, hard-baked layer of the lining were blown off, the under-lying, softer material was exposed and quickly eroded.

In close co-operation with Cullinan Refractories (Pty.) Ltd., Olifantsfontein, several plastic refractories have been tried out, but none of these held for more than three hour's operation. These tests lasted for seven or eight months, as every new lining had to be carefully applied, dried for at least a week, and slowly baked to avoid cracking, and to ensure a hard baked surface layer.

After the above mentioned negative results with plastic lining material, it was decided to abolish this idea and to try fire brick linings.

In order to avoid the manufacture of special bricks, it was decided to use bricks which could be obtained ex stock.

However, to suit these bricks the diameter of the burner had to be increased. As it was observed that the main burning zone was still lying very close to the outlet nozzle, it was also decided to increase the length of the burner. A totally new design was made as shown in <u>Figure 7</u>.

The dimensions of the combustion space of the burner were now: 36" long and 20" in diameter, instead of 16" and 14" respectively as in the previous design. The construction of the water cooled hood containing the oil burner and the primary air and coal inlet pipe remained unchanged. The secondary air inlet system, however, was modified considerably. The secondary air was supplied to

an air/.........

an air jacket, enveloping the major part of the main burner body, before it was blown into the burner through nozzles fabricated from steel plate. The design of these nozzles was such that the air was blown in tangentially through a long narrow gap, about ¼" wide, to obtain the necessary air velocity.

The outlet nozzle was also re-designed, and was made of steel and provided with water cooling. It consisted of two concentric tubes. Longitudinal partitions were provided in the space between the tubes, and were arranged in such a way that the cooling water entered one compartment between two partitions, flowed longitudinally to the other end of the nozzle, bent around the end of a partition into the adjoining compartment and flowed back longitudinally to the front end where it left the nozzle through a tube joining a common outlet pipe.

The length of the outlet nozzle was such that it protruded 9" inside the burner thus providing a space around it where unburnt coal particles were kept long enough to burn completely.

The slag tapping hole was situated in the front plate of the burner, instead of in the outer shell as in the previous design shown in Figure 5. This was done for better accessibility and to minimise the blow out of unburnt coal which swirls around in the space between the outlet nozzle and the burner wall.

These modifications proved to be very effective as the blow out of coarse coal through the outlet nozzle stopped completely, and the amount blown out through the slag tapping hole was considerably reduced.

Unfortunately the size of the slag tapping hole was very limited due to the presence of the water cooling pipes for the outlet nozzle at the front end of the burner. This resulted in a continuation of the troubles previously encountered due to untimely freezing of the slag.

Six trials were carried out with the new burner. The first two were very successful. After about fifteen minute's operation on oil, the burner was hot enough to be switched over on coal and slagging started almost immediately thereafter. The slag had a glassy appearance after solidifying, which means that the temperature of the slag had been well above its critical viscosity temperature.

The burner consumed 200 lbs. of -1/16" coal per hour.

However/.........

However, the burner deteriorated gradually after the first two tests; the slag did not run out as easily, and during the sixth test, building up of the coarser coal started again, which meant that for some reason or other the air velocities inside the burner had decreased.

An inspection of the inside revealed that the secondary air nozzle had partly burnt away, thus widening the gap through which the air was blown in, to such an extent that the air velocity became too low to prevent

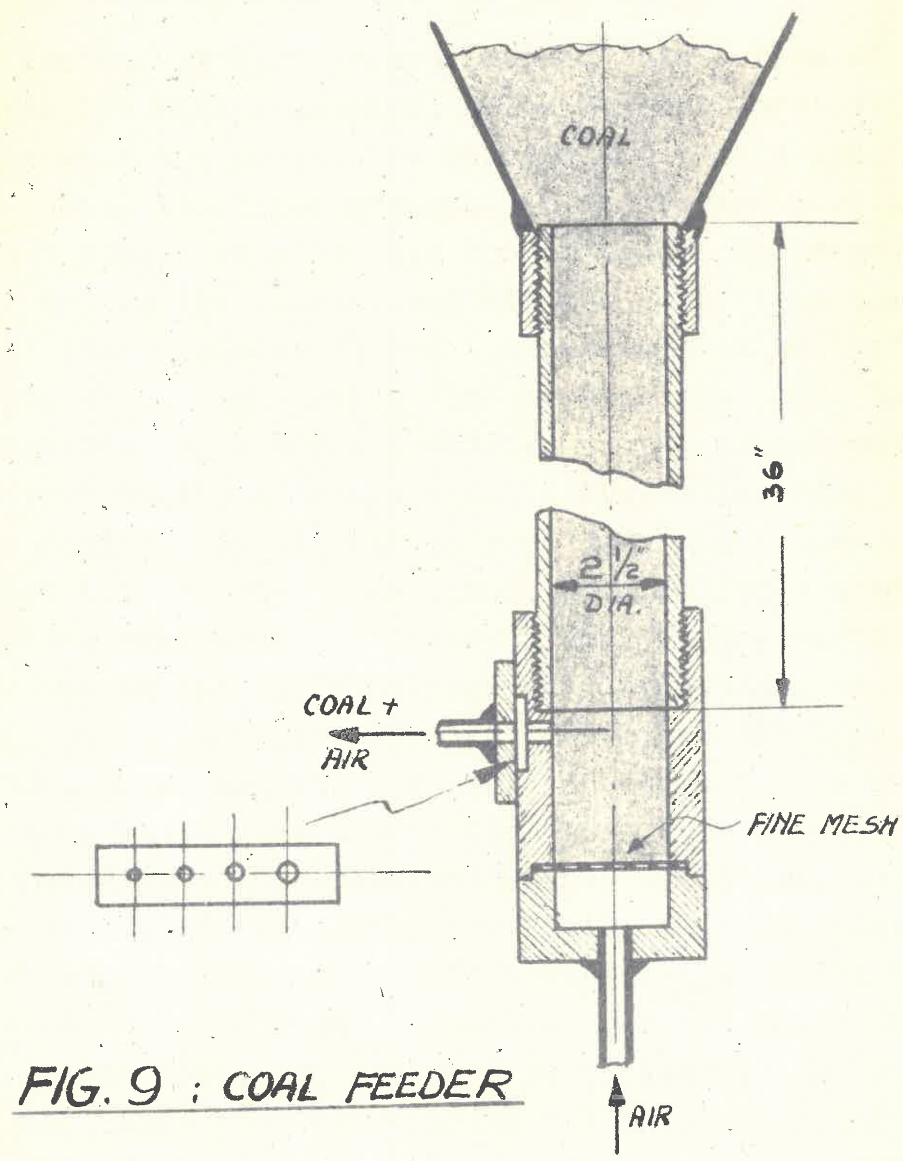


FIG. 9 : COAL FEEDER

liquid. The amount of coal discharged through this hole, and fed to the venturi tube, is regulated by varying the diameter of the discharge hole. This is done by way of a steel slide provided with apertures of different diameters.

To prevent the secondary air nozzle from burning again, a new water cooled nozzle was constructed, consisting of a steel box provided with water inlet and

outlet/........

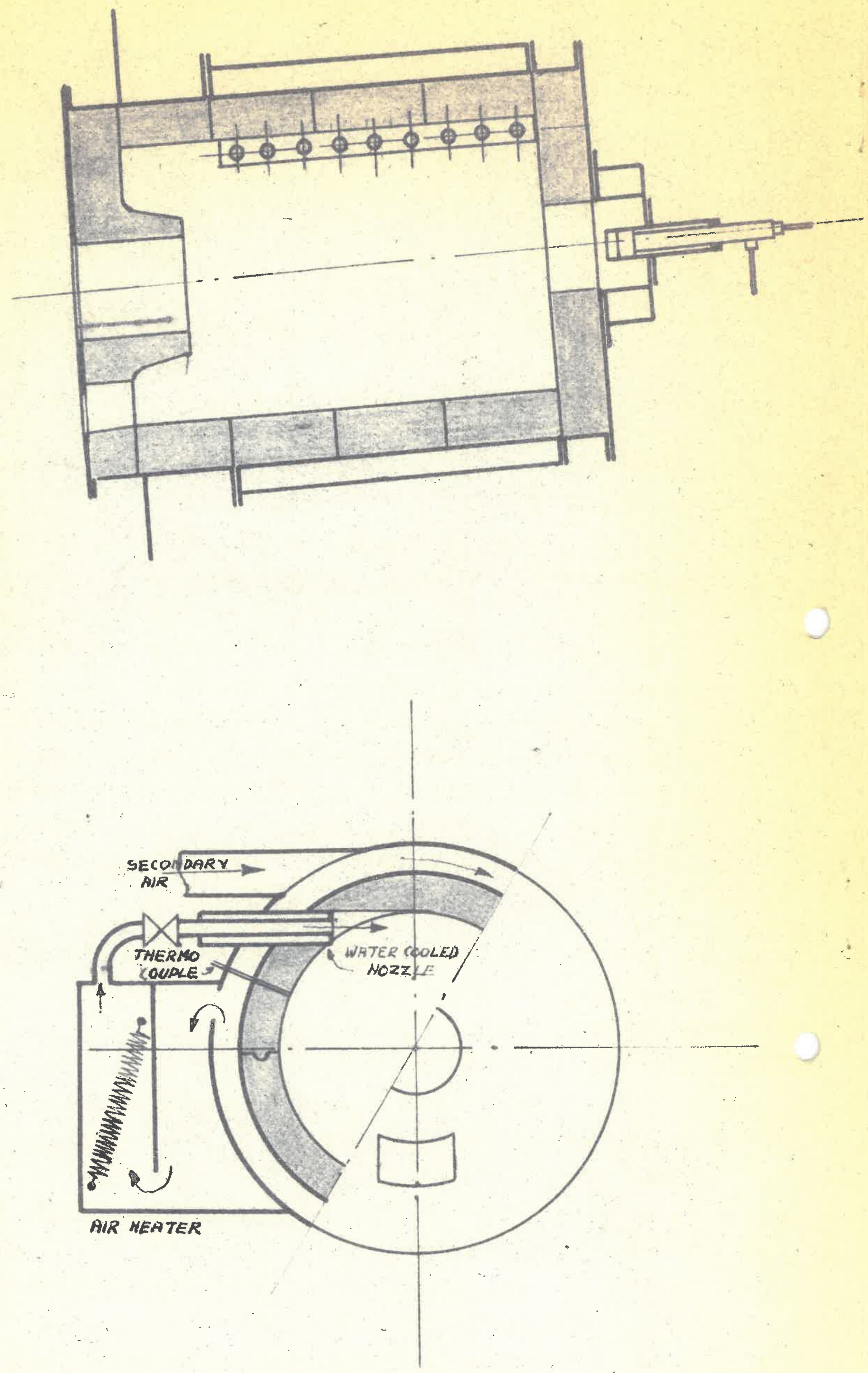


FIG. 8 : MODIFICATIONS TO OUTLET NOZZLE AND SECONDARY AIR SYSTEM.

outlet tubes, in which nine 1" diameter tubes were welded, each provided with a valve. These nine air tubes were connected to an air receiver which was connected to the air jacket around the burner. The secondary air now flowed through the air jacket into the receiver, and from there via the air tubes tangentially into the burner. The result of this modification was that the secondary air, which was pre-heated to a certain extent while it flowed through the air jacket, lost much of its heat again in the water-cooled inlet nozzle. Nevertheless, the air jacket served its purpose as a screen against radiation from the burner body, thus making the burner easily accessible for the operators.

The temperature of the flames issuing from the burner had been measured during previous tests with an optical pyrometer. This temperature had increased from 1100°C in the earlier stages of the development of the burner, to about 1400°C during the last tests. In order to increase this temperature still further and thus make the slag more liquid and prevent it from freezing too quickly when flowing out of the slag hole, it was decided to preheat the secondary air. To this purpose, an electric heater was installed inside the air receiver.

The new situation is shown in Figure 8.

A thermocouple was inserted in the burner lining to be able to measure its temperature during operation. This thermocouple was inserted into the brickwork to about ½" below its surface.

It must be mentioned that by now the brick lining inside the burner was covered with a layer of molten slag which served as extra insulation, and as a protective layer for the brickwork. The modification of the secondary air inlet nozzle necessitated renewal of part of the brick lining. This lining remained intact till the end of the tests.

After this modification, a few tests were carried out with great success. The burner could be switched over on coal after about 15 minute's operation on oil, and started slagging almost immediately. The slag had a glassy appearance, but the previously encountered trouble with the slag tapping hole occurred again. The hole had to be cleared continuously.

The highest/.......

The highest temperature measured with the thermocouple was about 1200°C. The burner could be switched over on coal if a temperature of about 900°C was indicated and started slagging at about 1100°C. Taking into consideration that the ash fusion point of the coal used was about 1340°C, we may conclude that the temperature measured with the thermocouple was about 200°C lower than the actual burner temperature. Thus the above mentioned maximum temperature of 1200°C coincides fairly well with the flame temperature of 1400°C measured with the optical pyrometer and mentioned earlier in this report.

During these last tests, the water-cooled outlet nozzle got so badly distorted and burnt that it developed severe water leaks which appeared to be irreparable. As it was felt that this nozzle would be a weak spot in the design of the burner, it was decided to do away with it and to replace it by a nozzle of more heat resistant material. Much erosion could not be expected at the nozzle as only a comparatively small amount of very fine coal passed through it, together with the flames, while coarser particles which had not yet been embedded in the molten slag, flowing along the inner wall, moved along the side of the burner.

Therefore, the main factors determining the usability of the nozzle would be the high temperature prevailing in this region of the burner, and its resistance to heavy thermal shock.

The nozzle and the front lining plate with the slag tapping hole were designed in four sections, but as it would take several weeks to manufacture these pieces, Cullinan Refractories advised the use of a specially manufactured refractory concrete.

However, during the next tests, when flame temperatures of 1480°C were measured, this material became soft and the nozzle collapsed, so all tests had to be postponed till the refractory brick nozzle was completed.

As the system of water cooling pipes for the steel outlet nozzle was discarded together with this nozzle, the size of the slag tapping hole was not restricted any more, and was increased considerably. Subsequent tests showed that this size increase was very successful. Blockage of the hole through

freezing/........

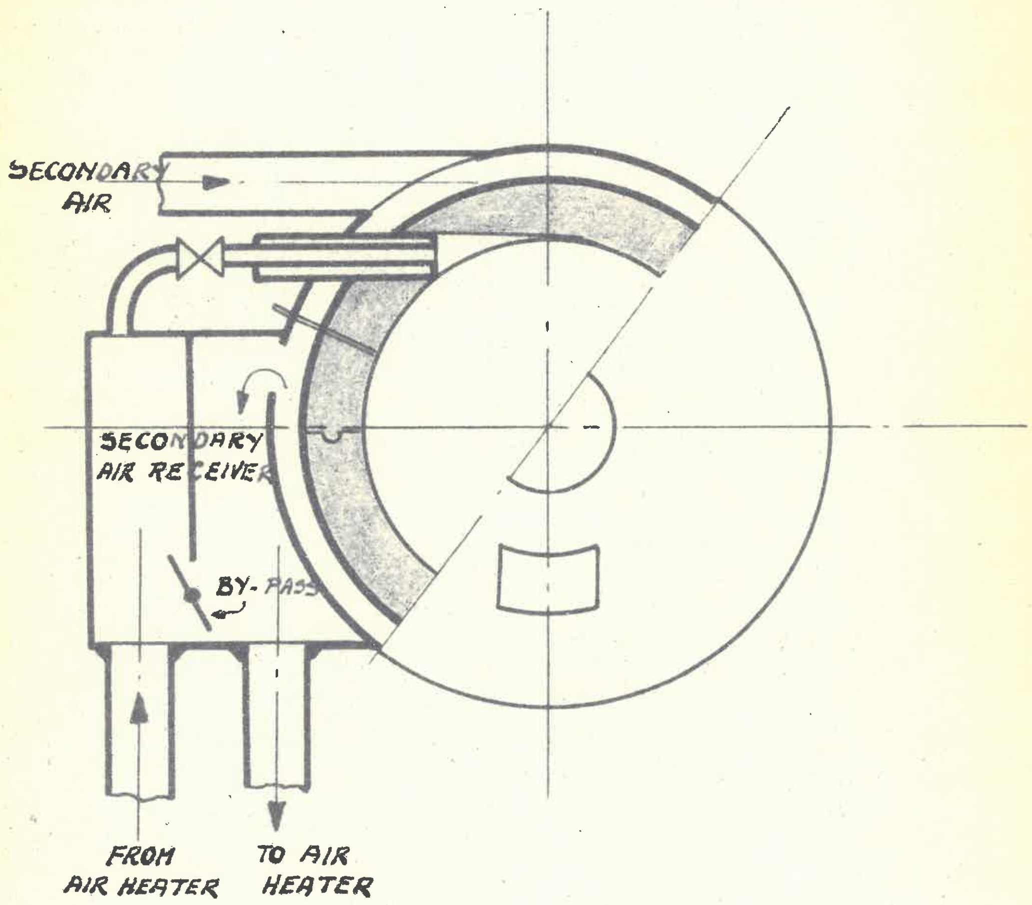


FIG. 10: 2ND MODIFICATION TO SECONDARY AIR SUPPLY.

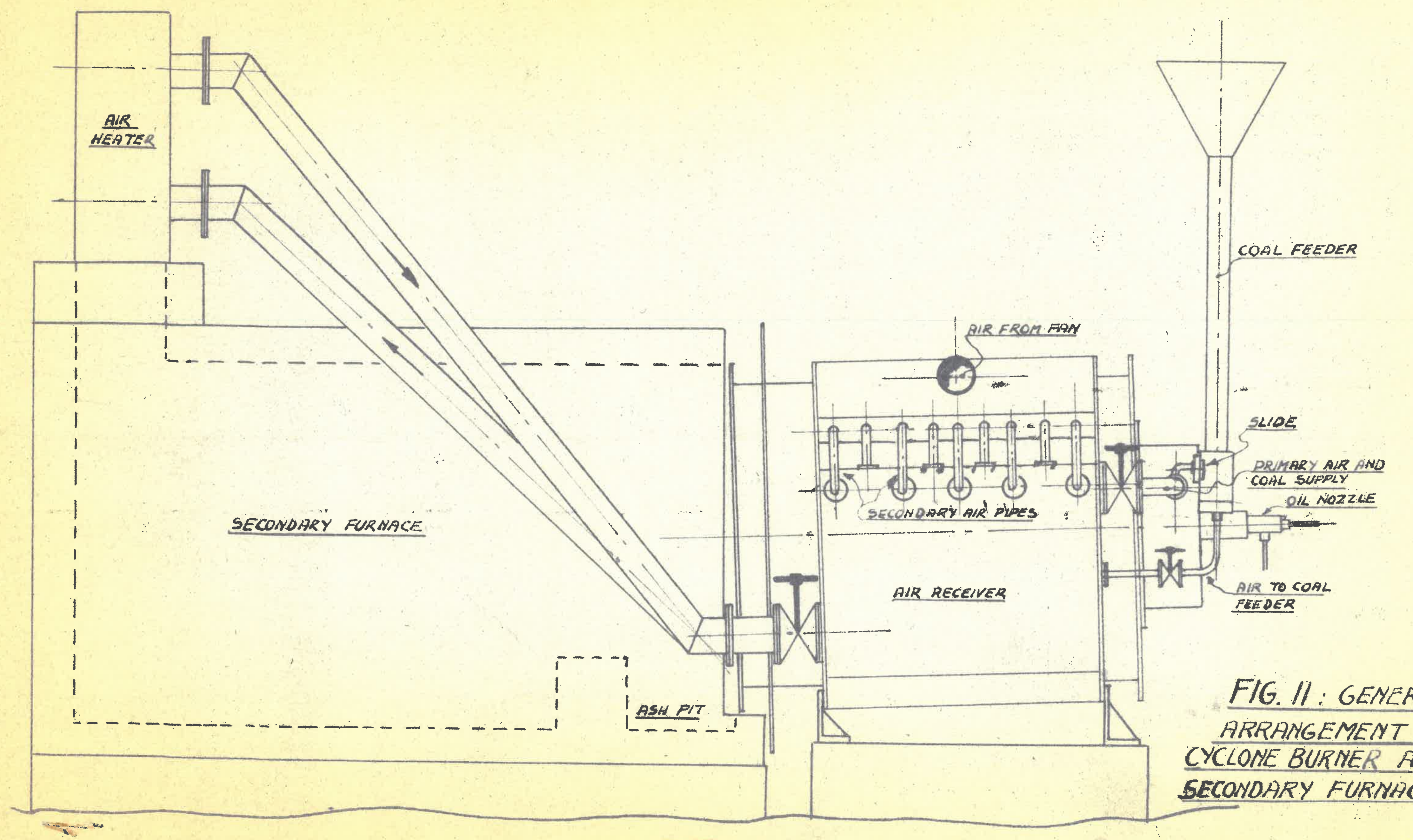


FIG. 11: GENERAL ARRANGEMENT OF CYCLONE BURNER AND SECONDARY FURNACE

freezing of the slag was completely overcome, while the amount of coarse, partly burnt, coal blown out through the slag hole did not increase appreciably, which proves that most of the coarse coal had been embedded in the layer of molten slag before it reached the vicinity of the slag hole.

As heating of the air had proved itself to be an advantage, and the burner was now considered to be in such a state of development that an effort could be made to operate it as near as possible to the conditions under which it had to operate in practice,it was decided to attach the burner to a secondary furnace which acted as the combustion space of a boiler, and to introduce an air heater built in the flue of that furnace.

The electric air heater elements were removed from the air receiver. This air receiver was then divided into two compartments, provided with a by-pass damper for proper air temperature regulation, and each compartment was connected to the air heater. Both primary air and secondary air were now branched off from the hot compartment of the receiver, while the air supply to the coal feeder was branched off from the cold compartment. The result of these alterations was that all the air supplied to the burner passed through the air jacket around the burner into the cold compartment of the receiver, and from there via the air heater into the hot compartment, after which it split into secondary air and primary air.

The above mentioned modifications are shown in <u>Figures 10 and 11</u>, the latter giving a general arrangement of the final set-up. The stack connected to the air heater is not shown in this figure.

After the burner had been fitted with the new refractory-brick outlet nozzle, a series of eight hour tests were carried out. The first three tests were carried out on -1/16" coal and were very successful. Temperatures of close to 1800°C were measured, and the slag flowed out easily.

As it was the object to operate the burner on -1/8" coal, the next three tests were carried out on this bigger sized coal. However, with this coal, the coal feeder developed serious trouble. In order to push the correct amount of 200 lbs. of coal per hour into the burner, the aperture in the slide of the coal feeder had to be $\frac{3}{8}$" in diameter. With this size of aperture, repeated blockages occurred which could only be overcome by using a $\frac{1}{2}$" diameter aperture. This resulted, however, in an over-loading of the burner, as now about 300 lbs. of coal per hour were fed into the venturi. Large amounts of unburnt coal were blown out of the burner and heaped up in the secondary furnace. The temperature inside the burner went up to 1900°C.

Thus, for the -1/8" coal and for this size of burner, the fluidised-bed feeder was unsuitable. Furthermore, the refractory brick outlet nozzle which had given no trouble during operation, developed cracks during every cooling off period till it finally fell to pieces after about 48 hours of operation.

Cullinan Refractories then recommended the making of a new outlet nozzle from a new refractory cement, Carbo frax No. 5, which was reported to be able to stand up to temperatures of 1800°C, and to have a very good resistance against thermal shock. This nozzle has been designed and made at the Institute.

It was also decided to replace the coal feeder by an ordinary screw feeder, as this was considered to be the kind of feeder which eventually would give the least trouble. A variable speed drive on this feeder should enable us to regulate the amount of coal fed to the burner.

Before this alteration could be realised, however, the Fuel Research Board decided to discontinue the tests on combustion appliances.

CONCLUSIONS:

All the work described in this report was, in the first instance, carried out with the object of developing a cyclone burner which would be suitable to burn as wide a variety of South African coals as possible. Though final tests could not be carried out, the results obtained have shown that this burner is suitable for this purpose due to the fact that as much as possible of the generated heat is initially kept inside the burner to obtain a sufficiently high temperature to bring the molten slag into a liquid state. The amount of heat taken up by the molten slag and carried away through the slag tap hole, must be regarded as an inevitable loss inherent to this type of burner. As this slag contains

combustible/.......