350
10/9/84
PB

①
2-0463-4

DOE/ET/10393-1588
(DE84009277)

**OPERATING EXPERIENCE WITH
GRIMETHORPE DISTRIBUTOR PLATE SEAL-
PART 1: INITIAL DESIGN AND FIRST STAGE
MODIFICATION**

By
NCB (IEA Grimethorpe) LTD.

March 1981

Work Performed Under International Agreement No.: ET10393

For
U. S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
NCB (IEA Grimethorpe) LTD.
Grimethorpe,
Barnsley,
South Yorkshire, England

**TECHNICAL INFORMATION CENTER
OFFICE OF SCIENTIFIC AND TECHNICAL INFORMATION
UNITED STATES DEPARTMENT OF ENERGY**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A03
Microfiche A01

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issues of the following publications, which are generally available in most libraries: *Energy Research Abstracts (ERA)*; *Government Reports Announcements and Index (GRA and I)*; *Scientific and Technical Abstract Reports (STAR)*; and publication NTIS-PR-360 available from NTIS at the above address.

**OPERATING EXPERIENCE WITH
GRIMETHORPE DISTRIBUTOR PLATE SEAL-
PART 1: INITIAL DESIGN AND FIRST STAGE MODIFICATION**

By
NCB (IEA Grimethorpe) LTD.

March 1981

Work Performed Under International Agreement No.: ET10393

For
U. S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia 26505

By
NCB (IEA Grimethorpe) LTD.
Grimethorpe,
Barnsley,
South Yorkshire, England S72 7AB

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

OPERATING EXPERIENCE WITH GRIMETHORPE DISTRIBUTOR PLATE SEAL

PART 1 - INITIAL DESIGN AND FIRST STAGE MODIFICATIONS

PREPARED BY: J. Cavanna (Experimental Programme Department)
 B. Morsbach (Engineering Department)
 A. R. Jack

SUMMARY

During the early stages of hot commissioning of the Grimethorpe Experimental Facility it was found that the Distributor Plate Seal did not operate correctly. It allowed the upward leakage of fluidising air and the downward leakage of bed material out of the combustor.

The seal was modified and has now performed satisfactorily during a number of hot commissioning trials. Additionally, a further modification involving the elimination of the seal from the base of the combustor is being developed and will be available should the first modification prove to be unacceptable as a long term solution.

APPROVED FOR ISSUE:

A. R. JACK, Project Director

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

TABLE OF CONTENTS

	Page
1. Introduction	1
2. Original Seal Design	1
3. Operational Background to the Seal Problem Cold Commissioning and the First Two Attempts to Burn Coal	2
3.1 Cold Commissioning	
3.2 Flooding of the Combustor 3rd June, 1980	
3.3 Hot Run on 9/10th September	
3.4 Hot Run on 16th September	
3.5 Inspection of Combustor	
4. Actions Following 16th September Run	4
4.1 General	
4.2 Distributor Plate Calibration and Solids Tests	
4.3 Hot Run on 23rd September	
5. Postion Following 23rd September Run	6
5.1 Conclusions Reached	
5.1.1 Seal	
5.1.2 Tube Bank Failure	
5.1.3 Erosion of Water Walls	
5.1.4 Access	
5.2 Options Identified	
6. The Modified Seal	10
6.1 Seal Design	
6.2 Installation	
6.3 Monitoring of the Modified Seal	
7. Performance of the Modified Seal	11
8. Concluding Remarks	13

Figures 1 - 12

Appendix 1

Non Destructive Testers Ltd. Report on
Survey of Water Wall Tube Thickness,
Carried out 1st - 3rd October, 1980.

LIST OF ILLUSTRATIONS

Fig (In text)	
	Damage to Riser Box and Seal.
1	Combustor Layout.
2	Segment of Seal (Schematic Only).
3	Original Distributor Plate Seal Assembly on North and South Walls.
4	Original Distributor Plate Seal Assembly on East and West Walls.
5	Plots of Bed Δ P, Air Mass Flow and Bed Temperatures - 9/10th September, 1980.
6	Plots of Bed Δ P, Air Mass Flow and Bed Temperatures - 16th September, 1980.
7	Distributor Pressure Loss Calibration - 22nd September, 1980.
8	Erosion Damage to Tube Bank.
9	Modified Distributor Plate Seal Assembly on North and South Walls.
10	Modified Distributor Plate Seal Assembly on East and West Walls.
11	Location of Thermocouples on Seals and Covering Plates.
12	Record of Distributor Flow Resistance.

ACKNOWLEDGEMENTS

The Grimethorpe Experimental Facility is intended to carry out research into pressurised fluidised bed combustion on behalf of the three Sponsors.

The Governments of the Federal Republic of Germany, the United States of America and the United Kingdom, under the auspices of the International Energy Agency, have agreed to share equally between them the costs of building and operating the Facility.

Project is funded by the Sponsoring Countries through the following agencies:

FRG Kernforschungsanlage Jülich GmbH

UK Department of Energy

USA Department of Energy

The Facility has been built on a site adjoining a power station at the National Coal Board's Grimethorpe Colliery, South Yorkshire, England.

1. INTRODUCTION

By the end of August, 1980 the Grimethorpe Experimental Facility had been "cold commissioned". About 20 systems covering both major and minor components of the plant had been operated separately and in an integrated manner for a limited period. The final steps of cold commissioning had seen the first firing of the combustor on propane, when for two periods of five hours a bed of dolomite was held at temperatures of 500 - 600°C.

Hot commissioning was started in September, 1980 and the first coal burning run was achieved on 9/10th September. Partial coal firing was performed for a period of about 45 minutes before the plant was shutdown due to high bed temperatures. The second run on 16th September progressed to a bed temperature of about 700°C on propane when this run was aborted. There were indications of a considerable loss of bed over a short period during both runs. Material found in the base of the combustor pressure vessel indicated that the major cause of bed loss in both cases was the downward flow of bed material past the distributor plate seal in the base of the combustor.

This report describes the investigations of the problem, the modifications carried out so far and the options available for the future operation of the combustor.

2. ORIGINAL SEAL DESIGN

The specification for the Grimethorpe Combustor called for a design which allowed the distributor plate to be readily moveable to different vertical positions in relation to the water walls and the in-bed tube bank. The Combustor Contractor, Vereinigte Kesselwerke (VKW) achieved this by supporting the major components of the combustor, i.e., the water walls, tube bank and distributor plate, independently. The Combustor layout is shown in Figure 1. The water walls are hung from the top of the combustor pressure shell while the distributor plate is supported on the coal feed, bed material feed and ash removal legs which pass through the base of the pressure vessel. The in-bed tube bank is supported from below on the risers and downcomers which pass between the water walls and distributor plate on the E and W sides of the combustor to the headers which are located in the space between the combustor and the bottom of the pressure shell.

When the risers and downcomers pass the distributor plate they are set in two refractory filled boxes which are supported from the distributor and make a direct metal to metal contact with the East and West water walls. The seal between the water walls and the distributor plate on all four sides of the combustor is effected by a total of 12 stainless steel elements which are manufactured by Metroflex Ltd., and illustrated in Figure 2. These are also located on the sides of the distributor plate and bridge the gap between the distributor and the riser-box on the East and West walls, and between the distributor and water walls direct on the North and South walls. The arrangement is shown more clearly in Figures 3 and 4.

The purpose of the seal is to prevent incoming air bypassing the distributor plate as it enters the combustor, and to retain solids within the bed while accommodating differential thermal movements between distributor plate and water walls. Differential horizontal expansions were expected to produce a 2.5mm narrowing of the gap occupied by the seal (nominally 86mm) during start-up while the dominant vertical movement was estimated to be a 24mm drop of the bottom of the water wall relative to the distributor plate. As both the seal and the riser box are located on the distributor, the vertical movement on the East and West walls is experienced across the metal to metal contact of the riser box and water walls. On the North and South sides the vertical movement is experienced between the seal and the wall, and in the vicinity of the distributor plate fillets have been welded between the water tubes to provide a better surface for the seal to work against.

Fluidising air is introduced to the bed through bubble caps located above the distributor plate and the design therefore anticipated that a stagnant layer of bed material would cover the distributor plate and seal. The seals are fabricated from Type 316 Stainless Steel and were supplied by Metroflex for anticipated operating temperatures of up to about 350°C. Thus the presence of a stagnant layer of bed material is essential in order to protect the seal from combustion temperatures of the order of 800°C.

3. OPERATIONAL BACKGROUND TO THE SEAL PROBLEM COLD COMMISSIONING AND THE FIRST TWO ATTEMPTS TO BURN COAL

3.1 COLD COMMISSIONING

The turbo compressor was commissioned in early 1980 and during the following six months the combustor was blown with air for about 800 hours, and ash, crushed refractory and dolomite were fluidised for a total period of 150 hours. At the end of cold commissioning, dolomite was fluidised for two five hour periods at temperatures of 500 - 600°C, achieved by propane firing.

3.2 FLOODING OF THE COMBUSTOR 3rd JUNE, 1980

On 3rd June the combustor was in cold operation with the turbo compressor when around 15 tonnes of water backed up from a cyclone quench vessel and entered the combustor. The direct cause of the flooding is not clear but it was probably due to a mal-operation during the commissioning of the ash quench system. On entering the combustor the water flowed down the inside of the water walls and over the seals for about an hour, until the level in the pressure shell reached the bottom of the water wall skirt and blocked the main air flow through the combustor. The water remained in the vessel for a further four hours before it was pumped out. A sample of water taken from the quench vessel at a later date had a chloride concentration at 290 ppm. The source of the chloride in the quench water has not been identified. The flooding was naturally a cause for serious concern, and a detailed investigation was undertaken which revealed that the backing-up of quench water could not have occurred under operational conditions. Nevertheless, a number of minor improvements to the control and interlock systems were agreed and implemented to provide additional security. The relevance of this incident to the seal problem will be discussed later.

3.3 HOT RUN ON 9/10th SEPTEMBER

The first coal test started at 1400 hours on 9th September. The test was delayed by trippages but by 0031 hours on 10th September full programme flow had been established to 8 of the 9 distributor compartments. At this time combustor freeboard pressure was 2.2 bar (a), bed differential pressure (ΔP) was 4 -8 mBar (equivalent to a well fluidised bed depth of 200mm). The mean bed temperature was 500°C. Bed feed was commenced and by dropping the airflow and raising the pressure a bed ΔP of around 26 mBar was achieved (equivalent to a theoretical depth of 320mm) while the temperature was brought to 700-730°C. At 0057 hours coal feed was initiated on line number 5, (0.5 tonne/hr. approx.) and propane compartment 1 was turned down and then off. The bed temperature rose to 830°C and although bed material was being fed at the rate of approx. 1.8 tonne/hr. the bed ΔP began to drop. At 0223 hours coal feed was initiated on line number 9 at the rate of 0.45 tonne/hr. and propane compartments 4 and 9 were turned down and then off. The bed temperature continued to rise to 880°C while the bed ΔP 's continued to decrease. At 0240 hours coal was initiated on line number 1 and propane compartments 2 and 3 were turned down and off. Bed temperature went off the scale (at 1050°C) and the plant was shut down manually. During this entire period bed material was being fed at the rate of approx- 1.8 tonne/hr. The build up of solids in the bed during the test is illustrated by the bed ΔP in Figure (5). Bed ΔP is plotted against time, alongside air mass flow and two of the temperatures from different levels in the bed. It is probable that the absolute values of bed ΔP are in error due to air leaking through the seals, but the trends illustrate the failure of the seal to hold back solids. Between 2200 and 2400 hours no material was fed into the combustor and the pressure loss fell slowly as material either elutriated or trickled away through the seals. At 2400 the dolomite feed was started and the bed ΔP rose rapidly until 0115 hours, when it plateaued before starting a sharp fall at 0300 hours despite the continued injection of dolomite.

From the operational point of view the seal failure occurred at around 0200 hours when solids started leaking out faster than the injection system could replace them. The real failure however, had probably occurred around 0115 hours or earlier when the solids loss started, but the effects were masked by the injection system until 0200 hours when wholesale leakage started.

Figure (5) suggests that the levelling off of bed ΔP coincided with the cut back in air flow, and that the dramatic decline started at a time when the bed temperature was around 675°C.

At first the loss of bed ΔP (and the implied loss of solids) was attributed to the rapid calcination and elutriation of dolomite, and a batch of inert molochite was ordered for the second test. Although dolomite was later found lying below the distributor plate, no special significance was attached to it at the time since dolomite had been used frequently during the cold commissioning period.

3.4 HOT RUN ON 16th SEPTEMBER

The second hot start-up began 1245 hours on 16th September using the recently acquired molochite as the bed material. Propane combustion was established in 3 of the 4 above-bed burners, and propane was introduced to 8 out of 9 of the distributor compartments. By 1409 hours the bed temperature was approaching 500°C with the bed ΔP at 10 mBar. Molochite feed rate was then set at 2 tonnes/hr. to build the bed. The bed ΔP profile for the second run is shown in Figure (6). At 1424 hours the air flow was cut back to increase the temperatures which at 1443 hours had reached 650-700°C. By this time 1.6 tonnes of molochite had been injected into the combustor and the bed ΔP reached 20 mBar. Seven minutes later the bed ΔP had fallen to 7 mBar and the run was aborted.

The bed ΔP profile shown in Figure (6) is similar to the first run in that the pressure loss rose before plateauing off when the air mass flow was cut back to raise bed temperature. The subsequent fall in bed ΔP started when bed temperatures were again around 675°C, but in the second case the drop was considerably faster.

3.5 INSPECTION OF COMBUSTOR

Later in the day the combustor pressure shell was entered and a large quantity of molochite and dolomite was found lying in the lower dome underneath the distributor plate. Most of the material lay in a long ridge directly below the seal on the south wall of the combustor. Material falling on the ridge had tended to run down towards the centre of the dome where the build-up was a couple of feet deep. A smaller deposit lay below the east corner of the North seal, part of which had also flowed to connect with the material in the centre. From the disposition of the "sand dunes" it appeared that the seals on the East and West walls had not leaked significant quantities of solids and that most material laying below these walls had flowed there from the North and South sides.

Looking up at each length of seal, particles up to 5mm in size were jammed in and wedging open gaps on both sides of the seal around the whole perimeter of the distributor plate.

About 3.5 tonnes of material were removed from the pressure shell.

4. ACTIONS FOLLOWING 16th SEPTEMBER RUN

4.1 General

Immediately following the 16th September run a series of urgent internal Project Meetings and telephone discussions with VKW were held. From an operational point of view the seal bed appeared to retain solids up to a bed temperature of 650-700°C. In this temperature range leakage of bed material occurred, but after shut-down of the combustor the seal was re-established as the temperature fell.

The six sections making up the North and South seals were removed for examination. All sections suffered from discolouration, attributed to heating of the crown, evidence of scuffing by bed material particles, and staining attributed to the flow of water during the combustor flooding on 3rd June. The sections had lost all of the "springiness" necessary to effect a seal across the gap in which they operated. On measurement the sections were found to have acquired a permanent set and were generally not much wider than the gap from which they were removed (Figure 2). Additionally there were a number of cracks in the stainless steel. One of the 12 seal sections was sent to the Coal Research Establishment for metallographic examination.

Turning to the disposition of material beneath the combustor, it was noted that the East and West seals had held back solids fairly well, possibly because these walls had a smooth backing plate for the seal to work against.

The only part of the North and South seal to hold back solids was the North West corner which had had a short backing piece fitted to fill a gap that was discovered before cold commissioning. This suggested that the uneven surface of the wall was responsible for dragging particles down into the seal and preventing proper contact between seal and wall. VKW had reached the same conclusion and it was decided to equip the entire North and South water walls with backing plates and a new set of seal sections before the third coal test scheduled for 23rd September. Meanwhile VKW were asked to carry out preliminary work on short and long term solutions to the problem.

The combustor was equipped with the modifications mentioned and on 22nd September a number of preliminary cold flow tests were performed on the distributor, and the seals were tested for solids tightness. This was possible following the recommissioning of the distributor ΔP measurements which had not been available during the first two hot runs. These tests are described in the following paragraphs.

4.2 DISTRIBUTOR PLATE CALIBRATION AND SOLIDS TESTS

The data collected from these tests allowed a pressure loss/mass flow calibration to be derived for the distributor plate in its modified state, see Figure (7). Apart from the two single data points shown in Figure (7) no accurate calibration of distributor plate pressure loss versus mass flow existed, so the results were compared with two estimates, (1 CURL, 1 IEAG), of what the pressure loss should be. Both estimates suggested that the current measured pressure loss was low by a factor of about four. The implication was that gaps existed in the seal or its vicinity that were similar to the design flow area of the distributor plate itself. Regardless of the seal's ability to retain solids, it was probably passing as much air as the distributor plate but in very localised areas around the water walls. The two single point calibrations suggest that the seal had continually degraded from early April until these hot commissioning tests but the data is rather sketchy and of uncertain pedigree.

In the test with solids 4.85 tonnes of molochite were fed into the combustor to build a fluidised bed 1m deep, and about 3.5 tonnes were recovered. The outstanding 1.35 tonnes can in part be accounted for by material required to fill up ash legs, by the layer of solids left behind on the distributor plate and by elutriation. The conclusion was drawn that only minor amounts of molochite had been lost through the modified seal when the bed was operated cold. One interesting feature of the test was that the bed ΔP readings were much improved in that they corresponded better with the amount of material fed to the combustor. This suggested that the air leakage on the North and South walls where the pressure tappings are located had been reduced to reasonable levels by the new seals.

4.3 HOT RUN ON 23rd SEPTEMBER

On the following day, the 23rd September, the third attempt was made to burn coal. As bed temperatures were approaching 550°C on propane the combustor bed was drowned as a result of a burst pipe in the tube bank. The rupture of the tube was due to a local erosion of the tube bank directly above the bed material feed nozzle.

5. POSITION FOLLOWING 23rd SEPTEMBER RUN

5.1 CONCLUSIONS REACHED

Prior to the run on 23rd September, the only problem which had been recognised was bed material leakage past the seal. Minor modifications based on circumstantial evidence had been attempted. The failure of a tube in the in-bed tube bank led to a more detailed examination of the bottom end of the combustor which had not previously been carried out due to the access difficulties. This examination showed that the problems were more widespread than had previously been recognised and included erosion of the tube bank and water walls, in addition to the seal leakage. These problems are discussed in detail below.

5.1.1 Seal

The stainless steel seal sections had suffered considerable degradation in service and even with the remedial measures carried out from 16th - 22nd September the seal region was still passing considerable quantities of air, possibly as much as the distributor plate itself. Despite this damage the seal was able to retain a bed of particles in the combustor during the initial part of the start-up sequence, but on the two occasions when the bed was lost, catastrophic particle leakage was experienced as soon as the air mass flow was reduced (as part of the start-up routine) and average bed temperatures reached 675°C. Following shutdown the seal would retain particles again.

This apparently reversible behaviour is not unreasonable because particles escaping through the seal do so in the face of the upward air-leakage and a reduction of air mass flow will facilitate escape. In addition the seal crown has a double skin and it is possible for a damaged seal, exerting little or no sealing pressure on its neighbouring components, to contract through a "bi-metallic strip" effect as the seal top gets hot and open a path for solids loss. The seal will hold back particles again following shutdown when temperatures have fallen and the air flow is restored.

Turning to the original degradation of the seal, the result of visual and metallographic examination of the seal sections showed that they had been subjected to temperatures in excess of the 350°C envisaged at the design stage. The seals had also suffered from stress-corrosion cracking, presumed to be a consequence of the flooding of the combustor on 3rd June. The seals had lost much of their "springiness" and had acquired a permanent set. From the evidence available it is not possible to determine the relative contribution of the overheating and stress-corrosion cracking. However, VKW, IEAG and Metroflex concluded that the overheating was the more serious long term problem and was caused by the upwards leakage of air past the seal. This caused fluidisation of bed material immediately above the seal, thus destroying the stagnant layer of bed material needed to insulate the seal from combustion temperatures.

5.1.2 Tube Bank Failure

An examination of the tube which failed during the run on 23rd September showed that the failure was due to external erosion. A further three tubes in the bank had also suffered erosion and required replacement. The area suffering from erosion was immediately above the bed material injection nozzle. Calculations indicated that the velocity of material being fed through the injector was up to 40 m/sec which is quite sufficient to have caused the observed erosion. The erosion on the failed tube is shown in Figure 8.

5.1.3 Erosion of Water Walls

During the clean-up of the combustor following the flooding of 23rd September, serious erosion damage was also found on the lower rows of the East and West water walls which was clearly related to air leakage through the seal region causing localising fluidisation and scrubbing of the water walls. The erosion was centred around two places on the East and West walls where a gap had developed between the riser box and the water walls. On the other side of the box opposite the gap the movement had crushed and torn the seal locally.

The inspection confirmed that the East and West seals in particular were leaking large quantities of air. The extent of erosion is shown in Appendix (1) which contains the results of an ultrasonic survey of water wall tube thickness. The worst thinning measured was from a nominal tube thickness of 4.5mm down to 1.6mm. Damage to the riser box and seal section in the vicinity of the eroded wall is shown in the following photograph which looks down on the plate and risers of the West wall.

RISERS (VERTICAL)

BUCKLING OF PLATE
FORMING SIDE OF
RISER-BOX

SEAL TOP SHOWING
DAMAGE CAUSED BY
THE DISTORTION

DISTRIBUTOR PLATE
WITH 'BENT OVER'
AND 'REGULAR'
BUBBLE CAPS

5.1.4 Access

Access to the combustor was restricted since no man-hole had been provided between the distributor plate and the in-bed tube bank. The inspections described above were carried out by gaining access through the ash let-down legs.

5.2 OPTIONS IDENTIFIED

It was clearly necessary to carry out the following work immediately.

- a. Replacement of eroded water wall tubes.
- b. Replacement of tubes in tube bank and modifications to bed material nozzle to prevent further erosion.
- c. Provision of a man-hole for access to the combustor.
- d. Modification of seal.

With regard to the seal, several options were identified in discussion with VKW as being available to the Project. A significant feature was that the Project Plan included a change of the in-bed tube bank after the first part of the experimental programme. VKW confirmed that the new tube bank could be available in March, 1981. The options were as follows:

OPTION A - Modify the existing seal in the light of the experience gained.

OPTION B - Eliminate the seal by either welding or clamping the distributor plate direct to the water walls with the existing Tube Bank (Tube Bank A) installed.

OPTION C - Delay action until the new tube bank (Tube Bank C) was available in March, 1981 and weld or clamp the distributor plate to the water walls during the installation of Tube Bank C.

OPTION D - Install a new design of seal.

It was considered that Option D was not attractive in that several weeks would be needed to implement it with no guarantee that it would be any better than the existing seal with modifications based on actual operation experience.

Option C would have resulted in several month's delay since Tube Bank C would not be available until March, 1981 and would have precluded any testing with Tube Bank A. Therefore top Priority was given to consideration of Options A and B. In the event it was found that Option A could be implemented together with the replacement of damaged tubes in Tube Bank A and the eroded water walls, the installation of a man-hole in the combustor wall and the addition of a deflector to the bed material nozzle, in the design time for Option B. VKW were therefore instructed to proceed with Option A.

6. THE MODIFIED SEAL

6.1 SEAL DESIGN

The modified seal design is shown in Figures 9 and 10. The essential features are as follows. The stainless steel seal is mounted lower than in the original design and is protected by a horizontal heat shield. This should reduce the chance of leaking air fluidising the bed material above the seal, and even if some fluidisation occurs hot bed material cannot come into contact with the seal to any significant extent. A feature not shown in Figures 9 and 10 is that the gap between the stainless steel seal and the radiation shield is packed with "Fibro frax" insulating material.

On the North and South sides the heat shields is welded to a vertical plate which slides against the water walls and an asbestos packing is provided between this vertical plate and the water walls. On the East and West sides the heat shield is welded to a vertical plate which is in turn welded to the riser pipe box. Outboard of the riser pipe box an asbestos packing, similar to that on the North and South sides, prevents leakage of air past the water walls. A system of clamps is provided to maintain alignment. Thus the seal is surrounded by plates which have no relative vertical movement with respect to the distributor plate, so that the seal only has to accommodate relative movements in the horizontal direction. The movements of these plates relative to the water walls is controlled by the clamps to be only in the vertical direction and air leakage is prevented by the asbestos packings.

6.2 INSTALLATION

The installation of the sealing arrangement was carried out by VKW in parallel to their repair work on the combustor water wall and tube bank in the period 14th October to 6th November. The distributor plate seal itself was fitted by IEAG in co-operation with Metroflex during the following week.

The following problems occurred during installation.

- The plate forming the riser box was bent and the gap between it and the riser box refractory was filled with bed material. That material was removed applying compressed air and a vacuum cleaner. The plate was straightened by pushing the new vertical plates against it with the help of hydraulic rams. In the straight position the two plates were welded together. A small gap remained between the plate and the refractory which was considered to be acceptable because leakage through that gap is not likely to occur.
- The distance between the water wall and the riser box was bigger than shown in the drawing. Therefore, 3 asbestos packings were used instead of 2.

- The vertical plates on the North and South side did not join flush at the bottom. Two brackets were welded on to hold them in position.
- Due to distortions and the additional plates the width of the gaps for the seal varied. Therefore, the shape of the seal varied as well and the seal did not fit together in the corners. Sleeves made up to the as-built dimensions of the gap were used to re-mitre the corner sections of the seal mounted on a special device in the workshop for that purpose. The seal sections had to be installed at different heights because the total height of the seal changes with the width of the gap and the tops of the seal sections have to be at the same level to prevent leakage where they join together.
- On each West and East wall a bracket welded on to the skirt at the distributor plate was cut out in agreement with VKW to enable the installation of the seal.

6.3 MONITORING OF TEMPERATURES AND THERMAL EXPANSIONS

The performance of the seal is dependent on the conditions it is exposed to. In particular, temperature has a strong influence. The temperatures at different points of the seal arrangement can also give a good picture of the performance of the seal. Therefore, it was decided to install 12 thermocouples on various points of the seal arrangement as shown in Figure 11. Four thermocouples were placed underneath the top of the seal in pockets spot welded on to the skin by the seal manufacturer especially for the purpose. The remaining 8 thermocouples were installed on the top of the covering radiation plates. In addition to these continuously recordable temperature measurements, the tops of the seal and the covering plates were painted with a temperature sensitive paint.

Finally "scratch plates" were installed to indicate the thermal movements of the water wall relative to the distributor plate. The working parts of these devices are painted so that the traces of the movement will be visible on the paint. The device shown on the drawing was installed on the North wall and a similar one on the South wall.

7. PERFORMANCE OF THE MODIFIED SEAL

Following the completion of VKW's corrective work on 6th November, instrumentation in the bottom of the combustor was reinstated and hot commissioning runs were performed on the 22nd, 27-28th November and 3rd, 10th and 16-17th December. In the first test operator inexperience and difficulties with the coal feed system prevented the stable transition from propane to full coal firing, but full coal firing was achieved in all the remaining tests. The total operating time on coal alone in the five runs was about 50 hours, and the longest run was for a duration of 16 hours.

There has not been time for a detailed analysis of the results obtained from the five runs. However, the performance of the modifications to the seal were carefully monitored. Throughout the hot running the temperatures of the flexible seals tended to remain constant at around 250°C, a temperature at which they should be expected to operate well.

Six out of the eight shield temperatures remained fairly constant between 250°C and 350°C. One shield temperature in the South West corner tended to run high and to cycle, at times exceeding 450°C. Another shield temperature in the North West corner tended to cycle widely between 200°C and 450°C. Visual inspection between hot runs revealed slight leaks of bed material through gaps in the gasket box on the East and West walls. These gaps were caulked with asbestos packing. The heat shield showed no sign of distortion or excessive temperatures. The lie of material on the distributor plate suggested air leakage from behind the tube bank riser box in all four corners. Following an inspection on 6th December these areas were caulked from inside the combustor. During the sixteen hour hot run conducted on 12th December seven of the shield temperatures ran steady in a band 225°C to 275°C. The previously cyclic temperature in the N.W. corner was amongst the lowest, but this thermocouple had probably burned out. The temperature in the S.W. corner remained high and slightly cyclic but did not exceed 350°C.

The distributor plate pressure loss was investigated between each run to monitor the condition of the seal, and Figure 12 shows the results obtained between the reinstatement of the combustor in November, 1980 and the first few runs in February following repairs in the January shutdown. The majority of pressure loss measurements fell within the range of theoretical prediction, and were well above the calibration obtained at the time of the failure, suggesting that any seal leakage has been limited to the order of 0 to 5% of total distributor plate flow. Points A to F were obtained in the period before Christmas 1980 and no significant degradation was apparent until F, following the run of 17th December when various temperature excursions were observed on the radiation plate thermocouples. Inspection of the combustor during the January shutdown revealed accumulations of slag on the distributor plate and a total of 12 burned bubble caps which were sufficiently damaged to account for the reduced pressure loss.

Also during the inspection the radiation shield and the flexible seals were removed and were found to be in the same condition as when first installed in October. The gasket on the outside of the East and West walls was found to be loose. The gasket holder was modified to allow a tighter grip on the gasket and when the system was reassembled a larger gasket was used. At the same time the gap between the riser boxes and the water walls was systematically caulked with asbestos rope from inside the combustor. Systematic ultrasonic thickness testing did not detect any erosion damage from the slight leaks which had been evident in the corners and at places behind the riser boxes.

The modifications made in January seem to have been effective and the distributor plate pressure loss improved in February as indicated by points G, H and I. Overall the modified seal arrangement has performed effectively for 100 hours of coal burning operation.

8. CONCLUDING REMARKS

In parallel with the modification to the seal VKW have assessed the possibility of welding the distributor plate to the water walls. The results of stress analyses for the worst case - start up when the temperature differentials are greatest - indicate that this is feasible and VKW are currently preparing detailed design drawings for this modification.

Effecting the present repairs and modifications to the seal area has pushed the Project Schedule back by about 2½ months and further delays will arise if the seal has to be welded up in order to complete Test Series 1. Only 100 hours of coal burning is not sufficient to allow a definitive judgement on whether the modified seal is wholly satisfactory. However experience to-date suggests that this will be adequate at least until the end of Test Series 1.

To set against the delay is the value of the experience gained in overcoming the problem, which will be of benefit to P.F.B.C. technology. These include:

- i) The difficulty of making a 100% air tight seal across a sliding metal to metal contact especially when operating in the direct presence of hot solids.
- ii) The relatively small leakage flows necessary to cause local fluidisation of layers of particles intended to provide thermal insulation.
- iii) The erosive capacity of the particle concentrations found in fluidised beds, even though the activating air flows are driven by relatively small pressure differentials. The surfaces to suffer the worst erosion were those "sticking out" into the flow as do the tubes of the East and West water walls. The flush surfaces of the North and South walls were not apparently affected.

FIGURE 1

COMBUSTOR LAYOUT

FIGURE 2

SEGMENT OF SEAL (SCHEMATIC ONLY)

SEAL DIMENSION (mm)	ORIGINAL SHAPE (mm)	IN SERVICE (mm)	AFTER FAILURE (mm)
HEIGHT 'A'	133,7	142	144,5
WIDTH 'B'	104,0	86	88,1

FIGURE 3 ORIGINAL DISTRIBUTOR PLATE SEAL ASSEMBLY ON NORTH AND SOUTH WALLS

FIGURE 4 ORIGINAL DISTRIBUTOR PLATE SEAL ASSEMBLY ON EAST AND WEST WALLS

FIGURE 5
BED ΔP ALONGSIDE AIR MASS FLOW AND TWO BED TEMPERATURES
FOR RUN ON 9/10TH SEPT. 1980

FIGURE 6 RUN ON 16TH SEPT. 1980, SEAL FAILURE ILLUSTRATED BY SOLIDS LOSS
PLOT OF BED PRESSURE LOSS ALONGSIDE BED TEMPERATURE AND MASS FLOW

FIGURE 8

EROSION DAMAGE TO TURBINE BANK DIRECTLY ABOVE BED FEED NOZZLE CAUSING ONE OF FIVE ERODED TUBES TO BURST.

FIGURE 9 MODIFIED DISTRIBUTOR PLATE SEAL ASSEMBLY ON NORTH AND SOUTH WALLS

FIGURE 10 MODIFIED DISTRIBUTOR PLATE SEAL ASSEMBLY ON EAST AND WEST WALLS

FIGURE 11 LOCATION OF THERMOCOUPLES ON SEALS AND COVERING PLATES

1. LOCATION ON SEALS

2. LOCATION ON COVERING PLATES

FIGURE 12

RECORD OF DISTRIBUTOR FLOW RESISTANCE

NON DESTRUCTIVE TESTERS LTD

123 Maltravers Road Sheffield S2 5AD / Telephone 0742 27317

MEFA/IAJ.

REPORT

Date 13th October, 1980

SR.4700/40

Your Order: 1555/D/32/856

Date of Test: 1-3.10.80.

Our Job No.: 4700/40

Client

Quinn Bros. Ltd.,
Midland Road,
Scunthorpe,
South Humberside, DN16 1DR.

Location of Item

c/o N.C.B.,
Grimethorpe Colliery.

Description of Item:

1. Item: Combustor Tube Banks.
3. Identification System: As shown
5. Surface Condition: No preparation.
7. Quality Code: -

2. Part of Item Tested: Small bore pipework lengths.
4. Type of Material: 15 MO3.
6. Procedure: Reference to NCB IS/QR3.
8. Inspector: D. Kerry

Nature of Test: ULTRASONIC FLAW DETECTION

Equipment: Krautkramer U.S.M.2.
Frequency: 5 MHz.
Probe Type/s: 0° Combined Doubles 5 & 10mm dia.
Ref. Block: 2-10mm flat and 2-6mm curved step wedge.
Couplant: Water paste.
Sensitivity: Full screen deflection + 4 db.

Results:

An ultrasonic thickness survey has been carried out using the above technique and the results logged in millimeters on the attached record sheets. Copies of which were left on site for onward transmission to the appropriate engineer for evaluation.

East & West Water Wall Horizontal Tubes 1-15

Each tube was checked between the vertical riser tubes, from inside the combustor. The results are shown on the attached record sheet copies.

North & South Water Wall Tubes

Each tube was examined along the full length from the East to West walls respectively. All the tube inner faces were found to be of nominal thickness of 4.5mm with plus and minus tolerance of .3mm. No record sheet was compiled of these results.

East to West Crossover Tubes of the Boiler Element Bank

Every alternative tube from 1-42 was examined along their full length and found to be of 4.5mm nominal thickness over half the circumference. No record sheet was compiled of these results.

RESULTS (Cont'd)

East Side Riser Tubes from the Bottom Header to the Distribution Plate

Tube Nos. 1-30 were examined along their full length and found to be of nominal 4.5mm thickness. No record sheet was compiled for these results.

West Side Riser Tubes from the Bottom Header to the Distribution Plate

Tube Nos. 20-35 were examined along their full length and found to be of nominal 4.5mm thickness. No record sheet was compiled of these results.

PP NON DESTRUCTIVE TESTERS LIMITED

M.E.P. ABRAHAMS,
SITE SUPERINTENDENT.

[illegible]