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**COMMISSIONING PHASE REPORT - VOLUME I
PRE-COMMISSIONING CHECKS THROUGH HOT
START-UP, SEPTEMBER 1979 - DECEMBER 1980**

By
NCB (IEA Grimethorpe) LTD.

February 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

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United States Department of Energy

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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.

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

FRG Kernforschungsanlage Jülich GmbH

USA Department of Energy

UK 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.

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NCB (IEA GRIMETHORPE) LIMITED

FLUIDISED-BED COMBUSTION PROJECT
GRIMETHORPE EXPERIMENTAL FACILITY

SECTION 1

History and Introduction

The Experimental Pressurised Fluidised-Bed Combustor has been built as an extension to the National Coal Board Power Station, which is adjacent to Grimethorpe Colliery, Yorkshire, England, and is described in this report.

The Government of the United Kingdom, the United States of America and the Federal Republic of Germany, under the auspices of the International Energy Agency, have agreed to share equally between them the costs of building and operating the plant, hereafter referred to as the Grimethorpe Experimental Facility. The Implementing Agreement, setting out the rights and responsibilities of the sponsoring Governments and laying down the rules by which the project would be conducted, was signed on 20th November, 1975 in Paris.

Control of the project was vested in an Executive Committee consisting of one representative of each Government with all decisions requiring unanimity. The actual operation of the project was vested in an Operating Agent, NCB (IEA Services) Ltd., a wholly owned subsidiary of the National Coal Board. In 1979 the function of Operating Agent was transferred to NCB (IEA Grimethorpe) Ltd., again a wholly owned subsidiary of the National Coal Board.

The broad objectives of the project were set out as follows:

1. To build a pressurised Fluidised-Bed Combustion Experimental Facility and to study combustion, heat transfer, gas clean up, corrosion and energy recovery in such a system.
2. To carry out tests over a wide range of operating conditions and to make measurements in greater detail than would be either economic or possible in a unit integrated with a gas turbine where pressure ratio, gas flow rate and combustion gas temperature are fixed within relatively narrow limits.
3. To provide data for analytical modelling of design data for larger commercial plant by empirical data extrapolation.

The Experimental Facility was to provide the means to conduct research into a number of aspects of large commercial plant, and in the immediate future, the following studies are sought;

- i) Combustor performance using high ash coal.
- ii) Effects of dolomite sorbent additives on sulphur retention.
- iii) Study of heat transfer, heat-transfer elements, materials, geometry and efficiency.
- iv) Gas clean up and dust removal prior to atmospheric discharge.
- v) Gas borne particulate erosion effects upon turbine materials.
- vi) Studies on exhaust gas driven turbines.

The range of conditions over which the Facility is required to operate is shown in Table 1 and it has been inherent in the design exercise that the Facility be flexible enough to cover this range. A schematic of the Facility is shown as Figure 1.

The Implementing Agreement lays down that the Project will be

executed in four stages:-

1. Procurement of Design Study with accompanying tender documents.
2. Tendering for construction of the Plant; study of appraisal of tenders.
3. Construction and acceptance of the Plant.
4. Operation of the Plant.

The Operating Agent, with the agreement of the Executive Committee, chose to accomplish Stage 1 by engaging design consultants who prepared tender documents which specified in broad terms the requirements for the Experimental Facility and dictated the standards to which it was to be built. Responsibility for the detailed design, however, was in all cases placed upon the successful tenderer. The tender documents for main plant items were approved by technical representatives of the Executive Committee before issue.

Stage 2 was a straight forward commercial exercise which, in the period October, 1976 to September, 1977, resulted in the placing of six major contracts for the design and construction of the Experimental Facility:-

1. Combustor and Steam/Water Circuit
2. Exhaust Gas Duct Work and Ash Extraction Systems.
3. Steam turbine driven Compressor.
4. Coal/Dolomite/Bed Material Injection Systems.
5. Fuel Preparation Plant.
6. Instrumentation and Control Equipment.

In addition to the major contracts, services were provided under a number of smaller contracts. To assist in the supervision and co-ordination of these contracts the Operating Agent, again with the agreement of the Executive Committee, engaged the services of a major United Kingdom contracting company to provide Management support to the Project throughout Stage 3.

In December, 1980 Stage 3 was approaching completion when hot start up and sixty hours of coal combustion in the pressurized fluidised-bed was successfully accomplished. This report describes in detail activities in the period September, 1979 to December, 1980 during which the various contracts were successfully integrated into systems. The various systems were then cold commissioned, the systems integrated and the whole Facility cold commissioned and finally the successful hot start up procedure developed.

In a unique Experimental Facility, setting to work is a sequence of careful steps into what is until then unknown territory. It would seem to be reasonable to suppose therefore that in the case of this facility, there is no point in attempting to write out beforehand how the commissioning will be done. On examining this Facility more closely, however, it was found that much of the plant was quite conventional and could be put to work in a pre-ordered way. Other parts of the plant, although unusual,

have elements which are conventional. The final working up of the Facility as a whole was where the experimental nature of the plant first became apparent. It was this final integration that presented the biggest challenge to the NCB (IEAG)/TWC Commissioning Team, and the management organisation adopted to overcome this formidable obstacle has, therefore, been described in some detail.

Table 1

Item	Units	First Build Tube Bank A*	"Datum"	Range
1. Air Mass Flow	kg/s	31	31	9 - 31
	lb/s	68	68	20 - 68
2. Combustor Pressure	bar	10	10	6 - 12**
	psia	145	145	87 - 175
3. Coal heat input	MW	75	87	10 - 90
	10 ⁶ Btu/h	255	297	34 - 307
4. Temperatures: Bed	°C	850	859	800 - 950***
Inlet Secondary Cyclone	°F	1560	1560	1470 - 1740
	°C	850	850	Up to 900
	°F	1560	1560	Up to 1650
5. Excess Air		27	10	10 - 100
6. Fluidising Velocity	m/s	2.5	2.5	0.75 at 9 bar
	ft/s	8.2	8.2	3.7 at 6.8 bar
				2.5 at 9 bar
				12 at 6.8 bar
7. Coal as fired_ Top size	mm	6.4	6.4	1.6 - 6.4
	inch	1/4	1/4	1/16 - 1/4
Moisture	%	3.9	Air Dried	
Ash	%	15.1	15.1	10 - 40
Sulphur	%	1.6	1.6	1 - 5
Feed Rate	kg/h	9960	11580	Up to 17,000
	lb/h	21950	25540	Up to 37,500
8. Steam Conditions: Pressure	bar	30.3	30.3	
	psia	440	440	
Temperature	°C	440	440	
	°F	824	824	
9. Emission of SO ₂	kg/GJ	1.17	0.52	0.52 max
	lb/10 ⁶ Btu	2.7	1.2	1.2 max
10. Dolomite Addition: Top Size	mm	-	6.4	1.6 - 6.4
	inch	-	1/4	1/16 - 1/4
Feed Rate	kg/h	0	1000	Up to 13,000
	lb/h	0	2200	Up to 23,000

* Ignores the effect of using Dolomite as a Sorbent

** Pressure shell shall be designed for 15 bar.

*** Combustor shall be designed for operation at 1100°C.

Table 1

Outline of Operating Parameters

NCB (IEA Grimethorpe) Ltd.,
Pressurised Fluidised Bed
Combustion Project
Grimethorpe Experimental Facility

NCB (IEA Grimethorpe) Limited
Grimethorpe, Nr. Barnsley
South Yorkshire S72 7AB

TITLE
GAS SOLIDS FLOW DIAGRAM

FIG. 1

NCB (IEA GRIMETHORPE) LIMITED

FLUIDISED BED COMBUSTION PROJECT
GRIMETHORPE EXPERIMENTAL FACILITY

SECTION 2

The Overall Commissioning Plan
and the Management Organisations

2.1

The Objectives of Cold Commissioning

To set the plant to work in a sequence that was logical so that so far as possible all services for a plant were available as each stage of testing was reached.

To demonstrate that each section of plant performed as specified and to show that it continued to run satisfactorily.

To find any limitations to performance, and where necessary, to modify so that specifications were all satisfied.

To demonstrate safe operation of plant, which satisfied statutory requirements and good practice.

To ensure that the operating staff were trained in all aspects of handling the plant, and were aware of limitations where applicable.

To record all tests and modifications arising, together with construction work outstanding at the time of Operational Handover.

The following sections describe the organisation of the cold commissioning programme designed to set to work and test each section of plant and then to integrate all sections into a working Facility exploring all process parameters short of actual coal combustion.

2.2. Method

2.2.1. Commissioning Philosophy

The Commissioning activity is the process of taking plant items that have already been constructed and partly, or completely, set to work and carrying out a series of tests that establish overall fitness for the purpose of the plant system, including the operator.

The process then continues by integrating individual plant systems into combined systems and carrying out further tests which progressively load the plant and give operational exposure over the operating range, thus establishing as far as possible, any weaknesses or shortcomings in the overall fitness for purpose.

The Commissioning activity therefore differs from the construction activity in a number of important aspects. Principally, these are the recognition that commissioning is primarily a 'Systems' orientated process as opposed to what is generally considered as an 'Area' orientated activity of construction where each area has a high degree of independence from other areas in completing the work.

The Commissioning activity has a high degree of dependance on other work and services, all of which need to be identified.

The recognition of the importance of the role of the operator and the adequacy of operating instructions is a further factor.

The Commissioning organisation for the Grimethorpe Pressurised Fluidised Bed Research Facility was set up as a joint team, consisting of NCB (IEAG) and Taylor Woodrow (as part of Taylor Woodrow's Management Support Contract), although final responsibility remained vested in NCB (IEAG).

Taylor Woodrow, through its connection with The Nuclear Power Company, arranged for a number of experienced Nuclear Power Commissioning Engineers to join the Team and the Commissioning Manager (Support) was appointed from that number.

The Commissioning Programme (Figure 2) dated 7th March, 1980, illustrates the state attained at that date, and the intentions for commissioning from that point onwards.

The Turbo Compressor re-build - following earlier failure of the HP rotor - was almost complete and the first 2 lines of the programme gives the sequence intended to run the turbo compressor. It was to run alone, and then to run to provide air to the combustor circuit for the ash quench system to run with water and without solids. After that the turbo compressor would provide air for running the booster compressor and drier for their commissioning. Finally the turbo and

booster compressors would run to the combustor for cold pressurised runs with solids.

The third line shows the ash quench system, using the Unit Control Panel 4 control station in the Central Control Room (16th line), the loop checks having been completed, starting trials without solids when turbo compressor air is available, and trials with solids when fuel injection system trials commence (line 6).

The fourth line shows that the burner compressor was already available as a service to the ash quench system for ash conveying.

The fifth line shows that the ashing compressor was available as a service to the ash quench system for vessel pressurising.

The sixth line shows the bed material system having completed some C & I checking, starting trials with solids when turbo compressor, booster compressor and drier are available for service.

The seventh line shows the Fire and Process Water being available for trials without solids of the ash quench system but whose final trials await CCR UCP5 final testing (line 17).

The eighth line shows the fuel preparation plant undergoing further trials using pseudo fuel (dolomite) when a demand existed during trials of fuel injection and ash quench systems with solids.

The ninth and tenth lines show the ash handling and dewatering plant completing preliminary trials, supplying LP and HP quench water to the ash quench system during trials without solids, and finally to be commissioned with solids arising from the trials of ash quench system with solids.

The eleventh line shows that the condensate polishing plant was already commissioned in isolation. The deaerator would be put into limited service along with the steam water circuits (line 12) and final trials would be undertaken after chemical cleaning of the boiler circuits and interconnecting steam and water pipework.

The thirteenth line shows CCR UCP1 as complete, for turbo compressor running. Modifications and testing would be done on completion of turbo compressor and booster testing, and prior to trials with solids.

The fourteenth line shows CCR UCP2 completing the testing, and having had valves repaired to be available for control of fuel injection operations (line 6).

The fifteenth line shows CCR UCP3 being used to control the deaerator and steam water circuits. Final trials will follow chemical clean.

The sixteenth line shows UCP4 having loop checks being completed, and then being used to control the ash quench system during trials without solids.

The seventeenth line shows UCP5 being rewired and tested to the extent necessary to allow ash quench, ashing compressor and fire and process water systems to run during trials without solids; and then for all testing to be complete for trials with solids.

The eighteenth line shows that Micro 'B' testing should have been complete for first runs of turbo compressor, and that Series 4 cabinets (line 19) should also be complete for them.

The twentieth and twenty first lines show that the supervisors desk should have been complete by early April, and that the Data Logger should be fully tested by early April.

The twenty second line indicates that the final integration of the Facility was to be achieved through a Safety Interlock Trip and Failure Mode Demonstration over the eight weeks following the chemical clean. This was later amplified to a sequence of 5 steps:-

- a. Safety Interlock Checks. The Main Plant interlock system will shut down the Facility when it is running, by closing the 9 coal feed line valves under the primary injection vessel, by tripping the propane burners, and by opening the steam dump valve.
- b. Simulated Start-Up on hand control. This was to be an operator training period, with plant running so far as possible, but without actual propane or coal feeding.
- c. Dynamic engagement of auto control. This was to bring in the Micro 'B' auto control systems in a progressive manner, demonstrating they could be switched in and out without causing perturbation to the running (cold) Facility.
- d. Safety Mode demonstration. The running (cold) Facility would in this test lose one supply at a time. Operator action had to be able to maintain proper safe plant conditions.
- e. Partial Hot Start-Up. The Facility was to be run to a point when a temperature of 700° C existed in the bed, and conditions were in all respects suitable for coal injection. This would be the first time that the light-up system would see propane.

The twenty third line shows that the electrical services and diesel generator trials would be complete by mid March, with final trials to be completed at chemical clean.

The twenty fourth and twenty fifth lines show the burner logic testing to be complete by the end of March, and testing with Nitrogen (as substitute for propane) during the early part of the Interlock test.

The final four lines of the programme show that the Instrument Air Compressors, the Propane Plant, The Nitrogen Plant and the Gas Oil Plant, were all available for service to other plant in the Facility.

2.2.2.

Commissioning Management

Prior to the formal creation of the Commissioning organisation considerable discussions had already taken place with the various contractors relative to the commissioning of their Plant. In some cases commissioning documents, in detailed or tentative form, already existed as a consequence of these discussions.

Due consideration was given to these and, indeed, they were a determining factor in drawing up the commissioning programme.

For each activity shown in the programme a specific commissioning document was drawn up showing the sequence as well as the contents of the required testing. It was required that each activity should be signed off as complete before proceeding to the next. All the documents generated are listed in Appendix I where the Instrument Air Compressor document is also included as a typical example.

One of the problems of the commissioning activity, is that it is at the tail end of a project programme and delays in the work preceeding commissioning or during commissioning lead to increasing pressure to shorten the commissioning programme, so as to maintain the overall project programme. Such pressures are sometimes particularly difficult to resist and it is therefore important to be able to differentiate between those activities, or states, that are essential and those which are desirable. To this end the commissioning plan must be reviewed when enough of the commissioning details are known so as to draw up a Management guideline that sets out the general principles by which the commissioning activity is to be governed.

One of the largest of the Plant Systems to be commissioned was the Turbo Compressor which is a key system and also an in-line activity which dominated combined system testing. The detailed Commissioning Document for this had already been drawn up and agreed between NCB (IEAG), TWC, the main Contractor, Compair, and their sub-contractor for the Steam Turbine, G.E.C.

The size of the plant and the supporting systems including the number of people involved in it appeared to make it an ideal area requiring Technical Management. The Production of a Technical Management Document for the Turbo Compressor identified particular principles and management guidelines that were suitable for application to the general area of commissioning, in particular combined plant operation.

Therefore, a generalised Technical Management Document was written and circulated to all relevant NCB (IEAG), TWC and Contractor personnel. This document set out the general principles of testing, the general principles of test management and the specific duties and responsibilities of the Test Managers.

Extracts from this document are reproduced in Appendix II.

Responsibility for the overall control and organisation of commissioning activities on the Facility was vested in a Commissioning Meeting. The Commissioning Meeting was a regular weekly meeting taking place, every Wednesday morning at 0900 hours.

The Meeting was to monitor commissioning progress with reference to the commissioning programme and was internal to NCB (IEA)/TWC with the option to invite other parties whose involvement might be germane to the considerations of the meeting.

The Commissioning Meeting was Chaired by a senior representative of NCB (IEAG), normally the NCB (IEAG) Project Manager, then, later, the NCB (IEAG) Operations Manager, and formal minutes were taken and subsequently issued to all members and other parties who required to be kept informed on a need to know basis. Any actions arising out of the Meeting were clearly identified and such actions were placed on named individuals, who then had the responsibility to ensure that such actions are discharged to the satisfaction of the commissioning meeting, or otherwise report progress of the action.

The meeting also needed to identify any circumstances that might pose a threat to adequate completion of the commissioning programme, in either content or timescale, and any such circumstances were highlighted for management consideration and possible action.

The institution of the weekly commissioning meeting supplemented existing management control of the Project and did not change the other duties undertaken on the Project by NCB (IEA) and TWC personnel.

The Commissioning Meeting was presented with commissioning documents, when written, for comment, discussion and when the meeting was satisfied with an individual document, it then had approved status.

The commencement of any commissioning activity under its own document required the approval of the Commissioning Meeting to ensure that all parties were aware of the implications of such commissioning activity.

The Commissioning Meeting was also required to nominate a small group of its members to tour the system about to be commissioned and satisfy itself and the meeting that this system was in a fit state to proceed with the commissioning activity. On satisfactory completion of this formal requirement approval to proceed could be given by the Meeting.

On completion of a commissioning activity a formal report was written and the system was then offered to the commissioning meeting for Hand-Over for operation to

NCB (IEAG). The Hand-Over package would include a signed-off copy of the commissioning document and all necessary certificates that constituted evidence of the completed system.

Where the system was not complete a list of Exceptions was required that identified each item that still had work outstanding.

Provided that the system was judged satisfactory for operation, Hand-Over could proceed but the work on the system that was required to bring the system to contractual completion needed to be regularly monitored by the commissioning meeting.

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FLUIDISED-BED COMBUSTION PROJECT
GRIMETHORPE EXPERIMENTAL FACILITY

SECTION 3

General Description of Commissioning Sequence.

This Report sets out to give a general description of each commissioning sequence which includes the criteria for plant acceptance.

The initial sequence was to prepare and test individual plant systems which led directly to the testing of combined plant systems on the main gas path. The two major activities relative to this initial sequence were therefore the pressure and leakage test of the combustor and exhaust gas system, including the supporting services that were required in order to carry out this activity.

Similarly the other major activity at this time was the commissioning of the Turbo Compressor in order to supply process air at conditions of up to 31 Kg/s at 12 bar and 230°C to support the next sequence of commissioning activities.

The preparation for the pressure test of the Combustor and the Exhaust Gas System, and the Turbo Compressor were parallel activities. In order to carry out the pressure test, it was first required to commission the burner air compressor which was to be used to pump up the gas circuit to the required pressure test conditions.

The burner air compressor was, therefore, commissioned under its own Document during the early part of November, 1979. The result of this testing established that the compressor delivered its design flow of 28.6 M³/min at 15 bar and functioned correctly in respect of the various alarms and trip functions. The burner air compressor underwent a 72 hour endurance run which was satisfactorily completed on the 20th November, 1979, and then submitted for Hand-Over. There were a number of areas of work which were not contractually complete but the plant was accepted as being in a fit state for operational Hand-Over generally and particularly to support the combustor and exhaust gas commissioning activity.

The principal area of outstanding work on the burner air compressor was to make the extent of instrumentation to comply with NCB Standards.

The instrument air compressors, which were required to support the Turbo Compressor Testing were commissioned, and achieved a 72 hour run in late November. Although not a complete system at this time it was deemed more than adequate to meet the site demands for this instrument air supporting other plant.

Similarly fire and process water was also part of the state of plant for Turbo Compressor Testing and commissioning, was carried out in order to ensure that adequate supplies of fire and process water were available, particularly relative to the turbo compressor area, where each hose point was tested at the point of use by squirting the fire water out of the nearest exit from the facility. This availability test of fire and process water was carried out frequently throughout the period of Turbo Compressor Testing.

The auxiliary steam supply was also instituted at this time to supply steam to the various heaters inside the Facility and other plant areas, for example, the propane vaporisers, the nitrogen vaporisers and the inlet air filter of the turbo compressor. This last item was a requirement of the state of plant for the turbo compressor testing.

The heating and ventilation system commissioning was also in progress at this time, providing space heating of office accommodation in the Facility Block, domestic hot water and control room air conditioning.

The requirements set out in these documents were subsequently met and both systems were handed over in late January.

By November 29th, 1979, the turbo compressor was ready to carry out the first step in its commissioning of running the turbine uncoupled from the compressor as a purely mechanical run of the G.E.C. Turbine, to establish that the turbine and ancillaries were in a fit state that would allow running with the turbine coupled to the compressor train. By the early part of December the turbo compressor had entered the coupled running phase. This entailed carrying out a number of runs at different speeds and inlet guide vane positions to give an early overall feel for performance and general mechanical integrity.

The air flow from the turbo compressor was exhausted to atmosphere through its own blow off valve with the main process air line to the combustor being spaded off. The booster compressor was also spaded off on the air side during this initial Testing of the turbo compressor.

On the 7th December, 1979, the turbo compressor was shut down in an emergency when a lot of smoke and a small fire appeared in the vicinity of the HP compressor casing drive-end bearing. Subsequent examination of the internals of the HP compressor showed considerable damage of the shaft and seals. The shaft rotor assembly was removed and sent back to the contractor's works at Ipswich, Suffolk. The turbo compressor did not then run again until 18th March, 1980, while awaiting a new shaft for the rotor assembly.

The combustor and exhaust gas pressure test was initially instituted at a low pressure of 5 p.s.i.g. on the 11th December, 1979, and on the 14th December, 1979, a formal test was instituted and additionally witnessed by representatives of Cornhill Insurance. The area under pneumatic pressure test included the combustor, heat exchanger, primary and secondary cyclones, primary and secondary scrubber vessels, ash quench vessel, ash transfer vessel, together with connecting pipework, connecting LT ductwork and connecting HT ductwork.

The final test at nominally 13 Bar on the 16th December, 1979, was witnessed by NCB (IEA) Services, D.I.P.E.D., T.W.C., and Cornhill, and a number of leaks were revealed. The conclusion at this time was that the system was not yet satisfactory and remedial work to cure leaks was instituted.

Further testing was carried out from the 11th to the 13th January, 1980, witnessed by the same representatives as previously. The criteria of acceptance was by soap bubble leakage and any noise made by the leak and the extent of the leak. A check of overall leak tightness of the circuit under test was carried out by stopping the burner compressor and observing the fall of pressure which, in fact, did not fall at all in half an hour.

The Commissioning Meeting noted that the test was completed successfully.

The failure of the turbo compressor constituted a major interruption to the commissioning sequence which resulted in at least two months delay before this sequence could be resumed.

During this delay to the main line sequence of commissioning plant systems that could be commissioned, or part commissioned in the absence of process air, were continued.

The Bed Ash Conveying and Quench System started its cold commissioning trials, by using the burner compressor to pressurise the combustor and cyclones instead of process air from the turbo compressor.

The ashing compressor was commissioned disconnected from the Facility gas path and exhausted to atmosphere by temporary pipework. Mechanical integrity, tripping functions and performance were all demonstrated including a seventy two hour endurance run. (The ashing compressor capability is so great compared to system demand that it spends most of its time when running in blow off mode and was subsequently connected to the burner air compressor air receiver in order to more usefully use its capability).

The commissioning of the fire and process water system was completed and handed over in late January, 1980.

Similarly the commissioning of the instrument air compressors was completed, exhausting to atmosphere. The performance and flow was tested to establish that it met the specified duty and showed that the plant capability was well in excess of system demand. Hand-Over was initiated in early February, 1980.

Also during January, 1980, an attempt was made to commission the Nitrogen Plant, and carry out flow tests. The outcome of this testing showed that pressure drops down the nitrogen supply lines were too great and the plant would be unable to meet its specified duty.

The supplier of this plant, Air Products, were therefore required to carry out major modifications to their plant which was principally the removal of two inch copper pipework and replacing with four inch stainless steel pipework.

The vaporiser steam bundles of both vaporisers developed tube failures and appeared to be a basic design type-fault. The supplier was therefore required to supply a new design of steam bundle and replace the existing steam bundle and carry out a further performance test. This plant was therefore subject to some delay before commissioning could restart.

The next sequence of commissioning centred on the rebuild and test completion of the turbo compressor which would then allow testing to proceed on the main gas path. This, in turn, would lead directly to trials with solids of the bed material and fuel injection systems, injecting pseudo fuel (Power Station ash) and also to operational exposure of the main gas path.

The ash quench and fuel preparation plants were therefore high priority items along with control room instrumentation and controls for controlling conditions of the main gas path. It was also highly desirable to bring the steam/water feed system into operation to remove heat from the circuit and allow operational exposure of this system before it became a critical item in the programme leading to hot start up.

The fuel preparation plant, carried out a seven hour run at nominally seven tonnes an hour in late February and was put forward for operational Hand-Over. This plant was subsequently required to process forty tonnes of Power Station ash to make the pseudo fuel for the system cold commissioning trials.

The turbo compressor with its new HP compressor shaft was rebuilt and ran again on the 18th March, 1980. On the 20th March the turbo compressor was put on the main gas path through the combustor and exhaust gas system.

The steam/water system, was put into service and circulation was established allowing testing of auto controls to proceed along with checks of system pressure and pressure drops.

The condensate polishing plant was also in service in isolation from the main system, and auto regeneration was established allowing this system to go forward for Hand-Over. Final proving of the overall system must wait until steam can be generated during Hot Start-Up.

The Bed Ash Conveying and Quench System, continued its commissioning using process air from the Turbo Compressor. While the Ash Dewatering and Water Treatment commissioning proceeded, the final testing of Ash Dewatering required solids and therefore awaited the next sequence of commissioning, i.e. cold pressurised runs with solids.

The running and proving of the Turbo Compressor proceeded through the rest of March. The problem with the turbo compressor was established as being the phenomenon of oil whirl and the solution to the problem was a new offset bearing design which gave improved stability to the bearing oil film.

These new bearings were fitted to the turbo compressor on 18th April, 1980, but there were still problems of the shrunk fit of the rotors causing movement and out of balance of the assembly.

All these matters were satisfactorily resolved and full performance measurements were carried out on the turbo compressor, thus establishing that the design contractual requirements were all met.

All the testing required, was completed with the exception of the GEC Turbine performance run which was waived by NCB (IEAG). Thus, by the end of May, 1980, the turbo compressor was ready for Hand-Over.

During this period of running the turbo compressor on the main gas path, a great deal of other work was in progress on other systems. The Booster Compressor and Pall Drier that provide the dry conveying air flow for bed material and fuel injection systems also entered its running commissioning phase, but encountered problems that prevented the compressor running at anything other than low speed and was therefore unsatisfactory. In order to allow bed material and fuel feed to proceed, the Booster Compressor was by-passed by putting a return bend between the compressor precooler outlet and after cooler inlet. This allowed process air to pass directly to the fuel feed system while the problems of the Booster Compressor were being resolved by the Contractor, Cryostar. The Pall Drier was satisfactorily tested during this phase of commissioning.

The gas path safety relief valves were tested in turn, one of which was found to be faulty and was corrected and subsequently retested. The individual test of each valve with the others gagged was satisfactorily concluded for a relief setting of 13.2 Bar. Finally, all valves were ungagged and a further test carried out which established that two combustor relief valves lifted in this total system test.

The Propane Plant commissioning, was in progress but required modification to vaporiser controls and remote plant controls.

The general activity of commissioning control systems was also proceeding and the operational exposure of Plant on the main gas path had drawn attention to a number of points relative to control and instrumentation.

Both the process air valve and the Freeboard Pressure Control Valves required the addition of retransmission systems. The existing system only gave the valve position demanded by the operator but did not indicate the actual position of the valve after the demand had been made. This led to operational difficulties in setting up plant conditions, particularly when valves stuck for any reason.

Although a considerable amount of instrumentation was in service there was still a great deal of work involved in final calibration, correcting mis-scaling and generally bringing control and instrumentation to a satisfactory operational level that would allow confident operation by the operator in the control room.

This particularly applied to the Micro 'B' which due to design faults became particularly delayed in respect of its commissioning and attempts to carry out work on it, in parallel with running the turbo compressor on the main path, caused unexpected plant excursions. This caused the turbo compressor to surge on several occasions, when the Micro 'B' mal operated and caused automatic closing of the process air valve.

At the end of May, 1980, the next sequence of commissioning with solids began. The material to be injected was Power Station ash of the same size as normal fuel and had been chosen because it was inert and its lower specific gravity allowed simulation of fluidisation characteristics for the gas temperature of nominally 150°C that would apply to this period of testing.

The initial commissioning of the Fuel and Bed Materials Injection Plant had been conducted and testing with solids, together with the Ash Dewatering, and Ash Conveying and Quench systems required the testing with solids to complete their testing.

The fuel preparation plant had prepared twenty tons of ash which had to be put through a second time due to high moisture. Nitrogen supplies were made available to the fuel feed storage injector and Bed Material filling hopper, and Hand-Over of the Nitrogen System was in progress.

The Booster Compressor still awaited design modification and the conveying air flow was provided by the by-pass scheme mentioned earlier for this period of testing. The turbo compressor was by now operational and handed over to NCB (IEAG).

The steam/water system was in operation, and the condensate polishing plant was being operated in isolation. Both of these Systems had now reached the stage of operational Hand-Over.

The burner air compressor was in service supplying cooling air to the burners and the aching compressor was available for operation to support the ash transfer system.

During the 29th/30th May, 1980, the cold pressurised runs with solids got under way and numerous teething troubles became apparent. The Power Station No. 2 Boiler providing steam for the turbo compressor had to be taken off line due to a collapsed ignition arch and was replaced by No. 4 Boiler.

The condensate return pumps would not start in remote one position and the clean drains pump had problems of air in the suction.

The fuel preparation plant was having problems with the Process Logic Controller and the gas-oil fired drier experienced repeated flame failure.

The burner air compressor receiver inexplicably lost its pressure and precipitated a search for an unknown user of burner air.

On resolution of these problems, fuel injection got under way and a bed was established in the combustor with 6.4 tonnes injected. The ash removal system was unable to remove this ash due to blockages in the ash transfer line to the ash quench vessel. The bed was subsequently extracted and by the bed material extraction system. This testing continued to the 3rd June, 1980, when whilst testing was in progress, it was realised that substantial water ingress into the combustor had taken place. The conclusion was that by some unknown mechanism the primary cyclone quench system had pumped water back into the combustor.

The process of draining the water out of the combustor and drying out the system was begun. Entry to the combustor was obtained and advantage was taken of this entry to start checking out the propane burner spark ignition system by observing the spark at the burner tips. Water samples were taken from the combustor and other water systems for analysis and by comparison confirm the origin of the water in the combustor.

The combustor was then boxed up again and a dry out was carried out by running the turbo compressor continuously for 48 hours driving warm air through the Plant, and all systems were then brought back into operation. The fuel injection trials continued until number nine line flexible hose burst releasing a large cloud of dust. The Facility was cleared of all personnel, and number nine line isolated; fuel injection continued but was subject to lines blocking up.

At this stage in the testing it had been shown that modifications were required to the fuel feed system which included replacing all flexible hoses by steel pipes due to the high degree of wear induced by impingement of fuel on the rubber pipes. The feed rate was only of the order of 2.2 tonnes/hour compared with design of 3.2 tonnes/hour. Pipework also needed to be straightened out by removal of bends to solve problems of plugging.

The Ash Transfer System Testing had also identified problems in that the level controls of the quench and blow down vessels were subject to malfunction. The cause was identified as magnetic particles in the sludge attaching themselves to the magnet of the level control probes. The cure was simply to clean off the debris but this required vessel entry involving plant shut down. For the future, water jets will be installed to keep the sludge off the probes.

Low rates of discharge through the bed ash conveying vessel pointed to blockages of the outlet nozzle. When entry was gained the nozzle was found to be blocked by "scabbling" bits used for concrete floor preparation.

Further testing led to further entries into the vessel when pieces of aluminium and rubber were discovered blocking the nozzle. A debris screen was introduced to prevent blockage but smaller debris was still blocking the nozzle. A modified screen is proposed to cure this problem.

By the 16th June, the Booster Compressor had been rebuilt with modified turbine and guide vane assembly but even so re-testing still failed to give adequate performance. The site believed that there was some peculiar aerodynamic effect taking place just upstream of the booster drive turbine. In order to prove this point a small test rig was built, where the whole of the turbine inlet pipe, plus its filter and fast-acting solenoid air operated valve was flow tested, using air from the instrument air compressor. The problem was established as being poor flow conditions at the contractor's fast-acting butterfly valve. A new valve of six inch size was ordered to replace the four inch butterfly valve and the pipework size increased to six inch to accommodate the new valve.

The commissioning sequence, therefore, continued as before by reverting to the booster compressor by-pass scheme to complete this particular sequence of testing. By the 22nd June, the plant was shut down in order to carry out the acid clean of the feed system over the next two weeks using hydrofluoric acid. Although this was a delayed construction activity, it is mentioned here since it did provide a natural break in the general sequence of commissioning.

The next sequence of testing was primarily concerned with plant system safety testing, under Document No. 25, which was in several parts:-

- Part (I) The overall testing of the safety interlocking system.
- Part (II) The overall operation of the Facility under manual control simulating Start-Up following the auto controls logic sequence.
- Part (III) Dynamic engagement of automatic control systems.
- Part (IV) Plant failure mode demonstrations.
- Part (V) Partial Hot Start-Up.

The overall intention of this series of tests was to establish as far as possible that:-

- (a) The total system was in a proper state, and safe to take into the Hot Start-Up sequence.
- (b) The operating instructions were adequate and both understood and capable of being carried out by the operator.

- (c) Under fault conditions of the plant, the operators had sufficient understanding of the plant to be able to deal with the situation safely, or alternatively, identify potential hazards before Hot Start-Up.

Other areas of work were also pursued at this time, which included completion of outstanding work on plant that had already experienced operational exposure where deficiencies had been found and rectification needed.

During early July, the plant was put back in service and set up for Document No. 25 (Part I) Safety Interlock Testing. Each plant area was visited in turn according to the Document and the trip initiating device was operated to bring about the operation of the interlock system. The Safety Interlock System then went through its own shut-down sequence until all the testing that could be done was completed.

There were areas where full testing could not be done at this time due to the non availability of equipment. Further testing was therefore deferred for completion at a later date.

By July 21st, 1980, Document No. 25 (Part II) Testing was underway, and the required state of Plant was achieved.

The turbo compressor was brought on line to the required facility start-up condition of 18 Kg/s at 8.5 Bar at the turbo compressor outlet with the IGV's set at 60° and the blow off valve on automatic. The pressure of the turbo compressor outlet pressure was then controlled and set by operation of the process air valve. The conditions in the combustor were then set by the position of the freeboard pressure control valve to give 2 Bar pressure and nominally 150°C.

The operations group were then required to follow the operations called up in Document No. 25 (Part II) through the various phases of Start-Up but not introducing propane or coal. This procedure was completed and then repeated with different control room operators to ensure that this operational experience was well distributed through the operating staff, and also to refine operating techniques. The outcome of this testing brought to light a number of points which resulted in a change of some of the details of the Start-Up Procedure.

The changes centred mainly on the allowable peak value of fluidising velocity.

The first issue of Document No. 25 (Part II) identified the peak fluidising velocity which was at the initial fuel firing point at 850°C as being 5.2 m/s. This value was derived from C.U.R.L. predictions of some antiquity and was by now considered high for stable fluidisation with the particle sizes in use. Experience during the C.U.R.L. link test confirmed this contention. It was also postulated that fluidising velocities in excess of 5 m/s could produce excessive erosion

and/or undesirable vibration effect in an in-bed Tube Bank designed for a fluidising velocity of 2.5 m/s.

The operating parameters were, therefore, adjusted to limit fluidising velocity to 3 m/s or below. The ramp reduction in mass flow through the propane phase and the ramp increase in mass flow and pressure through the coaling phase of Start-Up were therefore also required to be adjusted. Further testing was then carried out under a re-issue of Document No. 25 (Part II) that set out the new operating conditions. This part was then completed by late July, 1980. Actual experience of Hot Start-Up using propane, conducted with the advice of C.U.R.L., demonstrated that fluidising velocities could and should be restrained between 1.5 and 2.0 m/s in order to promote a smooth and reasonably rapid rise in bed temperature.

It had been intended to carry on with the engagement of the auto controls dynamic testing under Document No. 25 (Part III) but, unfortunately, the necessary work to allow this testing was incomplete particularly in respect of the reliability of Micro 'B'. This testing was therefore deferred until some later date.

The Booster Compressor had, by this time, been reinstated with its new six inch valve and associated pipework to the Booster air turbine. This plant system was therefore put forward for its commissioning trials and this time ran successfully to complete all the documented testing, including inter-action surge tests on turbo and booster, and was accepted for Hand-Over.

Document No. 25 (Part IV) Plant Failure Mode Demonstration was then carried out during the first week in August, 1980. Various system failures were introduced, i.e. Instrument Air, Nitrogen Plant, Ashing Compressor, Main Boiler Feed Pump. Loss of Control of Free-Board Pressure Control Valve, Slow Loss of Steam to Turbo Compressor, Fast Failure of Turbo Compressor, Turbo Trip with Booster and Diluter Lines Open.

There were other tests that still remained to be done on this Document at this time along with further tests of the interlock system.

In early August, 1980, the commissioning sequence moved into the trials of the propane burners. In order to assist this process, No. 3 Burner was removed and a window was substituted to allow observation of the flame of No. 1 Burner and the fluidised bed condition.

After checking the main plant building for any signs of propane leakage, the first attempt was made to ignite the freeboard burner but without success. Several other attempts were made but, in the end, the logic sequence was defeated to allow propane light up on the four main premixed burners. No. 1 premixed burner was lit but attempts to light other burners failed. Consideration of this experience raised several points. The spark ignition seemed

poor and was thought to be due to a number of causes, i.e. incorrect gaps on ionisation and ignition sparks, wrong positioning of electrodes, premix air/fuel ratio incorrect.

Advice from C.U.R.L. indicated that the free-board burner could represent a potential hazard and was therefore taken out of the light up logic sequence as part of a complete rethink of the proposed Hot Start-Up sequence.

A plug-in test box had been used to allow the burner logic to be checked out independently of the rest of the main plant. The test box also allowed burner simulation and by-passing of faulty flow switches.

Burner Trials continued and by the 10th August, 1980, with a bed established of 1.2 tonnes in the combustor light up on propane progressed to a stage where bottom burners were brought on, temperatures were rising and bed depth was increased. The process air mass flow was lowered to further increase temperature which precipitated a low mass flow safety interlock trip.

It was now quite late at night when the bed was extracted and the plant shut-down at 22.40 hours.

The window in the combustor was removed and No. 3 burner was reinstated. Further trials were more successful but several trips occurred due to the activation of the 'propane in exhaust gas high' trip. Further adjustments were made and the best combustor operating pressure of 1.8 bar was established allowing a reasonable light up on propane for a process air mass flow ramp down of 10 Kg/s to 6 Kg/s and bed temperature was flattened out to give a reasonable distribution of temperature throughout the dolomite bed by adjustment of individual burner flows. The Facility was now deemed ready to enter the Hot Start-Up sequence introducing coal for the first time.

The first run attempting Hot Start-Up on coal was on September 9th 1980, and by the following day subsequently achieved conditions of nominally 700°C on propane with a dolomite bed established.

Coal feed was then initiated at approximately half a tonne an hour on line No. 5, while propane flow was reduced to give a bed temperature of 850°C. Coal lines were progressively introduced and propane progressively reduced while bed material was being fed into the combustor at 1800 Kg/hr. The bed temperature rose to over a 1000°C at this stage and the plant was shut down.

A review of data and observations collected from this run strongly suggested that rapid elutriation of the bed had taken place and on this basis the dolomite was to be replaced with molochite on design advice.

Combustor entry was obtained at this time which brought to light evidence of large quantities of dolomite lying below the distributor plate. This material was removed and a further test was carried out using the new bed material, molochite, on the 16th September, 1980.

Propane was established and bed material was injected at nominally two tonnes per hour. The ramp down in air flow at constant combustor pressure of 1.8 bar, was started in order to bring the bed temperature to the desired value of 700°C, as given by the average of the 18 distributor plate thermocouples. The conditions in the combustor were then adjusted by introducing a small pressure ramp from 1.8 bar to 2.2 bar which subsequently reached 2.6 bar to give 6 Kg/s of process air flow at 700°C and 1.6 m/s fluidising velocity. At this point bed level began to fall off rapidly and the combustor exhibited similar symptoms to the previous run and the run was therefore halted at this point.

The combustor was later entered and a considerable quantity of molochite was found underneath the distributor plate. The distributor plate seals, which are in several sections, had sections removed. The sections showed evidence of discolouration due to heat and had lost their flexibility and sealing capability. A new set of seals were installed and the whole of the North/South waterwalls had backing plates to increase the sealing.

A test under cold conditions was then carried out which injected 4.8 tonnes of molochite and approximately 3.5 tonnes of molochite were recovered from the bed. An assessment suggested that since there was a certain amount of molochite in the ash legs and some elutriation had taken place that very little had passed the new seals. A further run on coal was therefore instituted on the 23rd September, 1980. During this run the bed was brought up to nominally 550°C through the propane phase. At this point the combustor bed was deluged by water from a ruptured pipe in the bed tube bank. This rupture was later established as being due to erosion of the tube bank by material exiting from the bed material injector. Erosion damage was also found on the lower rows of the East and West waterwalls tubes. The plant was therefore subject to considerable down-time whilst modifications were made which continued on into mid November.

The impact of these experiences on Hot Start-Up Procedures is detailed in Section 5.

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NCB (IEA GRIMETHORPE) LIMITED

FLUIDISED BED COMBUSTION PROJECT
GRIMETHORPE EXPERIMENTAL FACILITY

SECTION 4

Reports of Cold Commissioning Activities

4.1

Condensate Polishing Plant

The plant consists of a twin tower mixed bed unit, each tower filled with a mixture of anion and cation exchange resins. As condensate is passed through a vessel, all metal ions are exchanged for hydrogen at the anion resins, and acid radical ions are exchanged for hydroxyl ions at the cation resins.

A vessel remains in service, at a throughput of 20 Kg/sec, until onset of bed exhaustion is detected at the silica probe by a rise of conductivity towards $1\text{ }\mu\text{S/cm}$. The other vessel is then automatically put into service. Regeneration of the exhausted bed is then initiated when desired, and proceeds automatically or manually.

The quality of the water produced by a regenerated bed is a function of the quality of the rinse water used during regeneration. The time a vessel continues in service is a function of the quality of the incoming condensate from evaporators and of the dosing regime.

The plant was put into service after a number of wiring changes and improvement. No problems were found with the plant itself.

The RFW Tank had a long history of 'leaks, aggravated by hot condensate and on one occasion the ingress of steam through an overflow pipe. The tank has now been lined with fibreglass and epoxy resin, with some success.

The effluent pump could be overloaded as first built; throttling in the discharge valve was not successful, but an orifice plate in the line brought the pump back to the design point. A valved branch was put at this pump's discharge so that discharge to tanker was also available.

The reagent unloading points for acid and alkali barrels are in a common bund. In the interests of safety a fence was put in to separate the two pumps, and different coloured tiles were used, to attempt to prevent one chemical being unloaded into the other bulk tank. The sump of this bund was provided with a hand operated sump pump.

4.2. Steam and Water Circuit

Feedwater from Boiler Feed pumps flows first to the Heat Exchanger water walls, then partially bypasses the Heat Exchanger economiser and flows to the Combustor water walls. At the exit it divides 3 ways to

1. Combustor bed Evaporator coils.
2. Auxiliary heat exchanger.
3. Heat exchanger Evaporator coils.

These are all evaporators, and the flow through each is controlled by a temperature controller. The resulting steam flows recombine and from the joint flow, it again divides 3 ways to:-

- a. Broeker line to start up vessel
- b. Combustor freeboard cooler and bypassing to
- c. Heat exchanger upper tube bank which is the final superheater

The Broeker line is used during the early stages of start-up and automatically comes into use on a Main Plant Interlock trip. The steam leaving the final superheater stage is admitted via the main steam header to the Power Station and to the Turbo Compressor. There is also a line to discharge steam to the start up vessel through an attemporator.

From the start up vessel steam flows to a converted Turbo Alternator condenser (dump condenser) and the resulting condensate is pumped into the condensate header. Condensate from the start up vessel is pumped to the condensate storage tank, to which also the extraction pumps send condensate from the turbo compressor condenser. From the condensate storage tank, condensate flows through a cooler to pumps which deliver through the 100% duty twintower mixed bed exchanger polishing plant to the deaerator. The deaerator can be topped up from the power station condensate system via transfer pumps, and in an emergency a reserve feed tank and pump provide a shutting down standby supply. The deaerator operates by steamheating suction sides of the 3 main and 1 emergency feed pumps. The water is dosed at entry to deaerator (O_2) and at entry to feed pumps (pH).

Water flow for steam generation is designed to be 16/kg/sec through the Combustor and 6 kg/sec through the Heat Exchanger, with a Steam Pressure of 28 Bar at the Superheater Outlet. Each of the three main boiler-feed pumps is capable of delivering 16kg/sec and the 4th (emergency) pump has a design output of 7.4kg/sec.

All pumps have been run for extended periods, and although individual pump characteristics have not been measured, each has been shown to be capable of performing the duty required, without any having failed. The characteristic curve as tested by the makers, along with all the relevant data is available in the V.K.W. Operating Instructions (Part 4).

Initial runs were made with the object of establishing a regular flow through the system, and it was at this stage that Hydrazine and Sodium Triphosphate were introduced in order to maintain low O_2 levels and a basic pH.

However, this was proving very wasteful of Hydrazine, for the water tender to disappear overnight on many occasions, and fresh condensate and fresh dosing was required to maintain operating levels.

It was then decided to introduce a "steam blanket" over the water in the Deaerator and Hotwell. Whilst attempting to introduce the steam into the circuit, steam was twice inadvertently admitted to the RFW tank. Ultimately this was traced to the interconnection of the clean drains and a faulty pressure gauge, and the mechanically weighted safety limit valve was also incorrectly adjusted on the Hotwell, which allowed excess pressurisation thus blowing out the syphon. To help obviate this problem in future, a barometric loop was also fitted to the RFW tank at this stage.

Checks of water pH and Hydrazine content were being made at approximately weekly intervals, both before and after steam blanketing. This water was also seen to have a lot of solid material in suspension. Whether this came from the steam/water circuit or was introduced from the Power Station Surge Tanks was impossible to determine. However, after several drainings of the system and re-filling, the water clarity gradually improved. Subsequent to "acid clean" and a further few changes, the water now seems to be remaining clear.

VKW were of the opinion that future dosing should be with Ammonia for pH control and Hydrazine for O_2 content. The dosing pumps were set to work and are now being used regularly. It was necessary to move the pH dosing inlet to the common point on the bunker face pump Suction Mains.

Although no steam has yet been generated within the Facility, the complete circuit (other than the Auxiliary HE) has been kept water filled and water circulated as a normal operation. Pressures and flows being established and maintained automatically with the installed equipment, all the operations required being controllable from the the Control Room, other than operation of the venting and draining valves.

Setting of all safety valves, other than that on the shell of the Deaerator have been completed. However, the main steam safety valves on the Heat Exchanger have yet to be re-checked on steam, being set with water only.

With the exception of the oil ingress problem on the boiler feed pump motors, the pumps have performed well over many hours running, providing capable of delivering enough water for full circulation at pressure throughout the system.

Initial introduction of steam into Deaerator requires some care in order to avoid excessive "banging" and vibration. This was best achieved by having not more than 1 metre water in the vessel and introducing steam at about 5% valve opening and with spray valve controlling temperature to about 180°C.

4.3

Nitrogen Store and System

Two vertical cryogenic tanks contain liquid Nitrogen at $18\frac{1}{2}$ Bar. The liquid flows through one of a pair of vaporisers fed by aux. steam, and on to the supply main. Near the Facility some gas is taken through a control valve into the buffer vessel, at a pressure equal to a set 2 Bar above combustor, and this is used as motive force for fuel feeding. The main also provides nitrogen through a regulator for fuel preparation plant blanketting, and to a large number of smaller users including pressure probes and other instrumentation and the cascade bleed.

The first specification was that with one vaporiser in use - the other being the 100% standby - 5.65 tonnes/hr of nitrogen gas at 15°C is to be available at the Facility, at a receiving end pressure of 15 Bar G. The contractors' offer was for a flow rate of 5.14 tonnes/hr at a temperature of 35°C and a pressure of 15 Bar G at the nitrogen store outlet flange, and this is what was to be supplied.

On testing by blow off to atmosphere at the Facility, the pressure drop through the pipework local to the vaporisers was shown to be unacceptably high - less than 5 tonnes/hr was delivered, with a receiving end pressure of 9 Bar G. The performing rating of the vaporisers themselves was also less than that specified. The pressure drop through the main was a small part of the total pressure drop.

After the interconnecting pipework had been re-designed with a greater diameter and fewer bends, one vaporiser steam bundle failed, by corrosion at the air/water interface. It was repaired, and a replacement to improved corrosion resisting design and higher rating was put in hand.

When the new pipework was complete, a further blow to atmosphere was undertaken, with the original style vaporiser tube bundle. This test showed that the sustained output of the vaporisers was 4.1 ton/hr, and that the pressure drops at a flow of 5.65 ton/hr were low enough to give rated pressure at the Facility.

The MK.II tube bundle was installed, and another flow test was performed. This time the flow rate was a sustained 5.14 ton/hr, with correct temperature and pressure. The other vaporiser MK.II tube bundle still has to be delivered and installed.

Remote controls and alarms from CCR are not yet installed or tested. The booster (tanker unloading) pump has not yet been delivered from contractor.

4.4

Propane Plant

An underground tank contains 30 tonnes of liquid propane at about 4 Bar pressure. Liquid is drawn up through a dip tube by one of two 100% duty nitrogen driven positive displacement pumps. Liquid propane is delivered to the vaporiser associated with the pump, where a steam tube bundle boils the liquid. The gas passes down the main to the Facility and is used to light the system.

Controls were found to be unreliable; a considerable amount of re-design has resulted in a safe series of controls:-

- a. The steam supply to the vaporiser is controlled by the temperature of propane at the outlet. The steam control valve proved undersized but even when correctly sized quite wide fluctuations in propane pressure are experienced. An attempt to control the steam supply by the propane pressure at outlet was unsuccessful.
- b. The lower level float switch closes the propane gas outlet valve.
- c. The upper level float switch stops the liquid propane pump.

Performance of the plant has been demonstrated in two ways:- Firstly, a flare stack was set up, and gas production rates of 120 kg/hr were reached. Secondly, whilst lighting up the Facility, production rates of 600 kg/hr have so far been attained, which was the flow rate called for at that time. The specification calls for 720 kg/hr, and there is no reason to suppose this cannot be fulfilled.

4.5

Gas Oil Store and System

Two 100% duty positive displacement electric pumps draw from either of the 20,000 litre storage tanks, and deliver by deadleg and reducing valve to the fuel prep plant Rosin drier.

The pump delivery rates were established by diverting oil flow into a measuring vessel. The rate for each pump was 25% more than the specified 1000 litres per hour.

It was pointed out at this time that the deadleg system produced a more variable pressure at the delivery point (both transient and steady state) than was necessary - a full recirculation system was advocated.

Testing was done to demonstrate this and the recirculation modification was made.

On two occasions it was found that a pump seal was drawing air into the oil. Apart from renewing the pump seal, an air separation vessel was put into the recirculation system at the offtake to the drier.

Owing to troubles with the drier, it was decided to put a head tank on the oil system between pump and drier. Some small improvement can be expected from this, if recirculation continues.

At the time of writing the remote controls have still to be tested.

4.6

Fuel and Bed Materials Injection Systems

The fuel injection system comprises 3 lock hoppers in series; coal (with dolomite) is delivered into the surge vessel at atmospheric pressure, and the nitrogen in which it was entrained is then returned to the fuel prep plant. The next vessel is the storage injector- it is depressurised, the interconnecting valve opened, then closed by weight control, and the pressure brought up to match the primary injector. When the primary injector is at the low weight setting, the interconnecting valve is opened, and closed when storage injector is empty. The pressure in the primary injector is maintained at a set differential above that of the combustor, by nitrogen which is fed into the 9 fluidising cones at the base, to which the coal feed lines are connected via mix tees.

A conveying air supply from the turbo compressor is boosted to a preset differential at the booster compressor, and dried. 9 controllers deliver the conveying air to the coal feed lines, and take the coal to the nozzles above the distributor plate at the base of the combustor. Sample pots and valves enable coal samples to be taken at the point of entry.

The bed material system consists of a single injector vessel, loaded by a removable hopper, and pressurised by nitrogen. A single line feeds into a stream of conveying air, and on to a nozzle in the distribution plate. A return line brings bed material out of the combustor back to the top of the bed material injector vessel.

The logic of the controls to all valves, weight sensing etc., was checked through.

The weight sensing systems were calibrated, and some mechanical modifications were necessary to obviate hysteresis.

With combustor air flow established, and combustor pressure at 3 Bar G, the bed material system was proved to be capable of supplying, and removing material at above the specified 2 tonnes/hr. In fact the actual flow rates as high as 4 tonnes/hr (delivery) and 8 tonnes/hr (removal) have been indicated.

Several runs with pseudo-fuel were made on the fuel injection system, the pseudo-fuel being crushed refractory of density similar to coal with dolomite. A single line flow rate of about 2.2 tonnes/hr was attained, compared with 3.2 tonnes/hr. specified. Due to lines becoming blocked, the specified 16.1 tonnes/hr total through 9 lines was not attained either. A re-design of one line is now awaiting trial - it uses larger section pipe, and 2 x 90° bends have been replaced by 4 x 45° bends.

The short rubber hoses downstream of mixing tees were replaced with steel pipes.

On shutting down the fuel injection system, ash falls down into the last vertical 5½ metre length of each coal injection pipe, and the weight is too great for the normal differential to shift. Temporarily a nitrogen purge has been set up to keep lines clear until the bed has slumped or been extracted. It is suggested that the final valve on each line should be shifted up to immediately under the combustor to avoid this problem and to give other benefits. It is also suggested that a spectacle plate be inserted in each fuel line and the bed material line so individual lines can be blanked off and cleaned while the combustor remains in service if necessary.

Some error is introduced in the indicated weight of the storage injector owing to gas weight not being compensated for by the same method as the primary injector.

The vibrator at exit from surge bin was controlled from the Fuel Preparation Plant. It is intended that this shall be controlled from CCR.

If a conveying air valve is closed, the corresponding coal valve is automatically closed. However, if the flow of air is diminished at the flow controller, no closure of coal valve is instigated. It is suggested the flow controllers should be included in the interlock system.

The flow of nitrogen into the primary injector is controlled to a set differential above combustor - this setting determines the coal flow rate. If the combustor pressure rises, this differential will be maintained. If, however, the pressure in the combustor falls, no large fall in injector pressure is possible, and so the coal feed rate will increase and plug the lines. It is suggested that a vent valve be coupled into the differential pressure control system.

The conveying air is delivered to the mixed tees under the primary injector by non-return valves (to prevent hot combustor gases going back up the line) and by rubber hoses. If in service a hose should rupture, conveying air will continue to flow from supply end, and hot ash will flow back from combustor and into the atmosphere at the point of rupture. It is, therefore, suggested that the non-return valves be repositioned at the mixed tee end of the hoses, so the rupture will only cause air to escape. The use of rubber hose is suspect, and a steel pipe could be substituted instead.

The flow rate of material from surge bin to storage injector is only just able to match 16.1 ton/hr usage.

4.7

Ash Handling Plant

The plant is designed to produce cooled and cleaned-up water, and dewatered ash and fines from the slurry it receives. Design flow rates are up to 20 tons/hr of solids in 187 tons/hr of water.

Slurry from bed ash is led to the degritter, from which large particles (i.e. greater than 2mm) are removed to dump by gravity and mechanical separator and classifier. Fines flow over to the balance tank, into which slurry from primary and secondary cyclones is fed directly. Agitators continually stir this tank, keeping fine solids in suspension.

The thin slurry is pumped from balance tank to thickener, and dosed on the way by polyprep coagulant. In the thickener the solids slowly fall to the bottom and the rotating rake pulls the sludge to the centre of the funnel shaped thickener base.

The thickener overflow passes to the clearwell. From this it is pumped through the cooling towers to the cooling-tower pond ready for a further circuit through the ash quench plant.

HP & LP pumps supply this water to the ash quench plant.

Sludge from centre of thickener is pumped to the rotary vacuum drier. Dewatered sludge is outloaded on to a road vehicle or skip. Recovered water is returned to the clearwell. A sprinkler system supplies water (with acid when necessary) to the drier belt. A vacuum pump maintains low pressure inside the drier drum.

As far as possible all mechanical plant was set to work as individual items, in the dry. Tanks were flooded up with clean water, and pumps were set to work. The plant is largely manual with pumptrips to prevent overflowing of tanks, and alternative bypasses to prevent low levels being reached - these features were proved by simulation and then by actual level alteration.

Thickener rake torque switches were set before water was put in, to show that the rake would climb away from a deepening sludge layer.

Pump performances were all checked individually by rate-of-fall-of-water-level method.

When the ash quench system was ready to use water for setting up, the system was put on stream (without solids) and 72 hour runs of the machines were demonstrated.

When solids were produced in the Facility, during cold commissioning, it was shown that the degritter/classifier took out the larger end of the size spectrum and that the thickener was taking out the rest.

It was noticed that whenever a slurry transfer pump trips, the polyprep dosing pump does not, and so an unnecessary build up of neat dosing liquid occurs in the slurry transfer line. A change of logic is needed to trip the dosing pump on loss of slurry transfer pump.

The sump in the ash handling pumphouse has inflow from a drain to the north of the building into which ash and coal can fall. This sump is drained by sump pump into the cooling tower pond, and to prevent grit being put into this (clean) part of the system the sump pump discharge pipe will be re-routed to the balance tank.

The sumps in ash handling and ash dewatering pumphouses are open, and a hazard to operators. Steel grills have been put across the openings.

The flushing valves to clearwell and cooling tower ponds are out of reach of operators, and extension handles will be fitted.

The vacuum pump was set to work, and the acid storage system made available.

When solids had built up in the thickener, the sludge transfer pumps were set to work, and the wash water pumps and recovered water pumps were also set to work. The rotary drier is commissioned at the time of writing.

4.8 Ash Conveying & Quench System

This plant removes solids from the combustor bed and from the exhaust gas system. The bed ash flows through two valved down legs into the conveying vessel, where it is fluidised by air into an orifice and lifted into the quench vessel. It is mixed and cooled with water and when this level of the slurry reaches an upper set point the contents are discharged to the blowdown vessel. The blowdown vessel is partially depressurised, and then the slurry is discharged to the ash dewatering plant. The ash compressor controls the quench and blowdown vessel air pressures.

The exhaust gas is cleaned up by flowing through 4 primary and 4 secondary cyclones. Fines from each cyclone fall into quench vessels and then into blowdown vessels similarly to the bed ash system.

The design flowrate for bed ash was 9 tons/hr normal flow and 17 tons/hr emergency bed discharge flow. Up to 11 tons/hr total fines was envisaged from the cyclones.

Controls of the system is by automatic sequencing with manual override; the operators perform all functions from UCP4 in the main control room.

The equipment was set to work mechanically and electrically, and the logic of the control system was checked. The system was then operated pressurised with water.

The commissioning of the system with solids began during the cold pressurised runs when pseudo fuel was fed into the combustor, and was conveyed through the ash and fines system. Only short bursts of materials were available to be handled, and two kinds were used - crushed ash from the power station, and uncalcined dolomite.

The remainder of the commissioning run occurred during the hot runs. Material handled - again in small quantities - were dolomite, molochite, and ash.

The system proved in general to be able to handle materials successfully and the automatic controls have been shown to be reliable.

Bed ash conveying flow rates of the order of 5 tonne/hour have been attained, but exact performance and final adjustments for optimisation must await sustained hot running of the fluidised bed combustor.

The bed ash conveying nozzle has become blocked a number of times, by foreign bodies of various kinds and by wet ash clogging together. A 12 mm square screen has been placed above the nozzle, and when conveying cold ash, nitrogen instead of (saturated) burner compressor air is used.

Quench vessel high level switches gave trouble by a build up of iron on their magnetic couplings. A spray of water now keeps them clear of this trouble. Surging of water at the level probes was prevented by closing off the base of each stilling chamber.

Quench vessel discharge valves closed too slowly to prevent complete emptying of vessels - this action was speeded up by additional pneumatic exhausts.

Cyclone quench vessel vent valves eroded quickly owing to the large amount of ash dust entrained in the exhaust gas. It was established that gas from the cyclones was entering the top of the quench vessel through the antisiphon holes and the lower part of the diplegs were partially or completely blocked by ash deposits. Sprays are now fitted inside the vessel, so the handset water scrub's through the gas in the upper part of the vessel and cleans out the solids. The gas escaping through the vent should therefore contain little or no dust.

On a single occasion a large quantity of water entered the combustor, almost certainly by back flow from a primary cyclone quench vessel. The circumstances are not fully known; it occurred during a shut down of Turbo Compressor, and the system was running on manual control. It is not now permitted to run this system with water until the exhaust gas system is flowing with air.

The bed ash downleg valves were found not to be closing fully; the actuators have been replaced by larger sized ones.

Temperature control of slurry in the discharge pipework lines is achieved by injection of LP water while slurry is being handled. It was found that the LP water pressure at the injection points was lower than the slurry pressure. Alternative injection points were found further downstream, where the slurry pressure was less than the LP water pressure.

The HP purge valves were re-fitted with equal percentage plugs, obviating "bounce" experienced earlier.

Agitation motors on primary quench vessels were taking very high currents, and were re-wound to correct voltage specifications.

The agitator motor gear box on the bed ash quench vessel required additional stiffening.

4.9

Ash Compressor

An electrically driven centrifugal 4-stage machine provides 92.8 m³/min STP of air at 12 Bar Abs for the ash quench system.

The machine was checked statically and dynamically and put to work.

A temporary blow-off pipe with orifice plate and manometer was set up for establishing performance - this was found to be as specified within the limits of accuracy of the instrumentation.

In service the demands for air are intermittent, and due to the small volume of distribution system the unloaded machine cycles in pressure, and the auto blow-off valve operates every few seconds.

To make fuller use of this machine a pipeline was run to the burner air receiver, and the burner air compressor is now a standby machine.

The ashing compressor cell filled with oil vapour fumes when running - the oil tank vent pipe was extended to outside the building.

The instrument air supplies to seal and to shutdown purge are now separately alarmed and interlocked.

4.10

Burner Compressor

The burner compressor is a reciprocating compressor required to provide air via a receiver to the propane burners during start up.

The compressor is situated in the Power Station entrance remote from the Facility control block.

The burner compressor was the first piece of plant to be commissioned under the commissioning management procedures set out in Technical Management Document TMD 21 and reproduced in Appendix II.

The Burner Compressor Commissioning Document No. 10 identified the procedure for plant testing and also complied with the principles of TMD 21.

Prior to the institution of a commissioning team and the above mentioned documents the burner compressor had already had a trial run which resulted in the electric motor being burnt out and returned to Germany for repair.

The compressor then ran on the 6.11.79 blowing to atmosphere at the receiver end with the pipework disconnected from the receiver to blow out dust. The receiver was then connected and the compressor put through its commissioning trials up to the limiting allowable pressure of 14 Bar G. Compair pointed out that if we ran above this value then the guarantee would be invalidated.

A number of issues arose at this stage that finally halted the commissioning. The points emerging from this were as follows:-

- (1) The run-on timer (T_2) in the control cabinet was unsatisfactory and needed replacing.
- (2) The low oil pressure switch seemed faulty.
- (3) The audible alarm was found to be located inside the control cabinet and needed to be brought outside.
- (4) NCB (IEA) required all instruments to be calibrated but the contractor had no contractual obligation to calibrate instrumentation, and was not equipped to carry out on-site calibration.

It was agreed that commissioning would be restarted when the above points had been resolved.

The calibration problem was resolved by NCB (IEAG) undertaking to calibrate the instruments and this was done on the 13th November, 1979. The audible alarm was brought out of the cabinet.

The commissioning activity was then restarted on Friday 16th November, 1979, when Compair Industrial returned to site and replace the T₂ timer but the low oil pressure switch had performed well under calibration and was not therefore changed.

The commissioning procedure given in document No. 10 was carried out item by item without fault but it did become apparent that the high oil pressure trip needed to be reset to a higher value due to the fact that under cold start the pressure rose to the trip value and tripped the machine. The trip was reset to 40 p.s.i.g. from 37.7 p.s.i.g. and the machine ran up and settled after a period of running at 30 p.s.i.g. at stable outlet air temperature of 17°C at HP delivery.

The compressor then underwent a brief performance capacity test which gave a test result of 28.623 M³/min compared with the specified value of 28.60 M³/min.

Cold starting still gave problems and the supplier gave written confirmation allowing the trip value of the oil pressure to be raised to 43 p.s.i.g.

The burner compressor completed its commissioning trials and has been in service now (October, 1980) for almost a year, during that time several incidents of high temperature tripping have arisen which were indicative of loss of cooling water.

The raising of instrumentation to NCB standards incorporates extra tripping facilities on loss of cooling water but the calibration and proving of this additional instrumentation is the only work remaining on this plant item, along with the institution of the central control room general plant alarm initiated through UCP 5.

4.11

Instrument Air Compressors & System

Three 50% duty two stage reciprocating electric compressors supply a nominal 7 Bar system through a pair of receivers and a 100% duty heat regenerating drier.

The machine start and stop in any of 3 desired sequences, or if running continuously they load and unload. By setting up a temporary blow off valve and silencer, full load operation of the plant was demonstrated, using all combination of settings, over a total period of 72 hours. Several failures of the whole plant were found to be due to inadequately made electrical connections to cooling water solenoid valves. The cables were rejointed, and the control wiring system was modified so that no single fault could fail all machines.

While running to normal demand, which required single machines to start and stop periodically, a record was made of pressures and times. This, together with the volume of the system gave a measure of performance of the compressors which were generally 10% more than the specified 12.5 M³/min.

The drier was put into a full load condition of 25 m³/min using the temporary blow off valve. This was maintained for a total of ten days, during which the output was maintained at an indicated dewpoint of - 80°C (specified - 30°C). The drier proved to be capable of running for 70 hours at full flow before a tower changed over on becoming fully saturated. However, the 6 hour cycle is not enough to regenerate out this volume of water, and rather poor performance follows a period of this kind. The drier is run on time control now; the output is always - 80°C dewpoint, and the valves are exercised frequently.

Remote alarms and indications have been fully tested.

4.12

Fire and Process Water Pumps and System.

Two vertical pumps, rated at 125 m³/hr each draw from a forebay and supply a pipe which is connected to several fire hydrants, sprinkler system at propane unloading point, ash dewatering house, fuel preparation plant, and cross connection to act as a "shutdown" C.W. supply.

The forebay is fed either from the main cooling tower drain, or from the reservoir pumping main, via a motorized main inlet valve.

The pump capacity was measured by timing the rate of fall of forebay level, at a discharge rate controlled by pump discharge valve and maximum motor current - this rate was found to be 4% above specified in each case. The discharge valves were left in part open condition to prevent overloading pumps, once the overload trip had been proved.

Auto operation of main inlet valve was checked and the isolating valves part closed to limit maximum inlet flowrate of water to 50% above 2 pump net discharge rate.

A balance tank with gas pressurising blanket was installed as a modification and the pumps are now both controlled by local pressure switches, to start and to stop.

Remote alarm and controls have been fully tested.

4.13 Instrumentation and Control

4.13.1 Introduction

The instrumentation on the project was supplied by the respective contractors as part of a package specific to an area of the plant. The instrument and control contract, as such, only covered approximately 50% of the total site instrumentation.

As the contract specifications were ambiguous when relating to instrumentation installation, major problems were experienced during the erection and commissioning phases, these problems being emphasised by the differing types and manufacture of equipment supplied.

In the original plant specification it was envisaged that The Turbo Compressor, Fuel Injection System and Exhaust Gas Controls would be plant housed with only essential indications repeated in the central control room. It was soon evident, however, that this was not a practical proposition and all except the Turbo Compressor instruments were centralised in the control room, increasing panel size by a factor of three. Unfortunately the panel size had been fixed by this stage and was already in the manufacturing stages.

The new equipment was much deeper than the existing split architecture system and high density, congested sections of the panel were the result. This caused considerable problems during the commissioning phase.

The introduction of different equipment from that supplied by the main instrument contractor gave tremendous interface problems; these being chiefly power supply, earthing, signal levels, fusing and operating voltages. Major redesign in interface areas was the result which wasn't helped by contractors' reluctance to communicate with each other, causing most design changes to be channelled through a single design engineer.

The design of the instrumentation and controls is; electronic detection, transmission, control, indication; changing to pneumatic for final drives. The control principal is mostly pulse output drives, but analogue and digital systems are also in use. Most transmitting devices are electronic strain gauge or capacitor, two wire loop systems usually in a division two or explosion proof housing and mounted in racks or in individual pods, adjacent where possible to tapping points. However, such was the freedom of choice that some pneumatic systems were used especially on the propane controls. Total standardisation has not been possible and each commissioning exercise was handled from basic principals demanding a high skill level from the technicians involved with inspection and acceptance.

Each contract package had to be treated individually due to the differing rates of progress, but allowing for the vast range of equipment in use, some basic statements can be made about commissioning philosophy.

- (a) All tests and trials were witnessed by a technician on behalf of NCB (IEA Grimethorpe) Limited.
- (b) Documentation was produced for every stage to record performance and test data.
- (c) Each item of equipment was tested individually as a single item, whether it formed part of an instrument loop or not.
- (d) All tapping points and impulse pipework were inspected for correct installation e.g. pipe sizes, runs, falls etc. and was all pressure tested.
- (e) All cabling was insulation and continuity checked and records made.
- (f) All loops were checked in their entirety from as close to the primary element as possible.
- (g) Head corrections and alarm settings were checked at the loop check stage.
- (h) Control actions were cold commissioned by test injection whenever possible.
- (i) Cross comparisons were made with other instruments or by test methods to check the reading of all loops when set to work.
- (h) Loop control interaction was investigated when possible and modifications made to increase stability.

4.13.2 Specific Areas and Packages

The "Series 4" Controls manufactured by Babcock Bristol Ltd. These controls are primarily used on the steam water circuit, but some indication loops are used on the turbo compressor and the exhaust gas areas.

In commissioning the steam/water circuit no major problems were experienced but some areas did cause concern these being:-

- (a) Impulse lines were not fitted with top up points on vessel levels and flow measurement loops. These were fitted.
- (b) Tank level measurement design was changed from 'single wet leg' to 'dual wet leg' principle.

- (c) Pressurised vessels, level measurement compensation for temperature and pressure was incorrect.
- (d) Some instrument head corrections were incorrect; this is now resolved.
- (e) Certain instrument ranges were increased.
- (f) Failure mode of tube bank evaporator control valve changed to enable it to fail open.
- (g) Some control valves supplied under pipework and services contract were not compatible with series 4 controls, valves modified to suit.
- (h) Larger valve stroke times too slow causing controls to trip - controls modified.

The Turbo-Compressor Series 4 is used only for indication in control room, all local instrumentation being part of the compressor contract. Some problem areas were:-

- (a) Condenser vacuum transmitter had to be moved above its tapping point due to condensation filling the line and equalising the vacuum.
- (b) Inlet air humidity wrongly specified.
- (c) Inlet air temperature, resistance thermometer line resistance caused high errors until three wire measurement principle equipment was installed.
- (d) Compressor discharge mass flow calculation was changed and constants altered, also square root extractors gave reading errors below 10%. This was greatly reduced when complete system was statically rechecked.

The Turbo Compressor package has no specific instrument contractor or equipment. The basic instrumentation is mounted on two local panels; the only areas of complexity being:-

- (a) The turbine vibration monitors, which were statically and dynamically commissioned without problem.
- (b) The speed controls, which proved incompatible with the the main control microprocessor. This problem was resolved when the processor outputs were changed to pulse.
- (c) The antisurge package which was commissioned dynamically only by Compair.

The commissioning phase on the compressor showed a definite requirement for vibration measurement giving alarm and trip protection on the compressors and gearbox. This has now been installed and commissioned.

The Fuel Injection System consists of an analogue control system linked to a large relay logic network. This package was a problem. The design of the controls in all cases was incomplete, and the contractors intent had been misinterpreted by the instrument sub-contractor.

During commissioning it was found that:-

- (a) The flow loops had multiplier circuits and not dividers as specified.
- (b) All pressure transmitter ranges had to be changed to suit the revised controls.
- (c) Many wiring faults were rectified these being caused by the designers and not the installation contractors.
- (d) Most instrument ranges were changed.
- (e) The weight rate and temperature control interface was rebuilt.
- (f) All the valve positioners were removed from the flow loops.
- (g) Several valves were fitted the wrong way round.
- (h) Several valve trims had to be changed.
- (i) The nitrogen purge system for pressure tapping points was redesigned to conform to the main combustor installation.
- (j) The weight monitor - recording equipment scaling was completely redesigned to improve the accuracy of weight rate measurement.
- (k) The power distribution was modified in the bed material panel.
- (l) The flow circuit electronics tends to overheat and causes large amounts of drift. This problem still exists to some extent but has been contained.
- (m) Several potentially dangerous errors were corrected in the valve sequencing and shutdown logic.
- (n) The logic interface with the alarm system was redesigned.
- (o) The fusing and power distribution on the logic circuits was changed from one fuse to nine fuses.

- (p) The valve limit switches were all wired incorrectly; again a design problem.
- (q) The interface between the fuel injection logic and the Fuel Prep Plant, regarding the bin vibrator was redesigned.

The logic system was tested after a wire by wire procedure was written; firstly on the field equipment, then the panel and finally the whole system. It was while checking the overall system that several cabling errors were found. These were traced to the large junction boxes on the south wall, which being so densely packed with cables meant that the terminations repeatedly failed. The solution to fit a larger box was adopted.

The surge bin vibrator was found not to give sufficiently tight shut off of solids, so a new slide valve was fitted between the vibrator and the storage injector ball valve.

The combustor instrumentation comprises two basic instrumentation areas, pressure probes and temperature measurement, the combustor was a new concept for those parties involved in commissioning and major efforts were made to safeguard the installation from the possible hazards it would have to face.

Due to the very small purge flows down each pressure tapping to prevent blockage, it was very important to ensure that the probe pipework was leak-tight. On a system of this complexity, this task was a major problem with some probes taking days to cure. Leaks were even found through porous sections of the copper tube running to and from the combustor.

During the first plant runs with solids, water from the quench vessels entered the combustor. The resultant bed material-water mixture corroded the lower probe flexibles to such an extent that 100% replacement of all flexibles was necessary. From this time, however, no problems have been experienced except for the odd probe blockage.

The thermocouples were no problem to install but all the connecting cables had to be replaced for larger diameter due to constant breakages with the smaller size. Each thermocouple was checked through to the control room to prove loop integrity.

The design of the in-bed and distributor plate thermocouples has been constantly updated to try and improve reliability.

The data logger is based on the "Digital" PDP11-34 computer and is an Abacus II designed and built by Babcock Bristol Limited. The installation has been plagued with problems, most being a mixture of hardware failures and software mistakes.

The commissioning of the logger was straight forward, as its inputs fall into two categories (i) those signals fed from discrete transmitters, (ii) those inputs fed from other loops.

Where the signals come from discrete devices, the injections were made at source and checked through to the logger peripherals.

Where signals come from other loops, the injections were made from the take off diodes as the loop had already been checked previously. The ash weight signals, where the logger interfaces with the Exhaust Gas system, have yet to be commissioned due to hardware interface problems.

The software commissioning has been ongoing for many years in order to be sure that the end result was right, as the logger is the main data store and display mechanism. However, the people who engineered the software were not the ultimate users. The Experimental Function Team was only established in 1980 when considerable reprogramming was deemed necessary.

The automatic control is via a Micro B processor. The commissioning intention for the Grimethorpe Experimental Facility Combustion Control System has been that it should comprise three phases. At the time of writing phases 1 and 2 (except for the Test Cascade Software) have been completed. Phase 3 awaits a fully operational plant. Following is a brief description of each phase. The phase 1 was initiated by a functional check of the computer hardware and associated peripherals, using the Babcock Bristol Engineering Instruction handbook. Next, a check was made of the final control elements associated with the Micro B for correct operation and sense. Calibration was then carried out of all primary elements inputting signals into the Micro B. On satisfactory completion of the above, calibration of the Micro B input and output capability was carried out. At present the capacity stands at seventy two inputs and twenty four outputs. Together with the input and output calibration a check was made for correct operation of indicators, recorders and control element converters. In phase 2 a disk with the Grimethorpe System Software was loaded into the computer memory and a check made for system compatibility e.g. correct visual mimic displays. The operating philosophy of the application software was then checked by simulating inputs and measuring outputs. For convenience the software was divided into the following sections:-

- Pressure measurement systems
- Bed temperature measurement
- Bed level bed weight bed density calculations
- Air flow calculations
- X and Y fluidising calculations
- Bed level control
- Bed temperature control
- Turbine governor control

Flow regulating valve control
 Pressure let-down control
 Test cascade control
 Freeboard spray control

During this phase of the commissioning all plant parameters and other constants used by the Micro B were verified. With the plant shut down a check was also made for correct outputs from the Micro B to the final control elements for known simulated input disturbances.

Phase 3 is concerned with the selection of automatic control of all loops with the exception of freeboard spray and test cascade control. At present the only progress has been the selection of automatic control of the turbine governor. Results have been encouraging, though the loop has yet to experience interactive affects from the other Micro B control loops. Given a fully operational plant it is hoped to continue with selective automatic control finally resulting in:-

Turbine governor control
 Bed level control
 Bed temperature control
 Flow regulating control
 Pressure let-down control

Up to now no major commissioning problems have been experienced. Two points worth mentioning have emerged from phase 1 and 2 operations. The first concerns the very slow up-date of the coloured visual display unit. This results in a significant lag time for displayed measured variables and set point values. With regard to set points, it may well be advantageous to fit calibrated indicators, thus giving improved operator control. The second fact to emerge is the lack of software space for implementing any future modifications. Babcock Bristol have been consulted on the latter and we await their recommendations.

The propane burner controls were supplied as a section of the combustor contract and came complete with drawings and schedules and it was assumed by all to be a self contained complete package. It was only when a detailed design study was carried out that it was realised that the system was far from complete. No provision had been made for controlling the service pressures; propane, nitrogen purge air, and the interlocking also required redesign. The German designer came to commission the logic which only required minimal attention to make it as per drawing. Pneumatic controls were supplied for service control. These controls work poorly and really are not ideal for the duty supplied. Two flow loops were supplied under the main control contract to measure propane flow. These two loops use turbine meters as the primary element. Unfortunately, these meters were incorrectly calibrated at the factory and only recently have been recommissioned. In the light of experience, many modifications to the system have been carried out, and the logic has been vastly changed.

The Exhaust Gas System controls were a very lengthy commissioning exercise hampered by the high densities both in the control panel and round that area of plant. During commissioning it was found:-

- (a) The depressurising valve and pipework on the bed material quench vessel V301 was not large enough to drop the vessel pressure. A new valve and line has been fitted but the ash system as yet has not been fully commissioned, therefore, the effects of this modification have not as yet been fully evaluated.
- (b) Wiring changes had to be made on the primary and secondary quench vent flow loops due to a design error.
- (c) The air to the ash transfer vessel mass flow measurement temperature compensation had to be changed. This was due to the fact that the supply air was at a much lower temperature than was expected.
- (d) Serious water hammer and cavitation was taking place in the H.P. purge water valves. This was due to the valve plug characteristic. Changing plugs from quick opening to equal percentage opening plugs to slow down the rate of change of the water velocity prevented further water hammer. Also restrictor plates have been fitted upstream of the control valves which reduces the flow to 200m³/hr at a pressure of 6 bar (A) in the blowdown vessel giving a ΔP of 7 bar across the valve. Any increase in ΔP will re-establish the hammer and cause damage to the valves
- (e) The vent flow valves on each quench vessel were found to have serious erosion on the valve plugs and on the base of the valve casting. Holes had appeared in three of six valves, and the remaining three were badly damaged. All six valves were removed, the casing remachined and a stellite faced plug fitted.
- (f) Primary quench dump valves and secondary quench level valves, plus four level valves on blowdown vessels, all had signs of erosion on the plug face and teflon sealing ring. Each valve was replaced and new teflon rings fitted.
- (g) All level switches have experienced a build up of magnetic particles around them, this stops operating as they work on a magnetic changeover principle. Water sprays have been fitted recently, but not evaluated as yet.
- (h) Quench water flow loops, require their primary elements cleaning after each run due to the amount of solids in

the clean quench water. Water purges are proposed but not fitted yet due to shortage of cool clean water at the required pressure.

- (i) There were a number of minor problems with the sequence units but no redesign was required.

All the analogue equipment works satisfactory, however some changes in weight measurement on the blowdown vessels may be required to increase the accuracy.

- (j) Due to problems with available water pressure the blowdown vessel temperature control system had to be moved closer to the water treatment plant. This system has yet to be commissioned and at the moment is available on manual control only.

A complete booster compressor control package which arrived on site required services only. All the instrumentation was commissioned with the minimum of complication. The only major area of discontent was the difficulty in maintaining the services of the 'Cryostar' commissioning engineer on site to finish his work on the machine. Several analogue instrument modules were faulty when tested and it was observed that some modules served no useful purpose and therefore were removed from the system. From the completion of the commissioning no major problems have been experienced and the machine performs well.

A small ashing compressor control package commissioned easily. The air output-antisurge package is not correctly designed for a machine with no capacity in the exhaust. When no demand is required by the exhaust gas system the compressor outlet is effectively boxed and the machine oscillates wildly. The ideal remedy would be to give the machine a base load and the machine has now been connected through to the burner air receiver tank.

When the twin cylinder burner air compressor arrived on site and it was observed that it did not conform to the NCB specification so several additional instruments had to be fitted. The discharge temperature also is higher than that specified. This is due to the high outlet pressures required.

The Fuel Preparation Plant was the first major area of plant to be commissioned. A straight forward basic operation which was plagued with problems. The instrument package centre piece is a process logic controller utilising a D.E.C. LSI11 processor. The P.L.C. arrived on site with software already on R.A.M. It was obvious from a very early stage that the software had many errors and was incomplete. The contractors involved re-wrote the software in total, on site, a mammoth task taking almost a year. These initial early problems with the P.L.C. destroyed everyone's confidence in the machine and most electrical problems were blamed to it, for many months to follow. With the R.A.M. memory installed, the machine suffered from memory corruption due to transients caused by the nearby 550v switchgear.

This corruption was only alleviated when the R.A.M. memory was replaced with E.P.R.O.M. memory.

The remaining instrumentation either feeds information into the P.L.C., is fed by the P.L.C. or is part of the small panel instruments. Without exception every single item of equipment has failed, been adjusted, rebuilt, realigned and generally worked on in one way or another. To this day certain aspects of the plant are still untested, basically the blend system.

The Main Plant Safety Interlock system formed part of the instrument and control contract but the interlocks were only designed and installed within weeks of the commissioning, and was virtually the last area to be done. Being a hard wired system, the system checkout was an easy operation, it was when the dynamic interlock trials took place that several areas were shown to have weakness. The turbine speed switch to stop the F.R.V. opening until the compressor is up to speed did not work as the compressor speed measurement loop could not stand the additional load. The limit switches on the back end valves (P.C.Vs) to ensure the valves are open above 20% before the F.R.V. can be opened did not work, as in the reverse directions when the P.C.Vs were closed to maintain pressure, when the 20% value was reached, the F.R.V. would close, surging the turbo compressor. The "break in coal feed line" interlock also didn't work as planned. A complete design review is still required in this area. There are some seventeen interlocks in the system and initiating any one causes several of the others to follow. Therefore, after an interlock initiated shutdown, so many interlock lamps are lit it is impossible to detect which actually caused the trip. For this reason a "first up" log on the data logger lists the interlock action in order of operation.

The analysis equipment covering both water and gas analyses supplied by Hartmann and Braun was commissioned easily and has performed well. Only one gas analyser (CO) has failed and required the cell replacing; a minor defect on the O₂ analyser was solved when the Hartmann and Braun service engineer came to commission the water analysis. The propane analyser was re-ranged from 0.1 to 1.0% C₃H₈ after it was realised that the range was too small when running on propane burners only.

4.14

Propane Burners

In order to raise bed temperature to a point which coal will ignite spontaneously, propane firing is utilized. This propane is fed into the Combustor by 2 sets of burners.

First by means of 4 "in bed" (Premix) burners and subsequently by 9 main burners which are within the distributor plate.

Initial bed temperature is raised by means of the Premix burners and when, locally, within the bed this is high enough to ignite Propane. Propane is introduced onto the compartments under the Premix burner, this Propane igniting as it percolates through the bed, further raising the bed temperature.

Heat input of the 4 Premix burners is approximately 1.25 MW whilst, although each Bottom Burner is capable of delivering 1.5 MW design consideration of the distributor plate limit the total heat flow from the 9 Bottom burners to 9 MW.

Initially, a further burner (the Freeboard Burner) was installed, with the express object of ensuring that no unburnt combustibles were allowed to leave the Combustor. This has now been dispensed with, on advice from other experimental facilities See section 4.

The operating sequence is dictated by the logic within the panel, viz:-

Following a timed period (5 minutes) of air changes within the combustor, the 4 premix burners can be lit - when these are alight the main gas valves for the bottom burners open and gas can be introduced to any of these, subject to operator control regarding lighting those under premix burners.

It was discovered that, although the air piping was correctly installed according to VKW Drawings, an original error had been made in the interpretation of the burner manufacturer's drawing and the "ignition air" had been crossed with the "combustion air" inlets.

As the valve size on the 'ignition air' was now too large, effective air control was too coarse and smaller bypass valves had to be fitted across the larger valves for control purposes, and with the large valve closed, a 50% opening of the small valve gave more reliable ignition.

Also, information from Champion Spark Plug Laboratories, indicated that at increasing pressures higher ignition voltages would be required to obtain a satisfactory sparking at the electrodes.

The burners supplied are as those used in Power Stations to ignite oil. Apparently no work was done on investigating the operation under conditions of pressure and high air flow rates, so, unfortunately, no instrumentation is installed to give some indication of propane and air flows, and the two main rotary flowmeters (one for the premix burners and the other for total gas flow to the bottom burners) were incorrectly ranged and gave no useful information. In fact, the only method available of checking gas usage was to count the strokes of the positive displacement pumps in the propane supply lines to the vaporisers at the propane plant.

The starting (firing) of the premix burners initially presented problems, with a very erratic response, and no guarantee that a burner which lit before would re-light. This was attributed to a variety of possible causes, viz:-

Gas/Air mixtures incorrect.

Gas/Air pressures incorrect

Gaps on ionisation and ignition sparks incorrect

Bed Material in the ignition flame diffuser ring

Once ionisation was achieved, then the return signal was very irregular (varying from 5 - 30 volts or so on the indicating voltmeters). Nor were the signals from all 4 burners equal, and varied randomly, both between lightings and during the course of a combustor run. This is possibly a turbulence effect within the combustor. Large condensers were wired in parallel across the outputs of the ionisation amplifiers and the long time constant (5 secs) effectively steadied the signal sufficiently to keep the "ionisation on" relay energized (without endangering the fail safe features on complete loss of ionisation).

The 'window' temporarily fitted in place of No. 3 Burner was of considerable assistance, allowing a view of the flame from No. 1, and also to watch the behaviour of the bed when first introduced.

The freeboard burner was not made use of, as C.U.R.L. experience indicated that it, in itself, could represent a potential hazard were there to be unburnt propane passing up the combustor. The logic was adjusted to allow this mode of operation. Also, because of the erratic behaviour of the premix burners, on occasion the 'test box' has been employed to simulate one of the flow burners, allowing the bottom burners to be lit.

Various small problems were encountered such as wiring faults, cable crosses and poorly made off terminations, but these were rectified. More seriously, a number of small acts of nuisance value were discovered, wiring altered, relays damaged, boards left not properly inserted etc. This necessitated a check of the system before each attempt at using.

The logic supplied by VKW performed satisfactorily, being comprehensive and reliable. Minor wiring problems were encountered initially, which were resolved by VKW and on site.

It proved necessary to have a "plug in" test facility produced, allowing the logic to be checked without establishing all the plant parameters and interlocks. This test facility also proved useful as mentioned before to simulate a burner and has been used to bypass faulty flow switches etc.

The bottom burner appear to have caused little trouble, although without adequate flow indications available, the amount of gas actually being fed to a particular burner can only be guessed at, as the pneumatically operated valve controlling the propane flow is inherently non-linear, although the valve position is shown by a linear percentage scale. As a safety measure, one of the two main solenoid valves in the bottom burner gas line has been "slugged" pneumatically to prevent possible damage to the differential pressure controller by a shock wave started by a very rapid valve closure whilst at a high flow. Other minor modifications made for safety reasons were removal of manifolds on gas/combustor differential pressure controllers, double isolation or blanking of unused tapping points on Propane lines and the installation of venting systems, including facility for maintaining Nitrogen in the Propane line when burners not required. Nitrogen purge through all burners after plant trip is controlled from the interlock system.

4.15

Turbo Compressor

The turbo compressor commissioning revealed a number of problems requiring design resolution and modification.

This report is a summary of the modifications carried out during commissioning and further detailed information and background is available in Commissioning Report 21R entitled:-

"Interim Report on the Testing of the Turbo Compressor covering the period 29th November, 1979, to 7th December, 1979, and Part 11 Final Report on the Testing of the turbo compressor March 18th 1980, to 28th May, 1980."

The major design problem was the failure of the drive and non-drive end bearings of the H.P. Compressor C.604.

The results of vibration measurements obtained from a series of dynamic tests on the turbo compressor identified the failure mode of the H.P. compressor rotor and consequent damage to the rotor labyrinth seal.

This failure mode was identified as classical oil whirl which occurred at 8700rpm. The onset of oil whirl was generally associated with a resonance at 8640rpm and coincident surge conditions in the compressor. The mechanism of oil whirl is such that the oil film between bearing and shaft becomes unstable. The shaft itself normally runs stably and the shaft centre can be shown, on an XY plotter, to trace out quite a small locus of deviation from the bearing centre. Under oil whirl the shaft centre traces out a quite large locus that, under certain conditions, takes up the full bearing clearance and this was the case with the turbo compressor H.P. rotor that led to its failure.

In order to restabilise the oil film a new bearing was required where the top half of the bearing is offset horizontally in relation to the bottom half bearing. This has the effect of producing a particular wedge of oil thus stabilising the oil film and ensuring the running concentricity of the shaft in the bearing. Because this effect on the oil film is unidirectional these modified bearings would not be satisfactory for reverse rotation.

Subsequent running of the Turbo Compressor on the new off-set bearings at the drive end and non drive end of the H.P. compressor have proved very satisfactory and no sign of the problem of oil whirl remains.

The original vibration monitoring system of the compressor part of the turbo compressor were 'AMOT' simple seismic devices which gave an alarm at preset level. These devices sensed the vibration by disturbance of a weight at the alarm level of vibration. As an outcome of the turbo compressor H.P. rotor failure the AMOT seismic devices were considered to be somewhat crude and a more sophisticated vibration monitoring system was installed.

The new vibration monitoring system is based on proximity probes mounted on the H.P. drive and non drive end bearings, on the gearbox between the L.P. and H.P. compressor, and on the L.P. compressor outlet bearing.

The new system allows direct reading of the vibration level at each station and gives protection by an alarm and also by a trip at preset levels. The new vibration monitoring panel has been added to the compressor local alarm panel at the turbine end of the turbo compressor platform.

The Compair H.P. compressor C604, consists of a shaft carrying four separate centrifugal compressor wheels spaced out along the shaft to give four compression stages. The compressor wheels are each balanced and then heated and shrunk onto the shaft to give an interference fit between the inboard and outboard lands of each wheel and the shaft. The whole assembly is then finally balanced to be within 744gm.mm.

During the course of commissioning the rebuilt turbo compressor, with its new shaft, out of balance occurred and the shaft/rotor assembly was returned to Compairs Works at Ipswich. The reason for the out of balance was considered to be due to the temperature gradient between the compressor wheel and the shaft which caused the locked-in stresses of the interference fit to redistribute themselves. This could then lead to a compressor wheel moving relative to the shaft and thus causing out of balance. On this basis the assembly was modified by removing two of the shaft sleeves at the last stages of the H.P. compressor i.e. the hottest end where the highest temperature gradient existed.

The assembly was then rebalanced and returned to site and subsequently ran without further incidence of out of balance. (Mid April, 1980 to November, 1980).

The blow off valve of the turbo compressor was originally intended to keep the compressor free of surge when operating between fully shut and half open. The range of the blow valve operation was modified to two thirds full open to fully shut but was still unable to cope with fast transients arising from the process characteristics.

Example:- Process air valve trips from open to closed position causes turbo compressor to surge four times before automatic operation of the blow off valve recovers stable operation of the turbo compressor.

The commissioning document for the testing was No. 21 which was written as a Technical Management Document, embodying both principles and a summary of testing details. The section on principles was written as general principles applicable to all other plant commissioning as well as the turbo compressor.

The testing was divided into discrete phases. First the Turbine was run uncoupled from the compressor train to prove that the G.E.C. turbine package was mechanically sound.

Then the turbine was coupled to the compressor train and run as a complete unit for mechanical proving and initial performance proving. At this time the air flow route was solely via the blow off valve with the combustor gas path blanked off.

The final proving of the turbo compressor was carried out in the contract state connected to the combustor, where final aerodynamic performance of the machine was satisfactorily established and performance characteristics were drawn up, by the sub-contractor Compair, which showed that the design operating point was met with a small margin in hand. Final characteristic is attached.

The last stage of testing was an integrated test of the turbo compressor connected to the combustor whilst also driving the booster compressor. During this testing the influence of turbo compressor surge/instability on the booster was examined at three operating pressures and showed that these conditions did not surge the booster compressor. The overall fitness for purpose of the turbo compressor was generally established after resolving the problems mentioned earlier. The only testing which was not done was the heat rate test of the turbine which was waived by NCB (IEA).

It still remains to be established whether or not environmental noise emanating from the turbo compressor requires further work to reduce the noise level.

General noise levels of 107dB were found during testing with a peak value of 119dB at the L.P. compressor outlet bellows.

Compair have since put acoustic lagging around the bellows which has reduced the level but a full noise survey within the Facility still remains to be carried out by NCB Regional Experts.

PERFORMANCE OF REAVELL AIR COMPRESSOR

TABLE 2

BAROMETER = 1016 mb
 AIR INLET TEMP = 16°C
 REL HUMIDITY = 82%
 C.W. INLET TEMP = 30°C
 C.W. FLOWRATE = 160 l/hr
 EXHAUSTER FLOW = 2 Kg/s

4.16

The Booster Compressor

The booster compressor is driven by an air turbine on a common shaft where the air supply to the turbine is taken from the outlet of the low pressure casing of the turbo compressor.

First attempts to run the booster compressor up to its design speed of 28,000 rpm only achieved 21,000 rpm. The fault was thought, by the sub-contractor, Cryostar, to be a wrongly sized turbine and incorrect inlet guide vane opening. A new turbine was installed and guide vane opening corrected but the turbine still failed to run up to full speed.

The site independently carried out an air flow test of the turbo to booster turbine pipework and established that the problem was due to the four inch fast acting butterfly valve situated close to the booster turbine inlet.

When the butterfly valve was open the flow area on either side of the valve was considerably asymmetric resulting in a split flow to the turbine and high system pressure drop.

The sub-contractor was persuaded to change the four inch butterfly valve for a six inch butterfly valve and the turbo to booster pipework was re-arranged so that the six inch butterfly was well upstream of the turbine. The booster compressor then ran successfully over the full range of speeds, and met all its contracted requirements.

The design intention of the booster compressor is to provide conveying air flow to the Petrocarb Fuel Injection system at a differential pressure of 2.1 bar (i.e. 2.6 bar above combustor free board pressure) over the full range of operating conditions.

Under start up conditions the following process situation exists:-

1. The combustor pressure is nominally 2 bar.
2. The Pall drier on the outlet of the booster compressor is not designed to operate below 6 bar.
3. Item 2 above requires the turbo compressor to run to give 6.5 bar outlet pressure with the pressure controlled by the process air flow regulating valve.
4. Under these conditions the differential to the Petrocarb system rises to a minimum of 6 bar.

A modification is intended to fit a flow control valve downstream of the Pall drier which will introduce a large pressure drop and reduce the pressure differential between the Petrocarb fuel injection system and the combustor during start up.

BOOSTER COMPRESSOR

TABLE 3

4.17

The Pall Drier

The drier is a twin tower unit drying the conveying air flow supplied by the booster compressor to the Petrocarb fuel injection system.

The operational sequence requires one tower on line whilst the other tower is re-generated at atmospheric pressure.

In order to restore the re-generated tower to the circuit it must first be pressurised to circuit pressure from the other tower. This sequence caused initial problems in that the oncoming tower pressure was very low and caused instability of the booster compressor.

The problem was resolved by increasing the cycle time for re-pressurising the oncoming tower, since the alternative of increasing the rate of pressurising was unacceptable to the drier dessicant.

A small pressure disturbance during changeover of towers still exists of up to one third (0.3) Bar and was enough to give a fleeting alarm. The fleeting alarm has been cured by putting in a 100 second delay timer into the alarm circuit.

Hindsight suggests that an air receiver in circuit with the booster and drier would have been a neater solution but the current system seems adequate.

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NCB (IEA GRIMETHORPE) LIMITED

FLUIDISED BED COMBUSTION PROJECT
GRIMETHORPE EXPERIMENTAL FACILITY

SECTION 5

Reports on Plant Modifications
During Cold Commissioning

5.1

Condensate Polishing Plant

- i. Acid and caustic barrel emptying points occupied a common bund. A fence was erected, the pump hoses were shortened and the rear wall was tiled in 2 different columns, in an attempt to prevent a reagent being inadvertently discharged into the wrong tank.
- ii. The reserve feed water tank leaked badly, aggravated when hot water or steam was put into the tank. It was cleaned out and sealed with resin and glass fibre tape.
- iii. The ladder up to the effluent sump top was secured to the wall.
- iv. The effluent pump motor current was far too high. An orifice plate was fitted at the discharge side of the pump to cure this.
- v. The reagent unloading bund sump had no means of removing spilt chemicals or hosing down water. A hand operated sump pump was provided, discharging to the effluent tank.

5.2

Steam/Water Circuits

- i. Wet storage of boiler system was initially by high hydrazine dosing. Changed to steam blanket/low hydrazine.
 - ii. Reserve feed water tank overflow was fitted with an antisiphon barometric loop to prevent admission of steam to the tank from the main to the clean drainstank.
 - iii. Flash tank/start up vessel, uprated from 1 Bar (G) to $7\frac{1}{2}$ Bar (G) as part of steam dump modifications.
 - iv. Condensate booster pumps installed to feed condensate from old Power Station, with control from CCR, at a rate greater than by gravity.
 - v. pH dosing point upstream of boiler feed pumps fed to pumps 2 and 3 only. Repositioned to a point common to all pumps.
 - vi. Level switches on deaerator and hotwell could be tested and replaced only by draining the tanks. Additional and isolatable external standpipes fitted to carry the switches.
 - vii. Additional level switch added to deaerator to start emergency RFW pump at more appropriate level.
 - viii. Main boiler feed Pump Motors - problem of bearing oil ingress was due to thrust bearing/magnetic centre design. Glands modified as appropriate.
 - ix. * Quantities and materials for dosing boiler water to be agreed between VKW and Dewplan.
 - x. Flash tank/start up vessel main bellows replaced - initial type was unsuitable for duty.
 - xi. Deaerator vents and safety valve - stack pipes fitted for operator safety.
 - xii. ** Emergency boiler feed pump could not start with an open discharge valve to a low pressure in feed main; an orifice plate is required.
- * Modifications in progress
- ** Modifications in abeyance.

5.3

Nitrogen Store and System

- i. Water circulating pumps set to run at all times, not auto started and stopped, owing to mismatch of time controls.
- ii. Pipework in storage area increased from 2" to 4" bore and improved in layout to give acceptable pressure drop on full flow.
- iii. Steam control valves to vaporisers changed from 3/4" double seat to 3/4" single seat, to give adequate steamflow for full output.
- iv. Provision of liquid and gas stubs for possible additional vaporisers, to cater for future increase in demand.
- v. Vaporiser tank filling valves were provided from condensate line.
- vi. Vaporiser heating coils corroded at air/water interface. A re-designed coil puts the interface at a part of the coil virtually immune to chloride attack and thick walled.
- vii. Nitrogen buffer vessel provided, to give gas at a set pressure auto adjusted to 2 Bar above combustor freeboard pressure.
- viii. Condensate return pumping system rebuilt, using Propane vaporiser steam operated pumps to handle N_2 and C_3H_8 condensate, obviating unsatisfactorily situated electric pump.
- ix. Fuel Preparation Plant reducing valve increased to cater for larger demand.
- x. * Solenoid valves would close on loss of electrical supply. Inverter supply substituted, except for propane main purge valve which will open on loss of electrics.
- xi. * Vaporiser water pumps supply changed to duplex i.e. mains or standby diesel generator.

* Modifications which are in progress.

5.4

Propane Storage and Distribution System

- i. Vaporiser steam valves replaced by more suitable type.
- ii. Vaporiser high liquid level switch connected to liquid propane pump.
- iii. Pump nitrogen solenoid valve repositioned closer to the pump.
- iv. CCR controls improved and rationalised.
- v. To make the system safe to carry out modifications or maintenance to the distribution main or burners, a connection to the Nitrogen store was put in, so that by remote CCR Control the propane gas can be closed off, and nitrogen at the controlled pressure can be substituted. A spool piece on the propane line can subsequently be removed for positive isolation.
- vi. A positive venting system to empty the propane mains at each burner cluster was put in. This allows complete changing to nitrogen at the Facility, in conjunction with the mod. iii above.
- vii. * Traceheating system on gas main to be fitted with indication lamps to show system is operating correctly.

* Modification in progress.

5.5

Gas Oil Store and System

1. The system delivered through a pressure reducing valve to a deadend at the Rosin drier. Delivery pressure at the drier therefore varied transiently at demand change, and with a drooping characteristic. Additional recirculation back to tank filling lines put in, with an air separation vessel in line.

5.6

Fuel and Bed Materials Injection Systems

- i. * Coal lines of too small a diameter to convey at required rate. Rebuilt at larger diameter, and with two 90° bends each replaced with pairs of 45° bends (see separate report).
- ii. Bed material return line first build with a slight bed at one point, where rapid erosion occurred. Re-build with straight section.
- iii. First section of coal lines was made in rubber tubing, which eroded rapidly. Replaced by steel pipe.
- iv. ** Conveying air lines to primary injector ended with long hose with a non-return valve at inlet (clean air) end. Non-return valve to outlet (coal) end, so a burst hose would produce an air leak without coal.
- v. Nitrogen purge line connected into conveying air manifold, so coal lines can be kept clear of ashes during a Facility shut down.
- vi. ** Dust shield and bin installed at dust filter.
- vii. Dust shield and bin provided for coal sample pots.
- viii. ** Bed materials control panel mimic display improved.
- ix. ** Bypass valve fitted around pressurisation control valve to storage injector.
- x. * Control of surge bin activator transferred from PLC Fuel Preparation Plant to CCR UCP2.
- xi. ** Interlock provided from conveying air flow controllers to shut off valves.
- xii. ** Primary injector vent valve connected to automatically vent to avoid over feeding and line plugging in the event of rapid lowering of combustor pressure.
- xiii. ** Reposition final valves as near combustor as possible; so same valves can be used when larger pipework is installed, to reduce ash back pressure, to reduce unisolated line to minimum, and to enable maintenance to valves.

xiv. ** Insert thick dismantling piece spool piece
(spectacle plate) on fuel and bed material
lines above final valves.

* Modification in progress

** Modification in abeyance.

5.7

Fuel Injection Flow Rates

Although only 35 tonnes have been injected by the fuel feed system while under test, it was enough to demonstrate the inability of the system to exceed an injection rate of 2.4 tonnes/hr per line. As 3.2 tonnes/hr is required it is a serious problem. Of the lines that plugged, the plugging was at the first junction (MC8001) after the mixed-tee. Every indication while operating the plant would place the feed problem at the size of the pipe used. The fuel feed system uses 32mm ID pipe as against the bed material injectors 40mm ID. Conveying air pressure drops from the mixed-tees to the combustor are higher as would be expected considering the fuel feed and bed material injector handle the approx. same volume flow of air but have dissimilar sizes. Petrocarb have submitted a sketch for modifying a line - removing the first two right angle junctions (MC8001 - MC8002) and substituting four forty-five degree bends. The modification may solve the problem of plugging at these bends but is very likely to transfer it to the junctions (MC8003) above the sample pots where no forty-five degree bend will solve it. However, removal of the plugging is not going to increase the feed rate. The fuel feed system was effectively 'flat out' to achieve 2.4 tonnes/hr. Substitution of two right angle bends for four forty-fives will not reduce the friction losses that were evident even before the feed valves were opened. A primary injector differential of .7 Bar was required to increase the feed rate above that of gravity-lowering the conveying air flow to lessen the pressure drop did not improve the situation. Changing the conveying air pipe-work to 40 mmID (SCH.80) from 32 mmID (SCH80) all the way to the flange under the combustor should enable a feed rate of 3.2 tonnes/hr per line. There are in IEA stores some five sets of junctions, valves and mix-tees for use on this size line. They were originally for use on distributor plate D.B.2.A/B. If one line was changed and tried a conveying air set point of 75% should be used. There should be no need to change the present nozzles for use with 40 mm ID pipe.

5.8

Ash Dewatering and Water Treatment Plant

- i. * Pumphouse sump pump lifts dirty water onto the clearwell. Discharge pipe rerouted to balance tank.
- ii. Sumps in pumphouse and dewatering house unprotected. Steel grillage fitted at floor level.
- iii. Polyprep pump delivers coagulant into balance tank transfer lines, but continues to deliver when transfer pump shuts down. Reconnected to shut off polyprep pump in this circumstance.
- iv. * Clearwell and cooling pond flushing valves were out of the operator's reach. Modified to make them possible to operate.

* Modifications in progress.

5.9

Ash Conveying and Quench

- i. Ash conveying vessel orifice plugged by foreign matter and by damp ash. Screen installed to prevent this blockage occurring.
- ii. Kaymr valves on ash down legs required larger size actuators.
- iii. Conveying air receiver required a pressure gauge and a relief valve to be fitted.
- iv. Agitator motors on the four primary quench vessels rewound to correct voltage.
- v. Agitator on the bed ash quench vessel required its gearbox stiffening.
- vi. Each quench vessel has a high level and a low level ball operated level switch which communicates outside the pressure envelope by magnetic coupling. The permanent magnet is inside and close to the wall and its position is tracked by a soft iron follower outside. It was found that over a period of days, magnetic particles were building up on the magnets, and jamming the movements, so preventing signals.

The source of the particles was, in the main, the eroded water tubes at combustor bottom. Now the erosion has been modified out, it is likely that no further jamming will be experienced.

A water spray has been set up at each switch however, so that at any time and without interruption to the process, a spray of water can be turned on to any switch magnet to clear off any debris. The vessel level will have to be lowered below normal working level to clean the lower ones.

- vii. Slurry line temperature control injection points shifted downstream to where the slurry pressure is always less than the injection water pressure.
- viii. Quench vessel water level floats subject to surging from agitators. Additional baffles put in at base of stilling chamber.
- ix. In service the quench vessel vent valves eroded rapidly. Four actions have been taken:-

1. The base plug of each valve, in which erosion took place, has been stellite faced.

2. The flow through the valve has been reversed so the erosion is no longer directed at the vulnerable place.
 3. The vessel dipleg anti-syphon holes have been blanked, so incoming dust laden gas is forced to bubble up through the water and so the burden of dust tends to be taken up by the water. Because the purpose of the anti-syphon holes is to prevent back flow of water up to the cyclones in the event of overpressuring of a quench vessel above the pressure of its cyclone, the vent valves have been made fail-open in every eventuality, including high water level when the original logic provided closure of vent valves.
 4. The handset quenching water will be introduced into the vessel top as a scrubber spray, to remove dust from gas in the space above the water level.
- x. HP purge water valves causing water hammer. Plugs changed to equal percentage opening type; and restrictors fitted upstream.

5.10

Ashing Compressor

- i. Inlet manifold depression instrument changed to appropriate range.
- ii. Lubricating oil tank vent rerouted to outside wall.
- iii. Interlock for loss of instrument air (for purging and for sealing) rationalised.

5.11 Burner Air Compressor

- i. Loss of cooling water flow did not cause a trip. A flow switch was installed.
- ii. Inlet filter manometer installed.
- iii. Cooling water strainer pressure drop indicator fitted.
- iv. Oil pressure high trip setting was too low - reset to agreed higher value.
- v. Receiver drain - water trap fitted.
- vi. As a back-up supply, a pipe was laid from ashing compressor to the receiver.

5.12

Instrument Air

- i. No. 3 machine inlet filter manometer repositioned so operator could read it.
 - ii. Nos. 1 and 2 machine outlet valves repositioned to avoid injuring passers-by.
 - iii. ** No. 3 machine provided motive air to main receiver water traps; supply rerouted to common main.
 - iv. Drier inlet filter - isolation valve fitted to moisture trap.
 - v. Separate electrical isolators fitted to each compressor motor to allow separate isolation.
 - vi. Cabling to water solenoid valves reconnected to obviate earth faults.
 - vii. Single fuse for all controls replaced by one fuse for each machine.
 - viii. Additional timer fitted to drier to avoid fault signal at each changeover.
- ** Modifications in abeyance.

5.13

Fire and Process Water

- i. Additional alarm set up to detect loss of water supply to forebay main inlet valve.
- ii. Main inlet valve water taken originally from upstream side of filters - rerouted to take clean supply from downstream side.
- iii. Balance tank and pump auto-controls added to make system fully automatic.
- iv. Ash dewatering and water treatment plant branch fitted with strainer and reducing valve.
- v. Fuel preparation plant branch fitted with strainer and reducing valve.
- vi. Connection to cooling water system made with strainer and reducing valve, to allow facility shut down condition without having to run a main cooling water pump.
- vii. Balance tank originally intended to be gassed up by bottle Nitrogen. Pipeline put in to fill tank from nitrogen main.

5.14

Instrumentation and Control

- i. Impulse lines on steam/water circuit required top up points.
- ii. Generator, hotwell and receiver tank levels changed to 'dual wet leg'.
- iii. **Level of pressurised hotwell tank measurement requires temperature and pressure compensation.
- iv. In-bed tube bank evaporator control valve changed to fail open.
- v. Steam/water circuit valves in VKW supply modified to be compatible with the Series 4 control modules supplied by Babcock Bristol Ltd.
- vi. **Large steam/water control valves - actuators modified to increase stroking speed.
- vii. Turbo compressor vacuum transmitter raised to obviate condensate error.
- viii. Turbo compressor inlet filter humidity respecified.
- ix. Turbo compressor inlet resistance thermometer changed to 3 wire type.
- x. Turbo compressor discharge mass flow recalculated with new constants.
- xi. Turbo compressor speed control was incompatible with Micro B; outputs changed to pulse.
- xii. Storage, primary and bed material injector pressure transmitter ranges were changed to suit revised controls.
- xiii. Fuel injection weight rate and temperature control interface was rebuilt.
- xiv. Diluter airflow control valve positioners were removed from flow loops.
- xv. Fuel injection nitrogen purge system for pressure tapping points was rebuilt similar to combustor instruments.
- xvi. Fuel injection weight monitor - recording equipment scaling redesigned to improve accuracy.
- xvii. Fuel injection logic corrected in several instances.
- xviii. Fuel injection logic interface with alarm system redesigned.

- xix. Fuel injection power distribution - one fuse changed to nine fuses.
- xx. Fuel injection valve limit switches wiring redesigned.
- xxi. Fuel injection - additional valve inserted between surge bin and storage injector.
- xxii. Combustor thermocouples increased in size to avoid constant breakages.
- xxiii. Data logger - many hardware failures and software mistakes were rectified
- xxiv. Micro B converted to pulse operation.
- xxv. **Micro B-VDU updates too slowly
- xxvi. **Micro B - calibrated indicators required on set points to improve operator control.
- xxvii. **Micro B - software space required for future modifications.
- xxiii. Burners required pneumatic controllers for propane, nitrogen and burner air.
- xxiv. Ash quench - vessel V301 vent valve and pipework was replaced by larger size.
- xxv. Ash conveying - mass flow measurement temperature compensation changed in line with actual air temperature
- xxvi. Booster compressor - some control modules were removed as redundant.
- xxvii. Fuel pump - PLC memory changed from RAM to EPROM.
- xxviii. Fuel prep - PLC programme rewritten entirely.
- xxix. Fuel prep - every instrument has failed and been rebuilt.
- xxx. **Interlocks - Turbine speed/FRV inhibit overloaded compressor speed loop.
- xxxi. **Interlocks - PCV Limit switches unsatisfactory since on closing PCV to 20% FRV closes surging turbo compressor.
- xxxii. **Interlock - coal feed line break detector does not work - redesign required.

xxxiii. Interlock - a "firstup" print out on data logger was required.

xxxiv. Analysis - propane reranged from 0.1 to 1% to cover actual conditions.

* Modification in prograss

** Modification in abeyance.

5.15

Start-Up Propane Burner System

i.	<u>Flow Meters</u>	* Existing instruments to be re-calibrated and correction dated supplied for mass flow.
ii.	<u>Flow Meters</u>	**Fit individual flow indicators in each burner line to show volume flow.
iii.	<u>Main Panel</u>	Large condensers fitted across output voltage of the ionization amplifiers.
iv.	<u>Main Panel</u>	* Logic changes to be finalised for operation without freeboard burner.
v.	<u>Main Panel</u>	**Rearrangement of power supplies to to panel to make more 'secure'.
vi.	<u>Main Panel</u>	Design and fabrication of plug-in test box for logic checking.
vii.	<u>Cabling</u>	Crosses corrected in cabling between pre-mix burners.
viii.	<u>Cabling</u>	Minor faults corrected in panel wiring.
ix.	<u>Cabling</u>	Glands changed and wiring converted to Div.II Standards.
x.	<u>Propane System</u>	Atmospheric venting installed adjacent to combustor to allow N ₂ purging of gas line from Propane plant.
xi.	<u>Propane System</u>	Relays fitted within panel to give N ₂ purging of burners on main plant interlock failure.
xii.	<u>Propane System</u>	Change-over system installed in Propane plant allowing N ₂ purging and filling of gas line to Facility.
xiii.	<u>Propane System</u>	Pneumatic 'slugging' of one bottom burner main gas valve (to prevent undue 'hammer' on instruments).
xiv.	<u>Propane System</u>	Removal of manifolds on differential pressure controllers. Previously possible to feed propane directly to combustor air into propane line.
xv.	<u>Propane System</u>	All tapping points on Propane lines fitted with double isolation.

xvi. Premix Burner Air

Additional valves fitted to combustion air lines for fine control.

xvii. Panel

Final drawings required for panel, showing layout, wiring and logic.

* Modification in progress

** Modification in abeyance.

5.16

Turbo Compressor

- i. H.P. Compressor bearings failed due to oil whirl. Replaced by offset type bearings. See Section 4.15
- ii. H.P. and L.P. Compressors were originally fitted with vibration switches. Vibration indicators now fitted at gear box and all bearings except L.P. drive end. See full report.
- iii. H.P. Compressor rotor went out-of-balance on a number of occasions. Assembly rebuilt with shaft sleeves removed to improve thermal equalisation. See full report.
- iv. Blow off valve range increased to obviate surging under all but the worst condition.
- v. * Sound insulation on compressors and ductwork was not adequate as built. Further insulation fitted to reduce the sound hazard to operators.
- vi. **Lubricating oil tank was not fitted with oil heaters. Steam heaters provided to maintain temperature during a plant shut down.
- vii. Auxilliary lubricating oil pump (steam driven) steam pipe pressure drop was too great to allow pump to run adequately. Pipe re-routed, with some valves omitted.
- viii. Auto control of condensate extractor pumps did not work when on remote (CCR) control. Wiring modified to incorporate this.
- ix. **There was no provision for maintaining a dry atmosphere in the turbine during shutdowns. A fan and drier/heater is needed to achieve this.
- x. No local audible alarm was fitted to the turbine local panel. One was obtained and fitted.
- xi. Comprehensive vibration monitoring system installed.

* Modification in progress

** Modification in abeyance.

5.17

Booster Compressor

- i. On first run, the machine would not attain full speed. Turbine rotor was changed, and inlet guide vane assembly changed.
 - ii. The above changes did not allow full output to be reached. Turbine inlet pipe was rebuilt to larger bore and less severe bends, and fast acting inlet valve size increased.
 - iii. Only manual drains were fitted to compressor inlet and outlet coolers. Water traps were fitted to these drains.
 - iv. * To prevent inadvertently touching live terminals by an operator starting up the machine, and to keep out dust from the electrics, a perspex sheet is fitted across the lower part of the cubicle.
- * Modification in progress.

5.18

Fuel Conveying Air Drier

- i. On tower changeover, a severe drop in supply pressure was seen. By extending the repressurising time this has been reduced to an acceptable level.
- ii. On tower changeover, the fault alarm sometimes sounded. A new timer has been fitted to obviate this.
- iii. * During start up of the Facility, pressures of 3 Bar or less are maintained in the combustor, whereas the drier must be kept at 6 Bar or above for adequate drying. A reducing valve will be installed downstream of the drier in order to make less severe the pressure reduction seen by the flow control valves.

* Modification in progress.

NCB (IEA GRIMETHORPE) LIMITED

FLUIDISED-BED COMBUSTION PROJECT
GRIMETHORPE EXPERIMENTAL FACILITY

SECTION 6

Hot Commissioning to Established Hot Start-Up Procedure

6.1

Introduction

Hot Commissioning is deemed to have started on Sunday 3rd August, 1980 when the first attempts were made to heat up a fluidised bed by introducing propane through the distributor plate compartments. Work on developing a viable hot start-up procedure continued through until August 14th when tests were terminated by erosion damage to the primary quench vessel vent valves. At this stage a viable procedure had been developed for the controlled heating of a shallow fluidised bed with propane to temperatures in excess of 750°C, i.e. coal combustion temperatures.

Valve repairs and other maintenance work was accomplished over the next two weeks and hot commissioning recommenced on September 5th 1980. Hot start up commenced in earnest on 9th September and coal burning was achieved for some 45 minutes in the early hours of 10th September. The run was then abruptly terminated by a rapid loss of bed material and consequent loss of temperature control. At the time this phenomena was attributed to the rapid calcination of the dolomite, being used as bed material, at temperatures in excess of 700°C. The start up procedure was repeated on 16th September using inert Molochite as bed material. The same rapid loss of bed material was experienced as before and this time it was recognised that the flexible seal around the distributor plate was failing at temperatures around 650°C allowing bed material to fall back into the base of the combustor pressure shell. An attempt was made on 23rd September to reproduce the phenomena under more controlled conditions. The start up was aborted half way through when a tube in the in-bed tube bank eroded through due to impingement of solids from the bed material feeder. The nature of the distributor plate seal failure and the solutions are described in a separate report but the necessary rebuilding of the seal and replacement of eroded tubes and sections of water wall took until the middle of November.

Hot Commissioning recommenced on 19th November and a hot start up attempted on 23rd November. This start up was aborted for reasons described later. Subsequently seven successful hot start ups were achieved with a stable transition to coal combustion only; on 27th November, 3rd December, 9th December, 10th December, 11th/12th December, 16th December and 16th/17th December.

It is the purpose of this Section to describe the development of the Hot Start-Up Procedure from its conception in 1976 through to the successful outcome of December, 1980.

6.2

The Original Start-Up Procedure

In 1976, in collaboration with CURL Leatherhead, a tentative start-up procedure was drawn up and its requirements incorporated in the design sections of the relevant Tender Specifications. The fullest description was incorporated in the Instrumentation and Control Tender Specification issued in the Spring of 1977 and is quoted below. The description assumes semi-automatic control via the Micro B computer but the procedure would be identical under manual control.

The following description of the procedure for starting up of the plant given by way of example, covers that required when Tube Bank A is installed and subsequent operation is to be at 850°C bed temperature, 10 bar pressure and with an air mass flow of 31 kg/s. The example is based on the assumption that bed material stored in the bed material hopper has the required size distribution for operation under the stated conditions.

The first stage of start-up is to run up the compressor under local manual control with blow-off valve open and flow regulator valve closed. Control will then be passed to the remote station in the Control Room. The remote station will be used to establish the required air flow to the combustor. The compressor discharge pressure will be controlled to a constant pressure in excess of the freeboard pressure, which is equal to the system back pressure, with the pressure control valve wide open. The established air mass flow rate will be dependent on the prevailing combustor temperature and pressure in accordance with the following relationship that ensures that a constant state of fluidisation exists regardless of bed temperature and pressure.

$$M = \sqrt{\frac{x^2}{4y^2} T^{4/3} + \frac{P}{yT}} - \frac{x}{2y} T^{2/3} \quad \dots \quad (1)$$

M = Total mass flow of air into bed in kg/s.

T = Bed Temperature in °K

P = Freeboard Pressure in bar.

Where x = Constant)
y = Constant) To be set by the Operator.

In the present example of starting up, the initial air mass flow would be about 18 kg/s assuming the combustor pressure is about 2 bar.

Sufficient bed material is fed from storage under manual control to establish a fluidised bed approximately 0.6 metres deep. Four wall-mounted propane burners are ignited in sequence under manual control, subject to an automatic inhibit if any burner does not light or does not have the predetermined air/propane ratio. When all four burners are established propane is admitted, under manual control, to each of the 9 sections of the distributor plate in

sequence subject to an automatic inhibit if the predetermined gaseous combustibles content of the flue gas at the primary cyclone inlet is exceeded or failure of 2 out of 4 premix burners. During this process the bed temperature will rise from about 200°C to 700°C and the air mass flow will be progressively reduced in accordance with Equation (1) until it reached 8.8 kg/s at 700°C.

Coal flow to the combustor is now initiated through a single feed line under local manual control. When coal flow is established the bed temperature will start to rise and is countered by manually reducing the propane flow to maintain a bed temperature of 700°C. The bed temperature control is selected to automatic. Propane is progressively reduced under manual control allowing coal rate to increase automatically to maintain a constant temperature. From time to time additional coal feed lines will be brought into operation under local manual control.

When the four wall-mounted burners and the propane flow to the nine sections of the air distributor plate have been shut-down, manually, save for a small inert gas purge to the wall-mounted burners, coal feed will have been established on all coal nozzles.

At this time the air mass flow is increased to 14.3 kg/s the objective being to move from minimum safe fluidisation conditions towards the state of fluidisation to be used in the subsequent test. This is achieved by manually resetting the constants in the air flow control equation (1). The change is made as rapidly as is compatible with coal feed rate following to maintain a bed temperature of 700°C. The bed temperature is now set to the particular value (in the example 850°C) to be used in the subsequent test. The coal flow rate will automatically increase to obtain this temperature while the air mass flow automatically decreases to 13.1 kg/s according to equation (1). The resetting of the constants, bed temperature, etc. needs to be done with care as described later.

Feed of bed material from storage is now restarted under remote manual control. As the heat transfer tubes in the bed are progressively submerged, the tendency for bed temperature to fall is corrected automatically by increasing the coal feed rate. As the air mass flow remains constant, and the bed temperature remains at its set value, the oxygen content of the flue gas falls progressively. When the oxygen content reaches some predetermined value (expected to be that obtained under subsequent conditions of steady operation which, for the example will be about 7%), the air mass flow control will be transferred from the bed temperature and pressure relationship Equation (1) to maintaining constant flue gas oxygen content. At the same time, the down-stream pressure control valve is brought under automatic control to give a system pressure predetermined by a relationship between air mass flow and bed temperature;

$$P = x T^{5/3} M + y T M^2 \dots \dots \dots (2)$$

When the air flow regulator valve reaches the fully open position, air flow is controlled by regulation of the compressor speed.

Now, as bed depth continues to increase, coal feed rate increases to maintain a constant bed temperature of 850°C, the air mass flow increases to maintain a flue gas O₂ content of 7% and the system pressure will increase according to its present relationship. Only the rate of feed of fresh bed material is under manual control at this stage. This process continues until the required conditions for steady operation are reached, i.e. for the example 850°C, 10 bar and 31 kg/s.

The design of the combustor to accommodate this proposed start up procedure is illustrated in Figures 3 and 4. Figure 3 is a diagrammatic elevation of the two metre square furnace. DP's 1, 2, 3 and 4 are pressure measuring points in the walls of the furnace, there are three measuring points at each level. The indicated heights are the distances above the point at which air enters the fluidised bed through the holes drilled in the bubble caps. Figure 4 shows a detail of the distributor plate crosssection and also its plan view. It will be noted that the space between the top and bottom plates is divided into 9 compartments and numbered 1 - 1X Propane can be supplied at controlled rates to any of these compartments which then enters the fluidised bed through 10 selected bubble caps in each area. It will also be noted that the four main premix burners are off set from the centre line of each wall but are so orientated as to fire at the centre of the furnace. Compartments 11, 1V, V and VIII are laid out so as to introduce propane directly below the flames of the 300 kw main premix burners. It is not shown in Figure 4 but eighteen thermocouples penetrate the distributor plate and are so arranged as to measure the temperatures throughout the volume of the bottom 600 mm of the fluidised bed. Above each of compartments 11, 1V, V and VIII three thermocouples measure the temperature 290, 340 and 590 mm above the plate respectively. Above each of compartments 111, VI, VII and IX a single thermocouple measures the temperature 340 mm above the plate and above compartment 1 two thermocouples measure the temperature 340 mm above the plate. The readings of these temperatures are the major control variable during hot start up.

It will be noted that the originally proposed start-up procedure envisaged submerging the flames of the four main premix burners within a fluidised bed some 600 mm deep. The premix burners would be used to raise the bed temperature as high as possible, preferably to around 500°C the spontaneous ignition temperature of propane. However, it was always recognised that this might not be possible and that propane might have to be introduced through the distributor plate with average bed temperature well below 500°C, hence the orientation of compartments 11, 1V, V and VIII to introduce propane directly into the flames of premix burners. The purpose of the 150 kw Freeboard burner was to combust any propane which escaped the fluidised bed during the early low temperature, stage of start-up.

FIGURE 3 GRIMETHORPE EXPERIMENTAL FACILITY
FURNACE CROSS SECTION SHOWING
PRESSURE TAPPINGS AND PREMIX
BURNERS

The diagram is a plan view of a distributor plate, showing a 9x9 grid of air bubble caps. The overall dimensions are 1600 mm by 1760 mm. The grid is divided into nine 3x3 sub-grids, each containing a numbered circle (1-9) and a Roman numeral (I-IX). The circles are arranged in a 3x3 pattern, with the center circle of each sub-grid being shaded. The Roman numerals are placed in the center of each sub-grid. The diagram is labeled with various components: Premix Burner 1.1 (top center), Premix Burner 1.2 (top right), Premix Burner 1.3 (bottom right), Premix Burner 1.4 (bottom left), Air Bubble Caps (left side), Coal/Dolomite Feed Pipes (right side), Bed Material Injector (right side), and Ash Removal Pipes (bottom right).

FIGURE 4 Combustor Furnace Distributor Plate Design

6.3

Actual Hot Start-Up

In the Spring and Summer of 1980 further discussions were held with CURL Operations personnel for the purpose of finalising and detailing the hot start-up procedure. During the intervening years CURL had greatly increased their experience, in particular they had increased the range of fluidising velocities possible on the Leatherhead Combustor up to around 2.1 m/s; that is into the design range of the first build up of the Experimental Facility.

In the light of these experiences CURL expressed doubts on the viability of the original start-up procedure. They doubted whether the flames of the premix burners would be stable when submerged within the fluidised bed, further more additional information had allowed a reassessment of the likely heat-transfer coefficients within the Experimental Facility which suggested that even if the premix flames were stable when submerged they would not be capable of raising a bed 600 mm deep much above 300°C. Additionally they pointed out a weakness in the original design. Of necessity the Freeboard burner had had to be positioned above the tube bank at the 3.745 metre level thus if an inflammable propane/air mixture reached it there was likely to be a substantial volume of the mixture within the tube bank whose ignition could have undesirable consequences.

They suggested a modification to the procedure whereby the Freeboard Burner was dispensed with and start up was initiated using a shallower bed such that the flames of the four premix burners fired across the furnace immediately above the bed surface. Propane would then be introduced progressively through those distributor plate compartments immediately below the flames to raise the bulk bed temperature to 500°C and allow generalised propane firing on all compartments. Thus the premix burners would perform the function of combusting any propane escaping the bed but initiating that combustion immediately above the bed.

It was this procedure which was experimented with through August and September, 1980 when it was proved to be both viable and extremely flexible. Based on these experiences a detailed start-up procedure was worked up and issued to the Operating Personnel in November, 1980. Just prior to the second stage of hot commissioning. This procedure is given in full below:-

Hot Start-Up Sequence Rev. 3.

1. Carry out prestart checks.
2. Establish a flow of 19 kg/s on the steam feedwater circuit via the Broeker line and controlling the pressure on PCV 5522.
3. Start the burner air compressor and establish maximum air flow through the propane burners.
4. Start the turbo compressor and run up to 4100 rpm with the H.P. outlet set to 6-7 bar with a combustor pressure of 1.8 bar (fluidising velocity will be between 1.5 and 2 m/s). Air mass flow will be approximately 8 kg/s at 140°C.
5. Start the booster compressor with the valves to the fuel injection vessels system shut.
6. Establish conveying air at a reduced rate (approximately 50% of the normal conveying rate). Flow on diluter lines will be set at 35%.
7. Prepare ash transfer system, primary and secondary fines systems for operation.
8. Check nitrogen system is operating correctly.
9. Check propane system is operating correctly.
10. Prepare fuel injection system for operation.
11. Prepare burner system for operation.
12. Check all other services are available and operable and put the emergency generator on automatic standby.
13. Reset the main interlock system.
14. Light all four premix burners having reset air/fuel ratio. Ignition of premix burners 1.1, 1.3, 1.4 will be detected by thermocouples, 2105, 2107, 2101, 2103 respectively.
15. Ensure the Kamyr valves on the ash legs are shut and then establish a shallow fluidised bed of between 250 - 300mm deep. This involves feeding approximately 1 tonne of bed material. When the bed has been established DPlA, B and C should be reading between 10mb and 15mb.
16. Introduce a flowrate of approximately 0.5 MW (30% on the valve manual loading station) of propane to the underbed compartments commencing with those directly below the premix burners.

17. Compartments should be started in the order 11, V, 1V, V111 and 1 in succession waiting until the temperature stabilizes before introducing propane to another compartment. If there is no response within 1 - 2 minutes propane bypassing can be expected. A wait of 4 - 5 minutes between compartments is recommended.

The ignition of compartments 11, V, 1V, V111 and 1 will be detected by thermocouples 2111, 2112, 2109, 2110 2141 and 2146. Additionally thermocouples 2106, 2108, 2102 and 2104 should record similar temperatures to 2111, 2112, 2109 and 2110 as they are in the same compartments but lower down in the bed.

There may be a temperature rise shown on 2105, 2107, 2103 and 2101 as the respective bed sections ignite.

A check should also be made of any high local temperature in the tube bank.

18. Increase flow to the compartments 11, V, 1V, V111 and 1 by the manual loading stations in stages 50%, 60%, 80% and 100% in turn waiting for temperatures to stabilize at each stage. (100% is equivalent to 1.5 MW on each burner).

19. Propane is introduced to compartments V11, 111, 1X and V1 successively using the same procedure as before. The order of igniting the compartments depends on the lateral temperature distribution within the bed.

20. Whilst carrying out (19) the average bed temperature will reach 500°C at which time the bed material feed should be restarted at a rate of 1.5 - 2.0 t/hr.

21. As the bed deepens the temperatures across the bed should converge as rising temperatures allow the establishment of generalized propane combustion within the bed. To help this process the combustor pressure will be raised to approximately 2.2 bar at the restart of bed-material feed. The flow will be allowed to find its own level as the pressure is increased. (See Figure 5). After approximately $\frac{1}{2}$ hour the pressure can be further raised to approximately 2.5 bar.

22. The point at which coal feed can be started is the deepest bed at which average temperatures above 750°C can be maintained, DPIA, B and C should read at least 26 - 30mb. The oxygen level should be maintained at a minimum of approximately 7%.

24. Ensure that the average bed temperature is maintained above 750°C. Reset low bed temperature trip. Adjust conveying air flow on centre coal line No. 5 to operational level and start coal feed at minimum rate (0.7 - 1.0 tonne/hr. with 25mm mix tee).
25. As soon as bed temperature shows an increase, reduce the propane flow equally between areas by an amount equivalent to the minimum coal feed rate, which is approximately 3.25 MW.
1. If temperatures remain constant, increase coal feed rate and reduce propane flow so as to achieve 850°C bed temperature.
 2. If temperature rises, reduce propane flow when bed reaches 850°C compensating for any subsequent fall in temperatures by increasing coal feed rate.
 3. If temperature falls shut coal off, allow temperature to stabilise at 750°C and repeat exercise either with a higher coal feed rate or with a smaller reduction in propane flow.
 4. If temperature falls below 700°C shut off both coal and propane feed and repeat whole procedure from step 1, after leaving a sufficient time interval to purge the entire gas path with air (10 minutes at a combustor air flow of 10 kg/s).
- i. Bed temperature must be limited to 900°C.
 - ii. Oxygen content must be 7%.
 - iii. Oxygen content will respond more quickly than bed temperature.
26. Substantial freeboard combustion is indicated by bed temperatures remaining constant as the coal rate is increased with the oxygen level falling. If sub stoichiometric conditions become established the coal feed rate can be increased without affecting the bed temperature or the oxygen level but the carbon monoxide level will increase. This could cause a carbon build up in the bed and the bed temperature could go out of control.
27. Additional coal feed lines will be commissioned using procedure outlined in (25).
28. Conditions will be adjusted to get conditions onto the ramp line shown in Figure 5.
29. Having got onto the ramp line, the condition will be held long enough to characterise it.

Coal flow rate
 Air rate
 Flue gas analysis
 Temperature distribution
 Bed Δ P change with time

FIGURE 5 GRIMETHORPE EXPERIMENTAL FACILITY START UP SEQUENCE 11.12.80

30.

Continue up the ramp line. The coarseness of coal feed rate control probably enforces the following procedure -

- i. As bed deepens (from bed material injector allow temperature to fall to around 800°C).
- ii. Bring on another coal feed line and allow temperature to stabilise (up to 950°C is safe).
- iii. Simultaneously with ii. increase air mass flow and system pressure to hold O₂ content at 6 - 8% or at whatever level was established in 29 above.

This procedure will be continued until minimum flow is established on all coal lines. At this point the combustor will be quite high up the ramp line and the condition will be held to characterise the condition while considering the options:-

- i. Continue up ramp line (depends on bed depth, system pressure and performance of steam/water circuit).
- ii. Hold condition while investigating dynamics of steam/water circuit. The condensate recovery system will have been in operation throughout.
- iii. Terminate test by coming down the ramp line, hot commissioning the bed material transfer system to lower bed depth.

Option iii. will terminate the test whatever the final condition.

The premix burners have proved extremely temperamental with regard to establishing initial ignition. In many cases only two premix burners have been available when the start-up procedure was commenced. None the less the procedure has proved viable provided that only those distributor plate compartments below premix flames plus the central compartment are used for the initial phase of start-up.

There is a "dynamic" in the procedure during that phase of start-up when propane supply is being increased to the first 2 - 5 compartments. During this phase the bulk bed temperature is rising through the range 200 - 400°C and there is a tendency for unburned propane to escape the bed and bypass the premix flames. This phenomena is detected by a propane analyser obtaining its sample from the combustor outlet at the top of the pressure shell. If the rhythm required by the procedure is maintained, that is 4 - 5 minutes between each propane flow increase then over the first hour of start-up unburnt propane will increase steadily from zero to reach between 2500 and 3000 ppm as the bed temperature reaches about 400°C, thereafter the value declines rapidly to zero as the bed temperatures pass through 500°C, the spontaneous ignition temperature of propane. If the rate at which propane flow to the compartments is increased is significantly slower or faster than that recommended in the procedure then the amount of unburnt propane breaking

through increases and the propane content at furnace outlet can exceed 5000 ppm at which level the main interlock system shuts the Facility down.

Figures 6, 7 and 8 illustrate the bed temperature distribution during three typical start-ups. Figure 6 illustrates a second "dynamic" in the start-up procedure. When the bulk bed temperature is safely above 500°C the bed material feeder is restarted in order to deepen the fluidised bed to a depth suitable for coal firing (in excess of 600 mm) in parallel with the final stages of propane flow increase which raise the bulk bed temperature to around 750°C, the value required for coal firing. Figure 8 shows that from 16.15 hrs the bed was allowed to deepen too rapidly so that increasing heat losses to the walls caused the bed temperatures to peak at 700°C and thereafter decline to 650°C at which point coal feed was initiated. Temperatures then recovered rapidly and the transition to coal combustion without propane was successfully accomplished.

Figure 7 shows a normal start-up except that at 0010 hrs. pressure fluctuations in the propane supply system caused a total loss of propane. This situation was rapidly rectified and normal start-up continued successfully onto coal firing. In figure 8 the atypical behaviour of temperatures at the 590 mm level is attributable, it was subsequently discovered, to burning damage having occurred to several propane supply bubble caps particularly in compartments V and IV which were those in use for this particular start. The effects of this damage would have been to disturb even fluidisation in those areas and cause an unusually intense propane flame off the bed surface in these areas. It will be noted that from 22.30 hrs onwards, with the bed depth in excess of 600 mm and rising, effects due to this damage are no longer discernible. It should also be noted that, during the early stages of start-up a propane flame establishes itself above the shallow fluidised bed. Temperatures within the lower part of the tube bank rise with increasing propane flow as the start-up procedure proceeds.

6.4

The Transition from Propane to Coal Firing

In order to understand the imperatives of the transition to coal firing it is necessary to understand the process dynamics of the Petro Carb Fuel Injection system.

The Primary Fuel Injector vessel has nine conical outlets each of which connects to an individual pneumatic transport line. The layout of these transport lines on entry to the combustor is shown in Figure 4. Between each cone and the transport line there is a ball valve for isolation, a restriction called the "nozzle" and a "mix-tee", or ejector which encourages the transport air to pick up the fuel for transport to the combustor. The actual rate at which fuel flows through the nozzle is dictated by the pressure differential between the Primary Injector and the transport air at the mix-tee, however, the control variable which may be adjusted from the Central Control Room is the pressure differential between the Primary Injector and the fluidised bed at the level at which coal is injected into it. The booster compressor, which provides air to the pneumatic transport lines, takes a small portion of the air from the main Turbo-Compressor outlet and compresses it an additional 2 bar in order to provide the necessary driving force into the combustor. As has been described in 5.3 above during start-up the pressure at the outlet from the Turbo-Compressor is 5-6 bar whilst that in the combustor is 1.8 bar, control being exercised by the Flow Regulating Valve which is downstream of the branch to the booster compressor inlet. Thus at this stage of start-up the pressure at the outlet from the booster compressor/drier train can be somewhat in excess of 8 bar giving a differential across the coal feed lines in excess of 6 bar.

The control of transport air to each coal feed line is by means of a valve designed to vary the transport velocity on the assumption that the air pressure immediately upstream of it is 2.1 bar above that in the combustor at the point of coal feed. Thus, for a given setting of the control valves, the higher the pressure upstream of the valve the more air that passes the valve and the higher the pressure drop across the transport line from valve to the combustor. Therefore the higher the pressure upstream of the control valve the higher is the actual pressure on the transport line at the "mix-tee" where the coal from the Primary Injector joins the transport air. It is the pressure differential between the Injector Vessel and the transport air at the "mix-tees" which controls the rate of coal flow out of the vessel into the transport line. However actual control of coal feed rate is by means of a differential controller which adjusts the pressure difference between the Injector Vessel and the combustor at the point of coal feed, thus for a given setting of this differential, it is possible during start-up to change coal feed rate by changing the pressure of the transport air. These pressure differentials

are automatically applied to all nine coal feed lines thus, in theory, any setting will give the same coal feed rate on all nine lines.

The Petro Carb system in its present build is designed to feed up to 16 tonnes/h of solids on only 5 lines with a turn down of 3:1 on each line. Thus, if the pressure upstream of the air flow control valves is as per design specification, adjusting the pressure differential between the injector vessel and the combustor should allow coal feed rate to be controlled between 1.1 and 3.2 tonnes/h. However the additional ability to increase the pressure of the transport air at the mix-tee allows a further reduction in the minimum flow. At the initial start-up condition with a pressure of 1.8 bar in the combustor and around 8 bar immediately upstream of the transport air control valves with a 25mm nozzle in the mix tee the minimum flow is around 0.8 tonnes/h.

As coal leaves the Injector Vessel it passes through a nozzle which directs it into the "mix-tee". To cover the range of coal size spectra originally specified to Petro Carb they supplied three sizes of nozzle; 19mm designed for coal with a top size of 1.6mm. 25mm and 29mm designed to cover an originally wide range of flow rates for coal with a top size of 5 - 6.6mm. To obtain 16 tonnes/h on 5 lines would require the 29mm nozzles which for 5mm top size coal have a minimum flow around 1.5 tonnes/h even with manipulation of the transport air pressure. The 19mm nozzles have a minimum flow around 0.5 tonnes/h using coal with a top size of 5 - 6.4mm but not being intended for this size spectra they show a tendency to choke.

When first starting coal feeding it is desirable to use the minimum flow available in order to obtain the best temperature control during the transition from propane to coal firing. It has proved undesirable to increase the coal feed rate through the first line with progressive reduction of propane flow because when a second coal feed line is required it necessarily starts to flow at the same relatively high rate achieved on the first line causing an unacceptable step change in the rate of heat input. The aim must be to have three or four lines feeding coal at something near their minimum rate at the point where propane is no longer required.

The transition from propane to coal firing as run by the control room operators would be as follows:-

Once the initial propane supply compartments are at 100% the rest of the compartments can be brought in, the order being the compartments in the highest temperature areas being brought in first. With bed temperatures approaching 600°C the bed material feed is recommenced and continued until DP1 reads around 70mb

indicating a bed depth around 900mm. As the bed deepens the combustor pressure needs to be increased to 1.5 bar (g) in order to power up the propane system and reduce air flow rate to give bed temperatures in excess of 750°C which is the minimum requirement for the commencement of coal feeding.

On achieving a value of DP1 in excess of 35mb and temperatures average of around 750°C the bed depth is in excess of 600mm and rising and coal can be fed to the combustor through line 5, the central nozzle, using a differential pressure between the combustor and primary injector of 0.7 bar which is the minimum differential that will give a continuous coal feed without plugging the line. Temperatures then increase rapidly and to compensate for this the propane is cut back on all compartments to bring the temperature down to around 800°C. The differential between the combustor and primary injector can be increased up to 0.9 bar which in turn increases the coal feed rate and hence the bed temperatures which means that the increase must be again compensated for by reducing propane flow. It is important that after each incremental change in operating condition a sufficient period of time be allowed for the full effect of the change to be realised, otherwise a see-sawing effect will be experienced with the bed temperatures. When the injector/combustor differential approaches 0.9 bar then a second line should be brought into operation. To do this the differential is reset to 0.7 bar and the second line put into service. The pressure in the primary injector is relieved to the desired value by flicking open the vent and shutting it again immediately.

The O₂ analyser in the exhaust gas stream is observed closely to ensure that sufficient air is available to burn the coal being fed to the combustor. The fluidising velocity should be controlled to around 2m/s to minimise elutriation but initially it is found that insufficient O₂ was available and fluidising velocities of around 2.5 m/s were required until the combustor pressure reached about 4 bar (a) at which point the Freeboard Pressure Control Valve together with the Flow Regulating Valve can be adjusted to bring the operating condition back onto the ramp line. It is important also to have as many coal feed lines in service as possible at any one time and preferably operating with a low differential so that a blockage in one line can be quickly compensated for by increasing the differential in the primary injector. This gives time to allow the blocked line to be identified, isolated and a new line brought into service by the method indicated above. Blockages are normally in the mix-tee under the primary injector. Once the line has been isolated from the combustor the blockage can usually be cleared by stimulating the coal around the tee with the conveying air momentarily.

As a guide to the number of coal feed lines that can be put into service at any one time it should be noted that until the bed depth is two metres no more than 4 coal feed lines should be in use.

Once the operating conditions have been brought onto the ramp line the procedure is to step open the Flow Regulating Valve to increase the air flow rate to the combustor and to run up the ramp line. When the turbo compressor H.P. outlet pressure falls to $5\frac{1}{2}$ bar with the Flow-off Valve closed then the I.G.V.S. are opened intermittently with the F.R.V. until the F.R.V. is fully open maintaining $5\frac{1}{2}$ bar at the turbo compressor H.P. outlet. The I.G.V.S. are at present opened to a maximum of 20° with the freeboard pressure control valve being adjusted to keep operating conditions on the ramp line. The FRV and freeboard pressure control valves are operated with step increments of about 2%. Once the I.G.V.S. are at the 20° position further movement up the ramp line is increasing the turbine speed together with freeboard pressure control valve adjustments. A 50 r.p.m. increment in speed control with necessary adjustments at the F.P.C.V. assists a steady rise up the ramp line without varying bed temperatures excessively. Any increase in flow rate and pressure in the combustor need to be compensated for on the fuel injection system by the operator and hence a close liason with the operator must be maintained at all times.

Figure 9 shows the final stages of the transition to coal firing followed by an advance up the ramp line shown in Figure 5.

FIG. 9 TYPICAL TRANSITION TO COAL FIRING AND ADVANCE UP THE RAMP LINE

NCB (IEA GRIMETHORPE) LIMITED

FLUIDISED BED COMBUSTION PROJECT
GRIMETHORPE EXPERIMENTAL FACILITY

SECTION 7

Operating Procedures

7.1

Introduction

Due to the experimental nature of the Grimethorpe Facility, it is of paramount importance to have explicit and up-to-date operating procedures. This is particularly important as several areas of the plant operation have been, and will in the future be, developed in light of operational experience. Plant modifications and the addition of a large amount of research instrumentation also emphasise the need for up-to-date drawings, procedures and plant operating records.

The operating procedures at Grimethorpe have been developed at two levels:

- (1) At the higher level the documentation is specifically aimed at the Operations Engineer.
- (2) From the documentation produced in (1) above, procedures for the Process and Assistant Operators have been developed.

7.2

Operating Manuals

Initially NCB (IEAG) commissioned Preece Cardew & Rider Ltd., (Consulting Engineers) to write the first draft Plant Operating Manual. This document was completed in its final form in April 1980.

The document consisted of an overall start up and shut down procedure for cold and hot start up together with specific start up, shut down procedures and technical data on various plant areas. In developing the overall start up and shut down procedures the consultants relied heavily on NCB (IEAG) and CURL staff. The specific plant area sections were developed from information supplied by individual contractors in their operating and technical manuals.

The Preece Cardew & Rider manual consisted of the following sections:-

- (1) Introduction including overall Facility start up and shut down instructions with logic diagrams, permit to work system and basic philosophy of each system.
- (2) Detailed technical descriptions of specific plant areas. Most of this information was obtained directly from manufacturers specific technical data, and incorporated comments from the Taylor Woodrow commissioning team and NCB (IEAG) staff in developing the relevant operating procedures.

In April, 1980 NCB (IEAG) recruited a chemical engineer who was given the responsibility for developing and updating Plant Operating Procedures.

The work has been concentrated in the following areas. It must be again stressed that due to the experimental value of the Facility most of the tasks require constant updating.

- (1) Revision of the existing Preece Cardew & Rider Manual in light of commissioning and operating experience.
- (2) Abstracting the relevant information from the PCR Manual to produce documentation for the Facility Process Operators.
- (3) Development of run sheets for specific plant areas in light of (1) and (2) above.
- (4) Production and development of an overall Facility Start Up Procedure.
- (5) Overall production of Facility safety and pre-start checks. In particular these included detailed procedures and test documentation for plant interlock testing.
- (6) In conjunction with (5) above, pre-start check lists were initiated for each area of plant and the relevant documentation was provided.

7.3

Revision of PCR Manual

As stated previously the accuracy of the PCR Manual was largely dependent on manufacturers information. In many cases the manual was inaccurate due to late design changes, lack of technical information from contractors, or revised procedures and/or modifications which occurred during the plant commissioning phase. The different standards of various companys' technical manuals was reflected in the quality of certain sections of the PCR Manual. The project is working to achieve a uniform standard of procedures throughout the plant by supplementing those sections of the plant which are either out of date or need clarification.

In order to have accurate information on which to base the plant procedures, up-to-date drawings are essential. Prior to the plant start up and during shut down periods Process Operators have been marking up existing process and instrumentation drawings in conjunction with Operating Engineers.

A good example of a revision of the PCR manual is the section on the Turbo Compressor and Booster Compressor systems.

As a result of an extended commissioning there were many changes in the system from that described in the PCR Manual. In particular there were several changes in instrumentation and control and operating philosophy. This situation was exacerbated by having three different contractors, one for the steam turbine, one for the two stage process air compressor and one for the expander and booster compressor.

The first step in rewriting the Procedure was to obtain up-to-date as built drawings. Having obtained this the section was completely redrafted by the Procedures Engineer with assistance from the Operations Engineers, the Turbine Drivers and Process Operators.

The revised section was then circulated to operators and engineers for comment. As contractors' personnel were still visiting the site on the final reliability runs a draft of the section was sent to them for comment. All comments were then incorporated into the final document.

This document in its final form was then passed to new Turbine Drivers and Process Operators as the basic technical and operating document.

A similar procedure has been adopted on other plant areas but in some systems a complete rewrite is not necessary.

The Fuel Feed Injection System was built and has been operated according to the company's technical manual. This was reflected in the accuracy of the PCR section on this plant area. The changes in this section were due to minor modifications during commissioning. Additionally the Taylor Woodrow commissioning engineer produced a detailed logic drawing to supplement the operating procedures.

Once an accurate and up-to-date procedure has been developed, any Plant modifications which affect any area of plant operation are recorded and incorporated into a revised Operating Procedure.

7.4

Documentation for Process Operators

The Facility has twelve Process Operators who control various plant areas from the central Control Room, with assistant operators out on the plant. To facilitate training and operation each operator has been trained specifically on one plant area. When he is familiar with that area he is then put onto another area to learn that. Eventually it is planned that all the operators will be able to operate each plant area to give flexibility and an awareness of the whole facility operation. It is especially important on this Facility where one area of operation is dependent on others for stable operation.

The Facility for control room purposes has been split into four areas:-

- (1) Turbo-Compressor, Booster Compressor and control of the combustor pressure.
- (2) Steam/water circuit which includes all the tie ins with the Facility Power Station.
- (3) The Fuel Feed and Bed Material Systems (Petrocarb) and the propane burner systems.
- (4) The Fines and Ash Removal, and Quench Systems and the water treatment plant.

Documentation based on the revised PCR document has been given to the Process Operators. Training sessions have been held with the operators by the Taylor Woodrow commissioning engineers and contractors representatives.

Any changes in operating procedures by the process operators is incorporated into the documentation.

7.5

Development of Runs Sheets

The Procedures Engineer in conjunction with the Operations Engineers and Process Operators from a detailed study of overall and individual plant operations have developed log sheets for each plant area.

These specify what readings to record and at what frequency. This involves discussions with Experimental Programme personnel to ensure that all data they may require is also recorded.

The run sheets are generally split into two groups, control room and outside plant logs. The former are recorded by the Process Operators and the latter by Assistant Operators.

7.6

Production and Development of Overall Facility Start Up Procedure

The initial procedure written in the PCR Manual was developed from the original design concept which has since altered due to experience gained by CURL during the Project construction phase and the 'Link Tests'.

The procedure for hot start up was therefore developed in conjunction with Operations and CURL representatives.

For the first initial runs the procedure was revised in light of operating experience from each start up. The procedure now has been refined from the point of cold start to stable coal firing and only minor changes in this part of the procedure are envisaged in the future.

Changes in start up procedures for some plant areas such as steam/water circuit and ash removal system will be made as a result of operating experience.

7.7

Production of Facility Safety and Pre-Start Checks

The Facility has a main interlock system which trips the combustor on the activation of 13 trips. These include trips such as power failure, high temperatures and high hydrocarbon gas levels.

After each major plant shut down for maintenance and modifications the complete integrity of this system is checked. As many trips that can be physically activated are operated, the remainder such as high temperatures and pressures are simulated by instrument signals.

All the interlocks are tested and trip levels recorded. The completed interlock test document is then retained with the controllers log.

7.8

Individual Plant Areas Pre-Start Checks

In conjunction with the interlock test carried out above detailed pre-start checks are carried out on each specific plant area. These are normally carried out by the Process Operator.

These check lists are very specific, including valve positions and controller settings. The aim is that after a long outage no vents, drains are open or other valves in incorrect positions so that the plant can start up safely.

Some check lists are carried out during the running on a shift or daily basis. All the check lists are retained with the controller log. The overall pre-start checks and three for the ash removal systems are attached by way of example.

By way of example the generalised Pre-Start Check List plus the detailed list for the Exhaust Gas System are reproduced in Appendix III.

7.9

Summary

Operating Procedures have been developed for all main plant areas. However, as stated before it is still an ongoing task to update these in light of operating experience and plant modifications.

The additional research instrumentation will require detailed procedures to ensure that they do not impair on the present plant integrity. The procedures engineer and other operations personnel have been involved in the approval of both the format and content of the R.I. Operating Manuals being written by Babcock Woodall Duckham (the main contractor for the Research Instrumentation).

Operating Procedures will need constantly modifying during the life of the Project to ensure safe and efficient operation of the Facility.

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APPENDIX I

A.1.1. A List of Commissioning Documents

A.1.2 A Typical Commissioning Document
(Instrument Air Compressors)

1. Commissioning Documents Developed for the Facility

1. Steam and Water Circuits.

Part I Consensate Polishing Plant

II Pumps, Boiler Circuits, Vessels.

III Dump Steam System

2. Nitrogen Store and System.

3. Propane Store and System.

4. Gas Oil Store and System.

5. Fuel Preparation Plant.

6. Fuel and Bed Materials Injection Plant.

7. Ash Dewatering and Water Treatment Plant.

8. Bed and Ash Conveying and Quenching Plant.

9. Ashing Compressor.

10. Burner Air Compressor and System.

11. Instrument Air Compressor and System.

12. Fire and Process Water Pumps and System.

13. Lifting Appliances, and other statutory inspection plant.

14. Heating and Ventilation.

15. Auxilliary Steam System.

16. Exhaust Gas System Pressure Test.

17. Control Room and System

18. Electrical and Diesel Generator.

19. General Services

20. Burners.

21. Turbo Compressor, Booster and Drier

21A Turbo Compressor

21B Booster Compressor

21C Conveying Air Drier

- 22. Cold Run with Pseudo Fuel.
- 23. Safety Tests and Partial Start-Up

- Part I Safety Interlock Tests

- II Simulated Start-Up on Hand Control

- III Dynamic Engagement of Auto Control

- IV Safety Mode Demonstration

- IV Partial Hot Start-Up

A copy of Document 11, Issue B, is attached as an example of these.

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2. A Typical Commissioning Document.

DOCUMENT NO. 11

Instrument Air Compressors and Drier and Distribution

ISSUE B.

24th September, 1979

	<u>DESCRIPTION OF TEST</u>	<u>SIGNATURE OF N.C.B. (IEA)</u> <u>WITNESSES AND RESULTS</u>
	<p><u>PRELIMINARY</u></p> <ol style="list-style-type: none"> 1. Check that all necessary work test certificates are to hand and satisfactory. 2. Check that all instrumentation is calibrated and recorded correctly and adequately. 3. Check that all installation and erection has been carried out correctly. 4. Check that all necessary construction checks (such as NDT, radiography etc.) were carried out and recorded satisfactorily. 5. Check that all necessary construction tests (such as leak, hydraulic etc.) were carried out and recorded satisfactorily. 6. Check that the plant is safe to operate in respect of fire precautions and all safety requirements. 7. Check that plant operating limiting parameters and the extent of plant to be tested are declared, and operation staff advised of these limitations. 8. Check that the plant is operated under the NCB Permit to Work System. 9. Check that the necessary restricted access system is in force for live testing; access to Control Room will also be limited at such times. 	

	<u>DESCRIPTION OF TEST</u>	<u>SIGNATURE OF N.C.B.(IEA)</u> <u>WITNESSES AND RESULTS</u>
	<p><u>General Principles</u></p> <p>The plant will be operated, as far as possible, from the Central Control Room, and in as near to design state as the performance testing will allow.</p> <p>Readings taken and logged during each part of the tests will be lodged as results, as required in this document. Analysis performed subsequently will also be lodged as further results.</p> <p>The Master copy of this document is the one held by the N.C.B.(IEA)/T.W.C. Commissioning Dept. and all results and signatures must be added as soon as possible after each test is performed.</p>	

	<u>DESCRIPTION OF TEST</u>	<u>SIGNATURE OF N.C.B. (IEA)</u> <u>WITNESSES AND RESULTS</u>		
		1-2-3	2-3-1	3-1-2
	<u>INSTRUMENT AIR COMPRESSOR</u>			
2.	<u>COMPRESSOR STARTUP AND SAFETY</u>			
1.	Set selector switch to appropriate position, and all compressors on continuous duty.			
2.	Check that unloader valve closes as compressor comes up to speed.			
3.	Check and record pressure at which the duty compressor cuts out. (unloader valve opens) (7 bar).			
4.	Reduce pressure in system by opening receiver drain valve(s) and check and record the pressure at which the duty compressor loads up (unloader valve closes) (6.8 Bar).			
5.	Continue pressure reduction and check and record the pressure at which the first standby compressor loads up. (6.5 bar).			
6.	Continue pressure reductions and check and record pressure at which second standby compressor loads up (6.3 bar).			
7.	Continue pressure reduction, and check pressure at which low pressure alarm is initiated (6.4 bar).			
8.	Continue pressure reduction and check pressure at which low-low pressure alarm is initiated (5.8 bar).			
9.	Stop pressure reduction, and allow pressure to rise. Check pressure at which low-low pressure alarm is cancelled.			

	<u>DESCRIPTION OF TEST</u>	<u>SIGNATURE OF N.C.B. (IEA)</u> <u>WITNESSES AND RESULTS</u>		
		1-2-3	2-3-1	3-1-2
10.	Allow pressure to continue to rise, and check pressure at which low pressure alarm is cancelled.			
11.	Allow pressure to continue to rise, and check pressure at which 2nd standby compressor unloads (6.5 Bar).			
12.	Allow pressure to continue to rise, and check pressure at which 1st standby compressor unloads (6.7 Bar).			
13.	Allow pressure to continue to rise, and check pressure at which duty compressor unloads (7.0 Bar.)			
14.	Switch each compressor to intermittent duty.			
15.	Reduce pressure in system, and check pressure at which duty compressor starts up (6.8 Bar).			
16.	Allow 15 minutes to pass with duty compressor running, then continue pressure reduction and check and record the pressure at which the first standby compressor starts up (6.5 Bar).			
17.	Allow 15 minutes to pass with 1st standby compressor running, then continue pressure reduction and check and record pressure at which second standby compressor starts up (6.3 Bar).			
18.	Allow 15 minutes to pass with 2nd standby compressor running, then allow pressure to continue to rise, and check pressure at which 2nd standby compressor shuts down (6.5 Bar).			
19.	Allow 15 minutes to pass with 1st standby compressor running then, allow pressure to continue to rise, and check pressure at which 1st standby compressor shuts down (6.7 Bar).			
20.	Allow 15 minutes to pass with 1st standby compressor running then allow pressure to continue to rise, and check pressure at which duty compressor shuts down (7.0 Bar).			

	<u>DESCRIPTION OF TEST</u>	<u>SIGNATURE OF N.C.B.(IEA)</u> <u>WITNESSES AND RESULTS</u>		
		Compressor No. 1.	Compressor No. 2.	Compressor No. 3.
21.	During the above tests, simulate a failure in the cooling water supply on each compressor in turn, check that the alarm is initiated and note the set point of the flow switch.			
22.	Simulate low oil pressure, check that running compressor trips and record trip pressure.			
23.	Simulate high air temperature and check that running compressor trips and record trip temperature.			

	<u>DESCRIPTION OF TEST</u>	<u>SIGNATURE OF N.C.B. (IEA)</u> <u>WITNESSES AND RESULTS</u>	
		Drier on Timer Control	Drier on Dewpoint Control
3.	<u>AIR DRYER STARTUP</u> 1. With air compressors running and a leakage to atmosphere by temporary vent pipe, downstream of drier. 2. Switch on the dryer at individual control panel and check that indicator lamp lights. 3. Slowly crack inlet valve to ensure a slow build up of pressure in dryer chamber. 4. Check that there is a flow of air from the chamber under reactivation. 5. Check position of timer cams to ensure correct speed. 6. Check changeover for two sequences (at 6 hour intervals) to ensure correct reactivation. 7. Check dryness of air at outlet. 8. Check oil content of air outlet. 9. Simulate all faults, and check that the group alarm "drier fault" is initiated.		

	<u>DESCRIPTION OF TEST</u>	<u>SIGNATURE OF N.C.B. (IEA)</u> <u>WITNESSES AND RESULTS</u>		
		Compressor No. 1.	Compressor No. 2.	Compressor No. 3.
4.	<u>PLANT PERFORMANCE</u> Carry out capacity check by monitoring change of receiver pressure and temperature with time up to maximum receiver pressure, (12.5m ³ /min.)			

	<u>DESCRIPTION OF TEST</u>	<u>SIGNATURE OF N.C.B. (IEA)</u>		
		<u>WITNESSES AND RESULTS</u>		
		1-2-3	2-3-1	3-1-2
5.	<u>ACCEPTANCE TRIAL ON LOAD</u> 1. With temporary atmospheric vent set to 1½ x a compressor full output and all compressors on continuous duty, run plant for 16 hours, to ensure the duty compressor runs at full load continuously and the first standby loads and unloads at regular intervals. Run drier on dewpoint control, and check dryness of air. 2. At the end of the 16 hours 1½ x run, open vent further until 2nd standby compressor starts. Maintain this setting of 2½ x a compressor full output to ensure the 2nd standby compressor loads and unloads at regular intervals, for 8 hours.			

	<u>DESCRIPTION OF TEST</u>	<u>SIGNATURE OF N.C.B. (IEA)</u> <u>WITNESSES AND RESULTS</u>		
		1	2	3
6.	<u>FUNCTIONAL AND COMMISSIONING TESTS</u> <u>NORMAL LOAD</u> Maintaining compressors on normal load, check and record the following at appropriate intervals of time. For a month. (a) Compressor cooling water outlet temperature. (b) Instrument air receivers temperatures. (c) Manifold pressures in plant building. (d) Drier pressures. (e) Air aftercoolers Pressure. (f) Instrument Air receivers pressures.			

	<u>DESCRIPTION OF TEST</u>	<u>SIGNATURES OF N.C.B. (IEA)</u> <u>WITNESSESS AND RESULTS</u>
7.	<u>SYSTEM CHECK</u> Visit each manifold on the system. 1. Connect a pressure guage and record the pressure. 2. Open drain valve fully, and record manifold pressure. 3. Close drain valve, and record manifold pressure.	

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APPENDIX II

Extracts from the Document setting out
the Principles of Commissioning Test Management.

The following are extracts from the Technical Management Document (TMD.21) as issued to all relevant personnel:-

A.2.1 General Principles of Testing

- (a) The plant will be operated from the central control area and as close to the contract state as the testing will allow.
- (b) Local operations should be regarded as an exception to this general principle only because it is unavoidable. Compliance with this principle allows the progressive build up of operator experience and early familiarisation with normal operating procedures, together with an early opportunity to ensure that control room equipment is satisfactory.
- (c) All plant limitations, relating to the plant under test and peripheral supporting plant will have been declared and operational staff advised of such operating limits.
- (d) All instrumentation associated with item (c) above will have a final pre-start check immediately in advance of combined system testing.
- (e) All administrative procedures in respect of permits to work, plant isolations, fire procedures and general safety must be formally cleared prior to testing starting.
- (f) A system of restricted access to be set up for the plant under test including the central control room.
- (g) Copies of all readings taken from running plant will be lodged with the commissioning team before such readings are allowed off site to any other group or body.
- (h) The operator is expected to log all readings of instrumentation in the control room that relate to plant under test and a comparison of local versus control room readings should subsequently be made where comparable readings exist.
- (i) For any operation requiring remote control, a communications system will exist between the remote operator and the control room.

A.2.2 Test Management

It is expected that the testing will be managed by a test manager, who will be appointed by NCB(IEA)/TWC. The test manager will be the main line of liaison between the management body and the contractor whose plant is under test. The test manager will also be assisted by other personnel from NCB(IEA)/TWC including operating staff to man the control room.

A formal commissioning management panel will be set up for vetting the state of plant documentation prior to Testing that will give authoritative clearance for testing to proceed.

In order to ensure that the plant under test is not put at risk it is considered essential that any work on in-service or standby plant should be approved through the test manager.

Access to plant, including controls and instrumentation, must be requested for approval through the test manager. This will avoid situations where well intentioned independent bodies, who may not have a wide understanding of the overall implications, have access to equipment and thereby introduce an unknown risk.

A.2.3. Appointments and Duties of Test Managers
(As issued to Contractors)

NCB (IEA Grimethorpe) Limited require that each commissioning activity shall be conducted against a commissioning management document which lists out all the chronological stages through which the commissioning activity will proceed. No new activity will be commenced until evidence exists in the Master Copy of the Document that all preceding stages have been carried out. Until further notice the Master Copies are kept in the Commissioning Office on the top floor of the NCB (IEA) Control Block. The documents are generated by NCB (IEA) incorporating contractor documentation as appropriate.

NCB (IEA Grimethorpe) Limited intend to appoint a 'Test Manager' responsible to NCB (IEA), for the commissioning of each contract. At a later stage when integrated commissioning requires several contractors' equipment to be running, NCB (IEA) will appoint a Supervisor on each shift to co-ordinate the activities of the various Test Managers.

The Test Manager will be responsible for co-ordinating all the inputs and activities of his particular Commissioning Management Document and will be responsible for ensuring that all previous actions listed have been carried out before any new activity is proceeded with. Where a contractor requires additional labour for carrying out a test, the Test Manager will be responsible for procuring such labour from NCB (IEA) and will also be responsible for ensuring that the Contractor properly instructs such labour in their duties.

No Permit to Work for any commissioning activity will be issued without the prior authorisation of the relevant Test Manager.

Immediately prior to the commencement of any process commissioning activity the Test Manager will organise a formal meeting of all concerned and NCB (IEA) Safety Management. This Meeting will ensure that all necessary safety precautions have been planned and take steps to ensure that any overall site safety requirements are actioned.

The NCB (IEA) Weekly Commissioning Meeting will continue overall co-ordination of the commissioning activity.

A.2.4 Test Manager responsibilities were allocated as follows:-

	<u>Contract</u>	<u>Test Manager</u>
1 I	Condensate Polishing Plant	P. Rothwell
1 II	Steam/Water Circuit	S. Howard
2	Nitrogen Plant	S. Grant
3	Propane Plant	S. Grant
4	Gas Oil	J.R. Hooper
5	Fuel Preparation Plant	G. Griffiths
6	Fuel Injection	S. Grant
7	Ash Dewatering	P. Rothwell
8	Ash Quench	P. Rothwell
9	Ashing Compressor	S. Grant
10	Burner Compressor	W. A. Wildbore
11	Instrument Air	J. R. Hooper
12	Fire and Process Water	J. R. Hooper
13	Lifting Appliances etc.	J. R. Hooper
14	Heating and Ventilation	A. Paskins
15	Auxilliary Steam	A. Paskins
16	Exhaust System Pressure Test	G. Griffiths
17	Control & Instrumentation	P. Greetham
18	Electrics and diesel generator	R. Belshaw
19	General Services	J. R. Hooper
20	Burners	S. Howard
21A	Turbo Compressor	W. A. Wildbore
21B	Booster Compressor	W. A. Wildbore
21C	Conveying Air Drier	W. A. Wildbore

NCB (IEA GRIMETHORPE) LIMITED

FLUIDISED BED COMBUSTION PROJECT
GRIMETHORPE EXPERIMENTAL FACILITY

APPENDIX III

- A.3.1 Start-Up Procedure : Revision 3 of 080880/CJW
- A.3.2 Pre-Start Check List for Exhaust Gas Services :
Cooling Water, Purge Water, Steam, Nitrogen and
Lubrication.

A.3.1 Start Up Procedure : Revision 3 of 080880/CJW

Prestart Checks

- a. All checks presently carried out on individual systems compressor, steam/water circuit etc., should be carried out as normal. Additionally, the following checks should be carried out daily before start up.
- b. Kaymr cooling pumps must be operable to protect the gas analysers.
- c. Check all the gas analysers are operational. Inject test gas daily and check calibration.
- d. Check there is N_2 flow to all the combustor probes, analyser etc.
- e. Establish a flow of approximately 19 kg/s through the steam/water circuit via the Broeker line. Check the auto-changeover of the boiler feed pump and check that the emergency generator is running.
- f. Check all systems healthy to allow main interlock to be reset.
- g. Press the bed temperature override switch and route the steam water circuit via the start up lines and valves HCV 5521, PCV 5019. Shut the two valves on the Broeker line HCV 5522 and HCV 5523. Ensure that controllers PIC 5522 are set on automatic.
- h. Check Butterfly valve on the start up vessel is in its correct position and log its position.
- i. Inject a high hydrocarbon gas mixture into the hydrocarbon analyser and check that this trips the main interlock system.

The main interlock trip should initiate the following:-

- i. Close quick shut off valves on the primary fuel feed lines AV 8007/1 - 9.
- ii. Close propane valves to main burners GP 2318/1 - 9 and opens nitrogen purge.
- iii. Closes propane valves to ignition and freeboard burner GP 2306/1 - 5 and opens nitrogen purge.
- iv. Opens Broeker line valves HCV 5523 and HCV 5522 and closes HCV 5521.
- j. Before testing commences the back end relief system F.P.R.V. should be tested. Reduce the trip pressure to approximately 1 Bar g. and check the valve operates. This test should be repeated weekly.
- k. Propane System
 - i. The trace heating should be switched on at least 24 hours before propane is going to be used.

- ii. The vaporisers should be warmed up and steady conditions achieved.

- 1. Nitrogen System

- The vaporisers should be warmed up and steady conditions achieved.

- m. The nitrogen purge system should be reset after tripping the main interlock system to allow the burner system to be operated.

A.3.2 Pre-Start Up Check List for Exhaust Gas Plant Services
Cooling Water - Purge Water - Steam - N₂ - Lubrication
Ground Floor Level

System	Valve Description	Valve No.	Valve Position
Kamyr Cooling Water	No. 1 Pump Suction/Delivery	403/381	Open
	No. 2 Pump Section/Delivery	404/285	Open
	Make-up Tank Outlet	383	Open
NB: Make sure that make-up tank is full before starting pumps	Make-up Tank Inlet	No Number	Open
	LP c/w to Plate H/E Inlet/Outlet	449/450	Open
	Plate H/B Inlet/Outlet	427/426	Open
	2" Kamyr Valve	400/420	Open
	of Combustor	402/418	Open
Agitator Lubricators	N ₂ Header	GN 7958	Open
Steam Tract heating to Ash Legs	Steam Inlet North and South	466 467	Closed
HP Purge Water	WCV 3511 Isolation	037	Open
	Isolation	038	Open
	By-Pass	040	Closed
	WCV 3512 Isolation	033	Open
	Isolation	035	Open
	By-Pass	036	Closed
	WCV 3513 Isolation	029	Open
	Isolation	031	Open
	By-Pass	032	Closed
	WCV 3507 R Isolation	041	Open
	Isolation	043	Open
	By-Pass	044	Closed
LP Purge Water	WCV 3508 Isolation	135	Open
	Isolation	137	Open
	By-Pass	138	Closed
	WCV 3509 Isolation	139	Open
	Isolation	141	Open
	By-Pass	142	Closed

Ground Floor

System	Description		Valve No.	Position	
L.P. Purge Water	W C V3510	Isolation	131	Open	
		Isolation	133	Open	
		By-Pass	134	Closed	
<u>SLURRY</u>					
Exit V301	LCV 3507	Hand Jack		OFF	
		Isolation	022	Open	
Exit V302	LCV 3508	Hand Jack		OFF	
		Isolation	024	Open	
Exit V304	LCV 3509	Hand Jack		OFF	
		Isolation	026	Open	
Exit V306	LCV 3510	Hand Jack		OFF	
		Isolation	028	Open	
KAMYR Valves Closed on Start Up	North	(In Line)	502	Closed	
		(Sample)	508	Closed	
	South	(In Line)	503	Closed	
		(Sample)	509	Closed	
Ashing Air	Receiver Inlet Isolation Receiver PCV 3512 Hand Jack Ash Conveyor FVC 3507 Hand Jack HCV 3511 Hand Jack		429	Open OFF OFF OFF	

5.00 Level

System	Description	Valve No.	Position
V301	PCV 3507A Isolation	189	Open
	Isolation	191	Open
	By Pass	192	Closed
	TCV 3507 Isolation	045	Open
	Isolation	047	Open
	By Pass	048	Closed
	WCV 3507A Isolation	049	Open
	Isolation	051	Open
	By Pass	052	Closed
	P.I. 3027 Gauge Isolation	245	Open
V302	PTX 3507 Impulse Line Isolation	246	Open
	LTX 3307 Balance Line Isolation	345	Open
	Agitator Lubricant Inlet	482	Open
	PCV 3508A Isolation	193	Open
	Isolation	195	Open
	By Pass	196	Closed
	PI 3928 Gauge Isolation	247	Open
	PTX 3508 Impulse Line Isolation	248	Open
	LTX 3408 Balance Line Isolation	348	Open
	Agitator Lubrication Inlet	483	Open
V304	PCV 3509A Isolation	197	Open
	Isolation	199	Open
	By Pass	200	Closed
	PI 3029 Isolation	250	Open
	PTX 3509 Impulse Line Isolation	251	Open
	LTX 3409 Balance Line Isolation	349	Open
	Agitator Lubrication Inlet	484	Open
	PCV 3510A Isolation (2)	201/203	Open
	By Pass	204	Closed
	PI Gauge Isolation	252	Open
V306	PTX Impulse Line Isolation	253	Open
	LTX Balance Line Isolation	350	Open
	Agitator Lubrication Inlet	485	Open

5.0M Level

System	Description	Valve No.	Position	
V305/1	LCV 3505 Hand Jack		OFF	
	Isolation	018	Open	
V305/2	LCV 3506 Hand Jack		OFF	
	Isolation	020	Open	
Ashing Air	3 Isolation Valves Off Header to PCV's		Open	

7.5M Level

System	Description		Valve No.	Position
V303/1 Exit	LCV 3501	Hand Jack		OFF
		Isolation	010	Open
	DCV 3501	Hand Jack		OFF
		Isolation	022	Open
V303/2	LCV 3502	Hand Jack		OFF
		Isolation	012	Open
	DCV 3502	Hand Jack		OFF
		Isolation	004	Open
V303/3	LCV 3503	Hand Jack		OFF
		Isolation	014	Open
	DCV 3503	Hand Jack		OFF
		Isolation	006	Open
V303/4	LCV 3504	Hand Jack		OFF
		Isolation	016	Open
	DCV 3504	Hand Jack		OFF
		Isolation	008	Open
Agitator Lubricator	N ₂ Feed to Lubricator Lub. Selector		455 Not Numbered	Open Pointing to Full Res.
Agitator Cooling Water	V301	Inlet/Outlet	472/492	Open
	V302	Inlet/Outlet	473/493	Open
	V304	Inlet/Outlet	474/494	Open
	V306	Inlet/Outlet	475/495	Open
Agitator Foot Step Bearings	V303/3	Purge Water Inlet	376	Open

103M Level

System	Description	Valve No.	Position	
V303/1	TCV 3501	Isolation	056	Open
		Isolation	058	Open
		By Pass	059	Closed
	WCV 3501	Isolation	060	Open
		Isolation	062	Open
		By Pass	063	Closed
	Footstep Bearing Purge Water		371	Open
V303/2	TCV 3502	Isolation	066	Open
		Isolation	068	Open
		By Pass	069	Closed
	WCV 3502	Isolation	070	Open
		Isolation	072	Open
		By Pass	073	Closed
	Footstep Bearing Purge Water		375	Open
V303/3	TCV 3503	Isolation	078	Open
		Isolation	080	Open
		By Pass	081	Closed
	WCV 3503	Isolation	082	Open
		Isolation	084	Open
		By Pass	085	Closed
V303/4	TCV 3504	Isolation	088	Open
		Isolation	090	Open
		By Pass	091	Closed
	WCV 3504	Isolation	092	Open
		Isolation	094	Open
		By Pass	095	Closed
	Footstep Bearing Purge Water		377	Open
PCV 3507B	Isolation	173	Open	
	Isolation	175	Open	
	By Pass	176	Closed	

10.3m Level

System	Description	Valve No.	Position	
PCV 3509B	Isolation	177	Open	
		179	Open	
		180	Closed	
PVC 3509B	Isolation	181	Open	
		183	Open	
		184	Closed	
PCV 3510B	Isolation	185	Open	
		187	Open	
		188	Closed	
V305/1	TCV 3505	Isolation	096	Open
		Isolation	098	Open
		By Pass	099	Closed
	WCV 3505	Isolation	100	Open
		Isolation	102	Open
		By Pass	103	Closed
	FCV 3505	Isolation	163	Open
		Isolation	165	Open
		By Pass	166	Closed
Gauge	PI 3025	Isolation	242	Open
	PTX 3505 Impulse Line	Isolation	241	Open
	LTX 3305 Balance Line	Isolation	345	Open
	Agitator C/W Inlet		476	Open
	Outlet		496	Open
V305/2	TCV 3506	Isolation	108	Open
		Isolation	110	Open
		By Pass	111	Closed
	WCV 3506	Isolation	112	Open
		Isolation	114	Open
		By Pass	115	Closed
	FCV 3506	Isolation	168	Open
		Isolation	170	Open
		By Pass	171	Closed

10.3m Level

System	Description	Valve No.	Position	
V305/2	P1 3026 Gauge Isolation	243	Open	
	PTX 3006 Impulse Line Isolation	244	Open	
	LTX 3306 Balance Line Isolation	346	Open	
	Agitator C/W Inlet	477	Open	
	Agitator C/W Outlet	497	Open	
V305 1/2	N ₂ Feed	456	Open	
Lubrication	Lub. Selector 2 Off	Not Numbered	Point to Full Reservoir	
	Lubricant to seals inlets V305/1	486	Open	
	V305/2	487	Open	

System	Description	Valve No.	Position
V303/1	FCV 3501 Isolation	143	Open
	Isolation	145	Open
	By Pass	146	Closed
	P1 3021 Gauge Isolation	234	Open
	PTX 3001 Impulse Line Isolation	233	Open
	LTX 3301 Balance Line Isolation	341	Open
	Agitator c/w Inlet/Outlet	478/498	Open
	Agitator Lubricant to seals	488	Open
V303/2	FCV 3502 Isolation	148	Open
	Isolation	150	Open
	By Pass	151	Closed
	P1 3022 Gauge Isolation	236	Open
	PTX 3002 Impulse Line Isolation	235	Open
	LTX 3302 Balance Line Isolation	347	Open
	Agitator c/w Inlet/Outlet	479/499	Open
	Agitator Lub. to seals	489	Open
V303/3	FCV 3503 Isolation	153	Open
	Isolation	155	Open
	By Pass	156	Closed
	P1 3023 Gauge Isolation	237	Open
	PTX 3003 Impulse Line Isolation	238	Open
	LTX 3303 Balance Line Isolation	343	Open
	Agitator c/w Inlet/Outlet	480/500	Open
	Agitator Lub. to seals	490	Open
V303/4	FCV 3504 Isolation	158	Open
	Isolation	160	Open
	By Pass	161	Closed
	P1 3024 Gauge Isolation	239	Open
	PTX 3004 Impulse Line Isolation	240	Open
	LTX 3304 Balance Line Isolation	344	Open
	Agitator c/w Inlet/Outlet	481/501	Open
	Agitator Lub. to seal	491	Open

System	Description	Valve No.	Position
Kamyr Cooling Water	Inlet and Outlet Valves to Gas Analysers Header situated on the 18.5 m level Cooling water to Kamyr - Down Leg Valve Actuators Inlet and Outlet Sample	No Number 395/413 398/416 397/417	Open Open
V303 1 to 4 Agitators	N ₂ Feed to Lubricator Selector Valves	457 Not Numbered	Open Point to Full Reservoir
N ₂ Purge	N ₂ to Dust Legs and Sample Branches (	451 (452 (453 (454	Closed Closed Closed Closed