CHAPTER 5
TEST EXECUTION

5. TEST EXECUTION

5.1 PRE-TEST ACTIONS, PRINCIPLES AND COMMON ROUTINE ACTIVITIES

In this chapter the description of the actions listed below is based on a summary of the logbook of the events during the execution of the tests. The main happenings there revolve around the selection of mill configurations, oxygen and CO monitor readings, total air flow settings and unit operation. The tests were executed during the three weeks from the 2nd to the 20th May 1994, one batch of different coal quality per week, as previously described in Chapter 4.

There are however activities that are common to all the tests that need discussion first. These are mainly mill inventory stripping and grinding media make-up, pf sampling, oxygen and air flow corrections, soot-blowing, unit control set-up and the criteria and method of reducing the excess air.

Some of these activities involve certain enhanced methods and principles that had to be devised to improve the operational behaviour of the plant. This was necessary mainly due to sub-standard operational and maintenance discipline and out of normal range coal qualities to be tested. The latter also caused certain items of plant to underperform due to design parameter mismatch.

Some successful enhancement activities had been performed on the mills in the past, but the primary air heater, which is underdesigned in terms of its surface area to provide the required drying power for coal with higher moisture, has not successfully been attended to. These tests thus also provided the opportunity to evaluate the effect of, not only a new optimised total air flow, but a new ratio of primary to secondary air flow and its influence on mill loading and primary air heater performance. These items will be discussed in Chapter 6 and 7.

5.1.1 Mill load lines and grinding media level:

The testing of a batch of coal lasted a whole week, as explained in the schedule in Chapter 4. It was anticipated that these tests would start on a Monday and end on a Friday, one load setting per day. In the light of this the mills were stripped, ie. emptied of coal inventory, on the Sunday evening prior to the weeks' testing to determine the grinding media level. The required make-up mass was then added the next morning prior to testing and the mill power and feeder set points set accordingly as explained in Chapter 4 (also see Becht[16]).

No testing was done until all the mill controls were adjusted to operate on the load line. This procedure was repeated on the Tuesday and Thursday during each of the weeks of testing. (Normally the mills were subjected to this procedure weekly, but for these test purposes closer control was needed.)

The milling configuration at Lethabo according to burner level entry into the furnace is as follows:

	Front end (turbine side)	Back-end (precipitator side)
Top	A	F
Middle	D	C
Bottom	B	E

This is of importance in detecting poor performance of a mill or burner(s) responsible for incomplete combustion, producing high CO despite an overall high air flow in that region of the furnace. It serves as explanation to refer to the mills in service during testing.

5.1.2 Pf sampling:

As explained in Chapter 4.3.2, a pf sample for every test was taken isokinetically according to standard procedure (Van Boorn [17]) from D mill, non-drive end. It is physically impossible to sample every mill, both drive and non-drive ends during every test. The sampling times, samples and resources needed as well as the volume of calculations are just too numerous in practice. Therefore D mill, that would always be in operation, being a middle row mill (that would not be biased up or down), was selected. Pre-test samples had produced results which showed D mill most representative of all the mills, and its sampling point are easily accessible, The calculated results of the prepared samples during testing are given in Section 3, Appendix J.

5.1.3 Total air flow and oxygen corrections:

The oxygen sampling matrix, installed at the economiser outlet (see Chapter 3.6, and Figure 3.30), was proved free from blockage by ash by being purged with clean compressed air on at least a daily basis prior to testing and for determination of the panel instrumentation correction factors. These oxygen correction factors were determined by means of an "Otox" volumetric dry instrument which was calibrated with test gas (Bosch [22]). The C&I department cleaned blockages from each of the 36 secondary air measuring aerofoil impulse lines by purging with compressed air.

The draught group (namely LH and RH ID, PA and FD fans) control systems were also recalibrated and balanced. An old controversy as to whether fans or a draught group (LH and RH side) should be balanced on flow or motor current (amps) also had to be addressed here. The method or philosophy that was adopted is not presented as a universal method, since plant layouts and control philosophies differ. Since this topic normally presents a general problem that negatively influences boiler and control behaviour, the method devised at Lethabo is offered:

Initially, the ID fans are balanced. Their main purpose is to maintain a constant furnace pressure, by removing the flue gas from the furnace via the front and rear gas passes. Irrespective of load, in the case of Lethabo, the furnace pressure is maintained at 50 - 100 Pa below atmospheric pressure. The ID fans also create the negative pressure behind the air heaters, influencing the air heater leakage, which is directly proportional to load or flow. (Similarly, the FD fans also influence the magnitude of the air heater leakage from the positive pressure side). These fans thus have to maintain equal flow (LH vs. RH side) in the furnace and gas pass before the air heater leakage consideration. Thus, as a first iteration, the ID fans can only be balanced on motor current, since there are no gas flow measuring devices installed. Due to the stated air heater leakage, flow measuring devices after the heaters would thus be ineffective.

Functionally, balancing on current at this stage also makes the most sense, since the two furnace pressure readings, obtained from LH and RH side tapping points at 73m level of the furnace, are compared by the control system and only the absolute mininmum of the two values is fed as signal to both the fans. (Mass flow is also not the only parameter to influence motor amps. Vane setting, actuator and control arm stiffness, etc. exercise significant influence on motor current.)

Secondly the PA fans should be balanced, also on motor current. The available air flow devices are dedicated to specific mills and not to the two PA fans. The total demand of primary air flow is equally supplied by the fans in a load sharing mode by the control system. The PA fans should thus supply equal amounts of air, even when an uneven number of mills (eg. 3 LH and 2 RH side mills) are in service. The only option is thus to balance these on motor current, with the main purpose being to extract equal amounts of air from the LH and RH sides of the combined air flow ducts, prior to the FD fan suction points. The PA fans thus have to be balanced before the FD fans.

Thirdly the FD fans are to be balanced according to measured flow, specifically the flow entering the furnace as secondary air on the LH and RH side of the furnace. This eliminates the influence of probably unequally leaking air heaters. To accomplish this the mass flows of the secondary aerofoils on the LH and RH sides of the boiler (18 per side) have to be totalised respectively and the FD fans balanced according to this criteria of flow.

Iteratively, the ID fan balance can now again be evaluated according to flue gas mass flow exhausted from the furnace before the effects of unequally leaking air heaters influences the values. The criteria for measuring this can unfortunately not be parameters such as spray water or steam flows, temperatures or economiser outlet oxygen, since these can more greatly be influenced by non uniform performance of burners or mills. The parameter that can often be used most representatively for this purpose is the flue gas temperature at the pyrometers, or the economiser outlet LH and RH sampling matrices. The

ID fan balance can thus be fine tuned this way and the above two steps repeated accordingly, evaluating not only the motor currents and flows where applicable, but the gas temperatures as well.

The test boiler showed no imbalance after these actions, either before and during testing. Also the LH vs RH CO and oxygen readings indicated that there were no delinquent burners which indicated the outage actions, as detailed in Chapter 4.2, had been carried out to a high standard and quality control. The secondary air heater seal gap sensors were checked for any imbalance or total error[15]. After re-adjustment, the difference between the LH and RH was better than the allowed error of 0,5 mm tolerance on the radial seal gap. This resulted in the LH vs RH A/HTR outlet and ID inlet oxygen levels also running in very close agreement. (This was done prior to fan balancing.)

The total air flow to the furnace is measured by the two aerofoils situated in the FD fan suction ducts on 41m level. A correction factor for the process computer reading was taken once per test as a differential pressure by manometer, with temperature and relative humidity compensations as described in Chapter 4.7.5 and Sample Calculation 2, Appendix A, based on accepted procedure (Storm[20]). Prior to any of the main tests, a comparison check was performed according to the above mentioned procedure and compared with the panel reading, for 600, 500 and 400 MW loads. The correction factors amounted to the difference between the panel reading (Sicomp computer) and the calculated reading from the manometer. These values were used to interpolate for the equivalent correction factors for 550 and 450 MW. The results are shown in Table 5.1.

Table 5.1: TOTAL AIR FLOW CORRECTION FACTORS [kg/s]

600 MW:	Manometer	Panel reading	Correction
LH	270,97	268,59	
RH	274,54	268,66	
Total	545,51	537,25	+8,26
550 MW:		Interpolated Correction:	+6,31
500 MW:	Manometer	Panel reading	Correction
LH	243,73	243,90	
RH	249,93	245,40	
Total	493,66	489,30	+4,36
450 MW:		InterpolatedCorrection:	+2,87
400 MW:	Manometer	Panel reading	Correction
LH	193,73	194,20	
RH	196,55	194,70	
Total	390,28	388,90	+1,38

These correction factors were found to stay constant within a very small deviation throughout the tests and were automatically employed in the calculations of Appendices F, G and H.

5.1.4 Sootblowing:

The sootblowing of the unit was important regarding consistent testing, due to the following considerations:

(a) The boiler efficiency has proved to improve after proper sootblowing. This beneficial change can be lost within a day or two of normal running, or sometimes sooner due to abnormal coal quality and air flow depending the area of the furnace. A consistent sootblowing regime is thus necessary to create as constant as possible a basis for efficiency comparison between tests. The dirty boiler and resulting reduced heat transfer coefficient is to be eliminated as much as possible. Ash build-up and clinkering due to specific air flow quantities is thus a factor in determining whether the air flow has to be increased from a minimum or decreased from a maximum at intervals during testing on a constant load.

(b) Apart from the air flow factors mentioned above, there are also factors due to the coal and its ash qualities [27]. Some coals can produce wall deposits which consist of dry, dusty type layers, which prove more insulating than the other common type of the sintered wall deposit. Experience has shown that furnace wall sootblowing has a significant initial effect on heat transfer, but the dusty layer soon returns to the original state. Lethabo has more a sintered type of wall deposit which has the character described as brittle bearding.

Coal quality can also cause a delayed heat release which is discussed below. Ash properties effect the surface emissivity of furnace walls, (reflectivity of the ash decreasing the heat transfer to the walls). Fortunately relative to the other effects, this has a minor influence(27).

Finally coal quality gives rise to the Gas Absorption Coefficient, which has a significant blanketing effect with increasing ash quantity in coal(27). The reference defines a term, the Reduced Ash Content = Ash/CV. An increase in this ratio causes an increase in the furnace exit temperature of the flue gas. Tests in the former Soviet Union at the Ekibastuz power station in Northern Kazakhstan, showed significant effects when higher ash coals were combusted in the furnace. The back-end temperature increased by as much as 10°C as a result of only a 1% increase of the Reduced ash content(27).

All of these factors were known and their influences were allowed for in the test results, but fortunately they were not seen to introduce additional variables to affect the consistency of the sootblowing regime or the varying of air flow on the combustion process. They will most probably serve as one of the explanations on the difference in the behaviour of the different coal qualities to be tested, but this is however what these tests were planned to achieve.

(c) Another factor to account for was that deliberate varying of combustion air flow between extremes is at times prone to produce more clinkering than normal. Irrespective of the consistency of testing and the efficiency concern noted above, it is simply good operational practice to pay extra attention to sootblowing during these tests for furnace well being. It was proven at Lethabo[6,7] that the cost of daily sootblowing, being that of production of demineralised water plus the coal energy used to produce steam not contributing to generation, is overridden by the efficiency losses and operational problems caused by not doing regular sootblowing.

(d) The optimum air flow was not known beforehand. Provision had to be made for the following scenario: If the final calculations produced a relatively high air flow as optimum, the recommendation and implementation thereof could not be impeded by metal temperature excursions of tubes resulting from better sootblowing in practice compared to testing. Contrarily, if the optimum air flow was calculated to be relatively low, certain steam temperatures, especially reheat, could not run below set-point due to sootblowing being done better during testing in comparison with normal practice thereafter.

(e) The air flow optimisation tests performed on unit 2 (Storm[2]) highlighted the importance of sootblowing in so far as not enough importance being given thereto at that time. Certain of the peculiar efficiencies that resulted from the calculation could be attributed to sootblowing as well as the order that the tests were conducted in, with air flow varying from high to low or the opposite without considering the effects. Normally the Lethabo furnaces do not foul excessively. The clinkering formed is more a brittle bearding rather than the bulky, fused hard clinkers associated with higher grade bituminous coal, when a relatively low amount of combustion air is supplied. Since the extremes of air flow and coal qualities were to be tested, the opportunity arose to also note the clinkering behaviour during these tests.

A more serious point of concern involving sootblowing involves the aspect of tube metal temperature excursions, which are common at Lethabo Power Station. This aspect is excluded from this study but it definitely impacted on the successful execution of these tests. Preventing metal temperature excursions in the platen and most often the final superheater regions emphasised the need for combustion air flow guidelines. It also caused the operators to exclude the platen region when selecting the sootblowing program. The matter was complicated by the fact that initially furnace wall sootblowers were installed but not commissioned. The secondary air heaters also tended to suffer severe blockages. These factors often caused boiler (steam and water side) and even furnace (fireside) imbalances and other operational deficiencies.

It serves no purpose to include a detailed discussion regarding all the above in this thesis, but since it impacted greatly on the behaviour of the boiler during the execution of these tests, some of the corrective actions taken are summarised below:

Firstly the author initiated and embarked on managing two sootblower enhancement projects[6,7] during the period 1988 - 1990. Included in these projects the following were addressed and achieved:

- The secondary air heater blockage was proved not to have being caused by the Lethabo phenomena called "popcorn" ash but rather malfunctioning air heater sootblowers depositing water droplets into the elements and solidifying the incoming fine ash. It was corrected by enhancing the parameters of the steam supply, program warming times, lagging of steam lines, poppet valve settings etc. ("Popcorn" ash is the local name given to ash particles ranging from ±4mm to 1cm diameter, light grey in colour, very low specific gravity (floats on water), originating from certain combustion conditions involving air flow quantity and coal quality.)

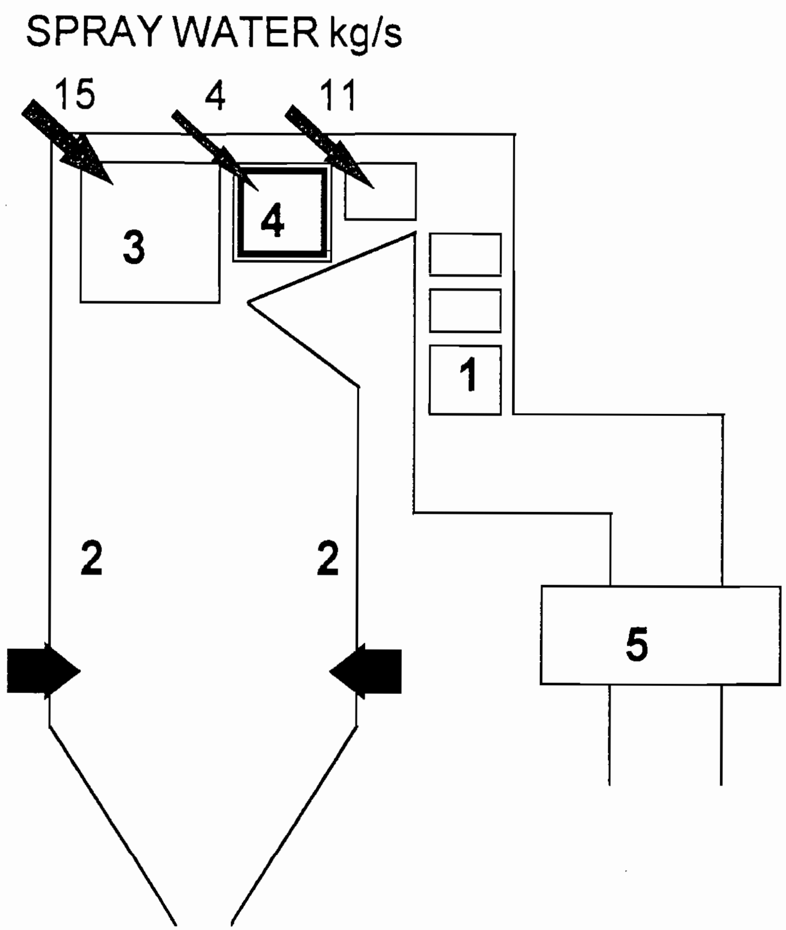
- The reinstatement and commissioning of the wall blowers and proving their value by means of efficiency and operational improvement tests.

Secondly a revised sootblowing sequence and philosophy was formulated, enabling the sootblowing of the platens without temperature excursions illustrating the resulting improvements. This sootblowing method was to be trialled and tested during the air flow tests and is summarised below (Figure 5.1 refers):

The aim was firstly to enable the sootblowing of the platen superheaters, which were mostly neglected due to fear of metal temperature excursions. To accomplish this, a high enough load is required (preferably >550 MW). Metal temperature excursions are more prone to happen at lower loads due to the higher ratio of flue gas to steam flow. Also, in order to accomplish the sootblowing of the platens, the "heat release barrier" was to be lowered as much as possible. (This term is defined by the author as the thermal equivalent of the geometrical centre of gravity of the fire ball where the effective heat is released.) Factors that would lower the heat release barrier are:

- Less total air flow (concerning velocity only).
- Less moisture in coal.
- Hotter combustion air.
- Higher heat in volatile content of the coal.
- Finer pf grading.

SOOTBLOWING SEQUENCE



1- ECONOMISER
2- FURNACE WALLS
3- PLATENS
4- SECONDARY S/HTR
5- SECONDARY A/HTR

Figure 5.1: SOOTBLOWING SEQUENCE

The above factors improve ignition and work against delayed combustion.

(1) The economiser was to be sootblown first. This supplies the drum with hotter water which enhances steam raising. The resulting increase in drum pressure will directly cause the firing rate to reduce.

The next step was to sootblow the secondary air heaters. This was to remove the debris just removed from the economiser and to provide hotter air to the burners. Since it is recommended that the air heaters be sootblown every shift, it could be considered clean enough not to warrant further blowing at that stage.

(2) Thereafter the wall blowers should be activated. They have the same effect as the economiser sootblowing on drum pressure, but the effect was found to be even more significant.

After these actions it was normally found that the firing and heat release barrier lowered sufficiently and imbalances such as drum level improved noticeable.

(3) The platen superheaters were then sootblown. The scenario for the worst case will be summarised as follows (the platens have long

since been blown, etc.). The danger was not only for temperature excursions, but also for the boiler to be tripped by the automatic black furnace protection due to the large amount of dust, adhering debris and clinkers falling down, obscuring the view to the flame pyrometers situated on 51m level. It was found best that the top lance on the front (turbine) side of the boiler be activated first, while the flame temperature indications and the pyrometers were watched closely. The lance should be retracted manually immediately should the gas temperatures and pyrometers show dangerously low indications. No exact guideline can be given for this action since skill improves with time. After the pyrometers and flame temperatures had been stabilised, the lance could be activated again. It would be found that each time the lance can enter further before manual retraction, until the full traverse was completed. The same procedure was followed for the next lance below, alternating between left and right hand side of the boiler. Moving to the next row from top to bottom and from the front to the rear end of the furnace will complete the platen element cleaning.

(4) Thereafter the final superheater and the rest of the front gas pass was treated in the same way if necessary.

(5) Finally the rear gas pass (including the economiser again) was sootblown up to the secondary air heater.

The point to note is that after the platens have been blown, the primary attemperating sprays, capable of 15 kg/s for each of the four legs, should have opened more, resulting in greater mass flow and cooler steam sooner in the cycle. Also the flue gas should be cooled more before reaching the final superheaters, demonstrated by the 4 kg/s spray stations closing more and only providing the final trimming effect for which they were designed. Following this procedure proved to drastically reduce the metal temperature excursions of the final superheaters, which was the critical issue. The above methodology also helped to the correct the proportions of the total heat requirement input into the various sections of the furnace.

It would have been more convenient if the pyrometers could have been pinned under supervision (one side at a time for some safety factor) for the platen blowing period. The problem reduced after 3 to 4 days to such an extent that all the front gas pass lances could be selected on automatic and the sootblowing completed without manual retraction for fear of black furnace trip. This emphasises the point that regular sootblowing is the key to reliable operating.

The above description was the procedure followed during testing every afternoon through night shift prior to the next days' testing to eliminate the variable of furnace heat transfer on efficiency and operational behaviour due to the clinkering caused the previous day. In practice subsequently it was found that it would be adequate to partially sootblow the economiser (every alternate lance) and the secondary air heaters every shift. All the wall blowers were also to be blown every shift, followed by half of the front and rear gas pass lances (every alternate lance) to be blown at least twice a week. The consecutive days the other half of the lances should be alternated. The prerequisite for this is regularity. This experience forms the basis of the recommendations concerning sootblowing in Chapter 7.

5.1.5 Control system setting:

Basically the mode of setting of the controls was the same as in the Unit 2 air flow optimisation tests (Storm[2]), which proved to produce the desired effect on performance. This procedure was followed every morning before testing and will be explained below:

Turbine controls:

- The load controller was switched off at the required load.
- The initial pressure controller was switched off.

Unit controls:

- Automatic generation control (AGC) was then switched off.
- Frequency bias was then switched off.

Boiler controls:

- Boiler master was set fully on automatic to obtain pressure support mode.
- The air/fuel correction facility was gradually adjusted for the required total air.
- For reduction in air flow below the lowest air/fuel correction setting, the secondary air duct pressure set point was reduced.
- For even further reduction in total air flow the secondary air control dampers could manually be adjusted.

However, a problem was presented concerning the above desired control setting since an emergency generation was declared by National Control due to the cold weather at that time and the unexpected forced outage of two 600 MW units on other power stations. The tests could not be postponed since the coal had already been ordered, mined and prepared, paid for and supplied from the stockyard with silo and bunkers filled with the low grade coal.

The behaviour of the national grid at that time resulted in the unit being unable to maintain steady load whilst on loads lower than 100% MCR, with priority dominated by the varying frequency and high load requirement. The problem was overcome by having National Control locking the unit on base load, at the required load of testing for that day.

5.1.6 Air Flow variation:

The main variables in this project were load, coal quality and total combustion air flow. The latter was to be varied between its extremes at each load for each of the coal qualities. Criteria for these extremes of total combustion air flow had to be defined. The high limit was dictated by the capability of the draught groups of course, if impeding metal temperature excursions on any superheater tubes were not evident before that.

The low limit for this air flow would be pyrometer alarms and excessive CO in the flue gas, as well as draught group minimum flow preferably being within the range of the air/fuel correction facility. These were the major criteria between which the total combustion air flow was varied, in as equal intervals as possible to cover the range, with the expectance being an apex or a maximum occurring in the overall thermal efficiency vs. air flow curve.

There were however other secondary aspects that had to be monitored that could also influence the limits of air flow. Possible damage to plant or operational difficulties had to be avoided, such as excessive clinkering caused by certain air flows with particular coal qualities. This also leads to the next point of concern in striving for the tests to be as consistent as practically possible. If more clinkering is prone to occur with lower air flows, the day's testing at a load for a certain coal quality should end with the least air flow, thus not negating the efforts of the previous night shift's sootblowing.

That logic is also in line with another requirement, learnt from the experience in the Unit 2 tests[2]. The unburnt carbon in fly ash is higher at lower air flows for constant coal quality, provided that all other parameters are kept constant. If the test program required the air flow to be increased from a minimum to a maximum, the higher carbon content fly ash which could have built up in stagnant bends of tube nests, would be blown off during the consecutive tests with higher air flows. This would result in the Cegrit sampler content (unburnt carbon in fly ash) not being representative of the specific test.

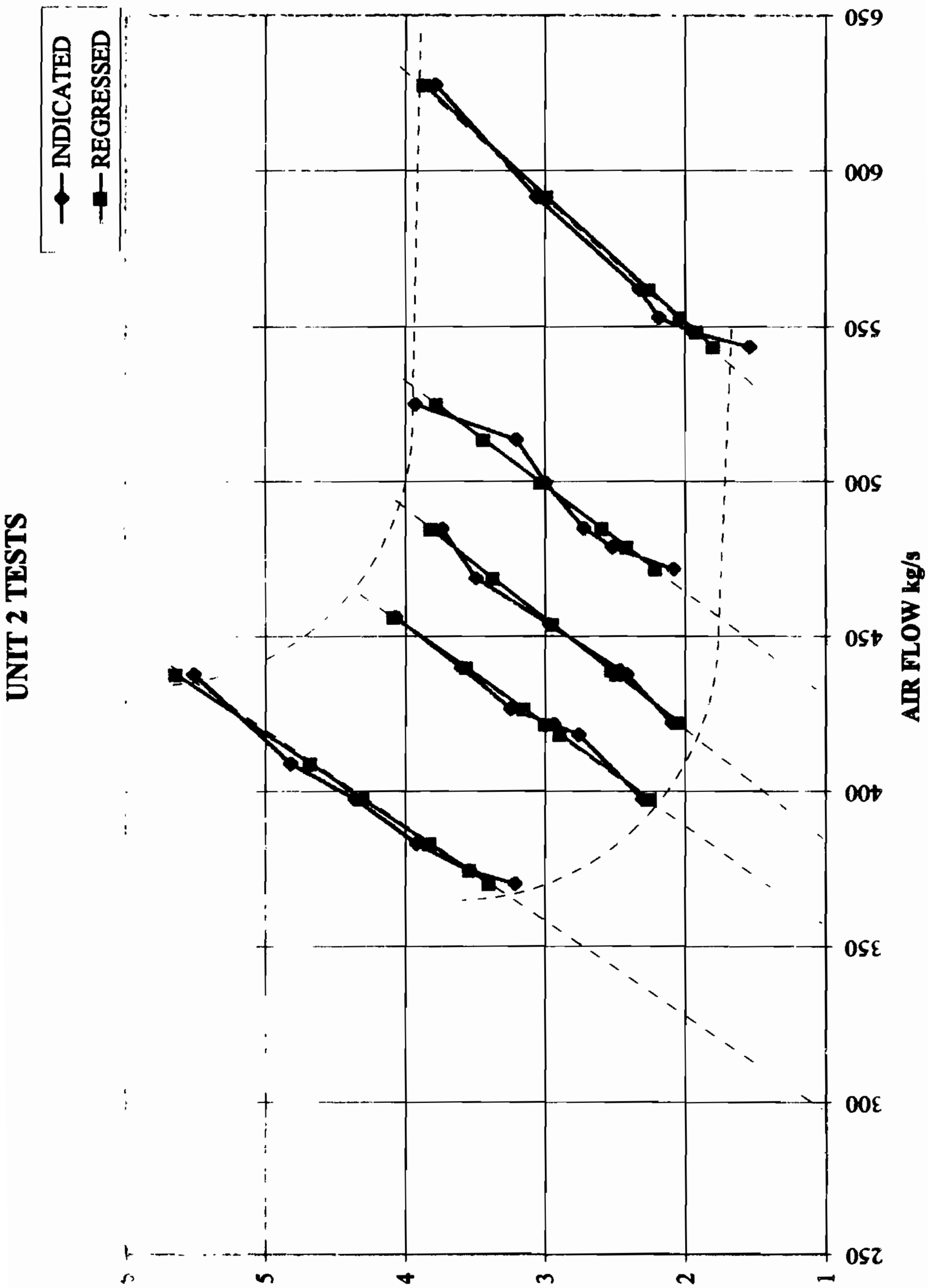
Experience thus dictated that the order of conducting the air flow tests for each day, should be to reduce the air flow from the maximum to the minimum. The only remaining aspect on air flow, regarding the execution of the tests, was the determination of the actual air flow limits. Again the experience of the Unit 2 tests[2] proved valuable, since the absolute minimum combustion air flow for blended spec. coal was known. This served as a guideline to determine equal intervals of air flow on a load for the days testing.

Regarding combustion air flow, each days' testing commenced with increasing the air flow on the unit (after all the other aspects such as control set-up, mills etc, had been attended to) to the limit of incurring metal temperature excursions. That set the air flow value for the first test with the maximum air flow. Whilst this test was in progress, there was ample time to manually calculate the equal intervals for the remainder of the six tests for the day.

Figure 5.2 shows the data of the Unit 2 tests refered to, plotting economiser gas outlet oxygen content as a function of total air flow, for the loads of 630, 550, 500, 450 and 400 MW respectively, for the highest to lowest values on the air flow scale. The actual indicated values for a set load followed a virtually straight line, only deviating slightly due to instrument corrections, etc. A linear regression of these values produced a straight line for each load, which were used for these forecasts.

Figure 5.2 also shows these values with the band of expected maxima and minima for all the loads. The maxima were the actual values occurring on the day at that point in time, the minima being those from the experience of the afore mentioned Unit 2 tests. The equal intervals were then calculated whilst this first test progressed, assuming that the minima would be in the same approximate order as the corresponding ones on the Unit 2 tests. (It can be seen that the unit 2 tests were not performed at uniformly equal intervals, since less information was then available beforehand and the tests were performed from least to most air flow.)

Figure 5.2: FORECAST FOR MAXIMA AND MINIMA OF AIR FLOWS



It is interesting to note that the point of intersection of the projection of the regressed lines and zero economiser oxygen on the air flow axis would forecast the stoichiometric (theoretical) combustion air for that load. This principle was applied similarly on values of the actual test values as explained in Chapter 6.

5.1.7 Operational Aspects during Testing

The following sections (5.2, 5.3 and 5.4) contain detail of the actual tests and is intended for operationally inclined readers, interested in specific test detail such as:

- The total air flow panel reading,
- The resulting economiser gas outlet oxygen percentage as well as the instrument corrections for the day,
- The Air/Fuel correction panel facility setting,
- The resulting CO monitor readings,
- The CV correction panel indication, etc.

as well as anomalies that occurred only during a specific test.

Further detail of all the parameters measured with the corresponding correction factors implemented, can be seen in Appendices F, G and H. However, there were aspects that were common to all these tests which can be summarised once as follows:

- Normally the top mills were biased down or the bottom mills were biased up. The percentage bias is noted at the test summary.

- The amount of CW pumps in service for all the tests can be seen in Appendices F, G and H. The specific pumps used for each test also had to be recorded to correct in the auxiliary power calculation. At Lethabo, all the pump impeller diameters are not exactly equal, resulting in all the pump powers not being equal. Also, the down time of the other units on the West side, units 2 and 3, sharing a common CW system, as well as the unit board auxiliary power supply interlinking was noted, to be reconciled in the auxiliary power during the final calculation of overall efficiency.

- The pyrometers were usually cleaned after the fourth test, just prior to the commencement of the last two lowest air flow tests as a safety precaution.

- The only occurrence during testing was E mill drive-end bearing running slightly hot with the vibration level not being satisfactory, but not critical or rising. This gave cause for concern since E mill, being a bottom mill, is essential for the tests. It was monitored closely with the vibration level recorded daily. Fortunately, the status had not deteriorated and E mill was available throughout the tests.

5.2 THE LOW GRADE COAL TESTS

It was decided to test the low grade coal first, due to the potential difficulties and unpredictability of the flame stability associated with it. The low grade coal also had the lowest moisture value of the three grades and was more prone to spontaneous combustion if left on the stockyard for too long. A trial run was thus necessary, achieved by not feeding all the mills with this coal simultaneously, since the actual quality received could easily have been unacceptable in practice, despite the calculations and forecasts as discussed in Chapter 4.

If this coal had been found to be of too low a quality and caused any unacceptable operational situation whilst being fired in the furnace, having had the silo (>5000 tons) and all six mill bunkers (800 tons each) filled, enormous problems would result in ridding the unit of the fuel. The bunkers of the mills on unit 1 were thus filled progressively from the Friday prior to the tests starting on the Monday, each mill bunker only filled in sequence after the combustion was found to be satisfactory for at least a shift with the previous number of mills having fired the low grade coal.

5.2.1 The Low Grade Coal 630 MW Tests

These tests were performed on 2nd May 1994 and included:

- L / 630 / 20 / 14h00
- L / 630 / 17,5 / 15h30
- L / 630 / 15 / 16h30
- L / 630 / 12,5 / 17h30

- L / 630 / 10 / 18h45

- L / 630 / 7,5 / 20h00

where the coding system is as explained in Chapter 4.

- The mill configuration included all 6 mills in service, with A and F mills (top) biased down to 38 %.

- The Air/Fuel (A/F) correction panel facility could be raised to 1,18 before incipient metal temperature excursions on the first test with the highest air flow. This facility has a range of 0,8 (lowest A/F ratio) to 1,2 (highest A/F ratio) with 1,0 being the mid-range.

- The total air flow panel reading ranged in equal intervals for the six tests from ± 600 - 515 kg/s. The correction factor being as in Table 5.1.

- This air flow resulted in the economiser oxygen ranging from LH 3,1% and RH 3,0% for the highest down to ± 1% for the lowest air flow tests. (The O_2 corrections for the day were LH +0,3% and RH +0,2%)

- This resulted in the CO monitor readings maintaining a steady low average value of ± 20 ppm for the first five tests, but significantly increasing to > 150 ppm on the last test. The respective LH and RH values of air flow, economiser oxygen and CO monitor reading gave evidence of a well balanced combustion process in the furnace.

- The CV correction panel indication stabilised at 0,77, which corresponds with low quality coal indication.

5.2.2 The Low Grade Coal 550 MW Tests

During the early morning of 3rd May 1994 (±4h30), the unit tripped. Some of the indicators of the incident included black furnace signals from the pyrometers. This initially gave cause for concern regarding the low quality coal. Fortunately the incident investigation highlighted faulty oil burners being the root cause with the operators tripping some of the mills during a load change. The trip was found to be independent of the coal quality.

There was a set-back however. The restarting of the unit caused numerous problems in re-instating the load at the required 550 MW with the mills and the whole control system experiencing difficulty in stabilising. The result was the abandonment of the tests, which proved unsatisfactorily, and repeating all of the low grade 550 MW tests later the week. These tests were then performed on 6th May 1994 and included:

- L / 550 / 27 / 8h00
- L / 550 / 24 / 09h15
- L / 550 / 21 / 10h15
- L / 550 / 17,5 / 11h15
- L / 550 / 14 / 12h30
- L / 550 / 10 / 13h30

where the coding system is as explained in Chapter 4.

- The mill configuration included all 6 mills in service, with A and F mills (top) biased down to 47% and 39 % respectively.

- The total air flow panel reading ranged in equal intervals for the six tests from ± 540 - 450 kg/s. The correction factor is as in Table 5.1.

- This air flow resulted in the economiser oxygen ranging from the average value of LH and RH being ±4,1% for the highest down to ± 1,2% for the lowest air flow tests. (The O_2 corrections for the day were LH +0,3% and RH +0,4%).

- This resulted in the CO monitor readings maintaining a steady low average value of ± 20-40 ppm for the first five tests, but significantly increasing to > 500 ppm on the last test. The respective LH and RH values of air flow, economiser oxygen and CO monitor reading again gave evidence of a well balanced combustion process in the furnace.

5.2.3 The Low Grade Coal 500 MW Tests

The first test for this day was repeated since the control system experienced problems when stabilising the unit. The fact was that an emergency generation situation contributed to the peculiar behaviour of the controls.

The behaviour of the unit improved (load was more constant) by changing the mechanical hydraulic control (MHC) to the electro -

hydraulic control (EHC). The problem was completely resolved by switching the load controller off and having National Control locking Lethabo unit 1 from there on base load at the required load for the remainder of the tests.

These tests were performed on 4^{th} May 1994 and included:

- L / 500 / 29 / 11h45
- L / 500 / 26 / 13h15
- L / 500 / 23,5 / 14h15
- L / 500 / 20,7 / 15h15
- L / 500 / 18 / 16h15
- L / 500 / 12 / 17h30

where the coding system is as explained in Chapter 4.

- The mill configuration included 5 mills in service, with A mill taken out and F mill biased down to 40%.
- The total air flow panel reading ranged in equal intervals for the six tests from ± 515 - 445 kg/s. The correction factor is as in Table 5.1.
- This air flow resulted in the economiser oxygen ranging from the average value of LH and RH being ± 4,4% for the highest down to ± 2,3% for the lowest air flow tests. (The O_2 corrections for the day were LH +0,3% and RH +0,2%).
- This resulted in the CO monitor readings maintaining a steady low average value of ± 30 ppm for the first five tests, but slightly increasing to > 60 ppm on the last test. The respective LH and RH

values of air flow, economiser oxygen and CO monitor reading again gave evidence of a well balanced combustion process in the furnace.

5.2.4 The Low Grade Coal 450 MW Tests

These tests were performed on 5th May 1994 and included:

- L / 450 / 30 / 10h45
- L / 450 / 27 / 11h45
- L / 450 / 23 / 13h30
- L / 450 / 20 / 14h30
- L / 450 / 16 / 15h30
- L / 450 / 12,5 / 16h30

where the coding system is as explained in Chapter 4.

- The mill configuration included 5 mills in service, with A mill (top) on stand-by.
- The total air flow panel reading ranged in equal intervals for the six tests from ± 490 - 415 kg/s. The correction factor is as in Table 5.1.
- This air flow resulted in the economiser oxygen ranging from the average value of LH and RH being ± 5,1% for the highest down to ± 3% for the lowest air flow tests. (The O_2 corrections for the day were LH +0,3% and RH +0,2%, which was the same as for the previous day).
- This resulted in the CO monitor readings maintaining a steady low average value of ± 30 - 50 ppm for all the tests. The respective LH

and RH values of air flow, economiser oxygen and CO monitor reading again gave evidence of a well balanced combustion process in the furnace.

Since the second last test the superheat and especially the reheat steam temperatures started dropping with reduced air flow. This was rectified by adjusting the steam temperature set-point until the actual values were satisfactory. It was peculiar that both the superheater and reheater temperatures dropped with very low air flow. (It is not uncommon for only the reheat to do so.) It was then noticed that the generator output increased slightly. This must have been due to the emergency generation required by National Control who had no other option due to low frequency on the national grid. One of the pyrometers started flickering during the last test indicating that flame temperatures were also decreasing (approaching 800 °C at pyrometer level and decreasing).

5.2.5 The Low Grade Coal 400 MW Tests

These 400 MW tests were performed after the 550 MW tests repeat, for the reasons described in 5.2.2, as can be seen by the indicated times. It was also difficult to obtain low loads other than during off peak times. Performing these tests late on a Friday suited the loading regime of National Control more than had it been performed earlier in the morning.

These tests were thus also performed on 6th May 1994 and included:

- L / 400 / 37 / 15h45
- L / 400 / 32,5 / 16h45
- L / 400 / 28 / 17h45
- L / 400 / 24 / 18h45
- L / 400 / 19 / 19h45
- L / 400 / 15 / 20h45

where the coding system is as explained in Chapter 4.

- The mill configuration included only the 4 bottom mills in service, with A and F mills (top) on stand-by.

- The total air flow panel reading ranged in equal intervals for the six tests from ± 440 - 365 kg/s. The correction factor is as in Table 5.1.

- This air flow resulted in the economiser oxygen ranging from the average value of LH and RH being ± 5,2% for the highest down to ± 2.6% for the lowest air flow tests. (The O_2 corrections for the day were LH +0,3% and RH +0,4%, which was the same as for the 550 MW tests earlier that same day, but different to those of the previous day).

- This resulted in the CO monitor readings maintaining a steady low average value of ± 30 - 50 ppm for the first five tests, but increasing slightly to ± 85 during the last test. The respective LH and RH values of air flow, economiser oxygen and CO monitor reading again gave evidence of a well balanced combustion process in the furnace.

Since the second last test the superheat, and especially the reheat steam temperatures started dropping with reduced air flow. Only the main steam flow temperature could be rectified by adjusting the steam temperature set-point, but not the reheat temperature. It dropped below the target of 540 °C at the boiler outlet due to the low air flow. Some of the pyrometers started flickering during the last test indicating that flame temperatures were also decreasing (approaching 800 °C at pyrometer level). The pyrometers were found to be more of an indication of dangerous operation than increasing CO monitor readings, which is in contrast with international experience as well as the tests performed on unit 2[2] with blended coal. This can be attributed to the peculiar low grade coal quality.

The firing also struggled to maintain boiler pressure. (The parameter called the critical pressure started showing a negative deviation. This can substantiate that this boiler was designed for base load and the load was uncomfortably low, especially with this low grade coal.

5.3 THE SPEC. GRADE COAL TESTS

The spec. grade coal was tested during the second week. As will be seen below, the milling combinations were the same per load as those of the low grade coal, since the CV of the two coals were virtually the same due to the higher moisture content of the spec. coal that was actually received for the test. There was a difference though, since the low grade coal is classified as such that due to its lower volatiles, not CV, which was evident during testing of the spec. grade coal. There was a general improvement in the unit's behaviour concerning metal temperatures at the high air flows, pyrometer warnings at the very low air flows, etc.

It will be noticed that the tests at different loads were not conducted on consecutive days, due to the emergency generation and the loads being dictated by National Control, as a result of public holidays falling within the days of testing, resulting in different demands on different weekdays. Basically, the 500 MW and 550 MW, as well as the 400 MW and the 450 MW tests were swapped.

5.3.1 The Spec. Grade Coal 630 MW Tests

These tests were performed on 9th May 1994 and included:

- S / 630 / 23,5 / 11h00
- S / 630 / 19,5 / 12h30
- S / 630 / 15 / 13h30
- S / 630 / 10 / 14h30
- S / 630 / 8 / 15h30
- S / 630 / 5,5 / 16h45

where the coding system is as explained in Chapter 4.

- The mill configuration included all 6 mills in service, with A and F mills (top) both being biased down to 45 %.

- The total air flow panel reading ranged in equal intervals for the six tests from ± 610 - 510 kg/s. The correction factor being as in Table 5.1.

- This air flow resulted in the economiser oxygen ranging from ± 4 % average for the LH and RH for the highest down to ± 1% for the lowest air flow tests. (The O_2 corrections for the day were LH +0,4 % and RH +0,4 %)

- This resulted in the CO monitor readings maintaining a steady low average value of ± 25 - 35 ppm for the first four tests, but significantly increasing to > 80 during the fourth and 450 ppm on the last test. The respective LH and RH values of air flow, economiser oxygen and CO monitor reading also gave evidence of a well balanced combustion process in the furnace.

- The CV correction panel indication also stabilised at ± 0,7 which also corresponded with the low quality coal indication, but due to the high moisture, as explained.

5.3.2 The Spec. Grade Coal 550 MW Tests

During this test, the boiler master cycled whilst the critical pressure maintained a negative value, resulting in the total air flow, economiser oxygen and flame temperatures swaying. The test was stopped and repeated after the boiler master had stabilised.

These tests were performed on 11th May 1994 and included:

- S / 550 / 30 / 13h45
- S / 550 / 26 / 14h45
- S / 550 / 22 / 15h45
- S / 550 / 18 / 16h45
- S / 550 / 14 / 20h45
- S / 550 / 10 / 21h45

where the coding system is as explained in Chapter 4.

- The mill configuration included all 6 mills in service, with A and F mills (top) both being biased down to 45 %.
- The total air flow panel reading ranged in equal intervals for the six tests from ± 570 - 465 kg/s. The correction factor being as in Table 5.1.
- This air flow resulted in the economiser oxygen ranging from ± 4,5% average for the LH and RH for the highest down to ± 0,9% for the lowest air flow tests. (The O_2 corrections for the day were LH +0,4 % and RH +0,4 %)
- This resulted in the CO monitor readings maintaining a steady low average value of ± 45 ppm for the first four tests, but significantly increasing to > 65 during the fourth and 500 ppm on the last test. The respective LH and RH values of air flow, economiser oxygen and CO monitor reading also gave evidence of a well balanced combustion process in the furnace.

- The CV correction panel indication also stabilised at ± 0,7 which also corresponded with the low quality coal indication, but due to the high moisture, as explained. However, it had to be reset for increased boiler response, since the critical pressure remained sluggish and maintained a negative value.

C mill started cycling during the fourth test and it was restripped, the power sonic and feeder set point reset and the test could be carried out successfully.

5.3.3 The Spec. Grade Coal 500 MW Tests

During this test, the boiler master and critical pressure also cycled resulting in the total air flow, economiser oxygen and flame temperatures swaying. It could be due to the air fuel correction adjusted too rapidly to obtain the next lower air flow. This valuable lesson gave visibility to the sensitivity of the controls against the bulk and thermal inertia of the machine, these tests could not be hurried. The test was stopped and repeated after the boiler master had stabilised.

These tests were performed on 10th May 1994 and included:

- S / 500 / 31 / 9h15
- S / 500 / 26,5 / 11h00
- S / 500 / 23,5 / 12h00

- S / 500 / 19 / 13h15
- S / 500 / 16 / 14h15
- S / 500 / 11 / 15h30

where the coding system is as explained in Chapter 4.

- The mill configuration included 5 mills in service, with A mill on stand-by and F mill being biased down to 45 %.

- The total air flow panel reading ranged in equal intervals for the six tests from ± 525 - 445 kg/s. The correction factor being as in Table 5.1.

- This air flow resulted in the economiser oxygen ranging from ± 5,1% average for the LH and RH for the highest down to ± 1,9% for the lowest air flow tests. (The O_2 corrections for the day were LH +0,4 % and RH +0,3 %)

- This resulted in the CO monitor readings maintaining a steady low average value of ± 10 - 45 ppm for the first five tests, but significantly increasing to > 350 during the last test. The respective LH and RH values of air flow, economiser oxygen and CO monitor reading again gave evidence of a well balanced combustion process in the furnace.

- The CV correction panel indication also stabilised at ± 0,7 which also corresponded with the low quality coal indication.

5.3.4 The Spec. Grade Coal 450 MW Tests

These tests were performed on 13th May 1994 and included:

- S / 450 / 28,5 / 09h00
- S / 450 / 25,5 / 11h00
- S / 450 / 22,5 / 15h45
- S / 450 / 19,5 / 16h45
- S / 450 / 16,5 / 17h45
- S / 450 / 12,5 / 19h00

where the coding system is as explained in Chapter 4.

- The mill configuration included 5 mills in service, with A mill on stand-by and B (bottom) mill being biased up to 56 %.
- The total air flow panel reading ranged in equal intervals for the six tests from ± 500 - 425 kg/s. The correction factor being as in Table 5.1.
- This air flow resulted in the economiser oxygen ranging from ± 5,6% average for the LH and RH for the highest down to ± 2,9% for the lowest air flow tests. (The O_2 corrections for the day were LH +0,6 % and RH +0,5 %)
- This resulted in the CO monitor readings maintaining a steady low average value of ± 25 - 45 ppm for all the tests. The respective LH and RH values of air flow, economiser oxygen and CO monitor reading again gave evidence of a well balanced combustion process in the furnace.

- The CV correction panel indication also stabilised at ± 0,7 which also corresponded with the low quality coal indication.

Plant problems however occurred that fortunately did not effect the tests. At 10h30 the 100% feedwater regulating valve gave problems, but was fixed and reinstated. F mill was taken out for forced grease nozzle repair and greasing routine at 12h13, but was returned at 15h21. This accounts for the time lapse between the second and third tests. Preferably the tests should be conducted with similar mill combinations for homogeneous variables.

5.3.5 The Spec. Grade Coal 400 MW Tests

It should be noted that only five instead of six tests were conducted, since the last test's parameters were forecast theoretically, but in practice that air flow was abandoned as it was too low due to operational safety reasons.

These tests were performed on 12th May 1994 and included:

- S / 400 / 34 / 09h00
- S / 400 / 30 / 11h15
- S / 400 / 26 / 13h00
- S / 400 / 22 / 14h00
- S / 400 / 18 / 15h00

where the coding system is as explained in Chapter 4.

- The mill configuration included the four bottom mills being in service, with A and F mill on stand-by and B (bottom) mill being biased up to 55 %. This rendered all mill PA flows almost equal.

- The total air flow panel reading ranged in equal intervals for the six tests from ± 445 - 395 kg/s. The correction factor being as in Table 5.1.

- This air flow resulted in the economiser oxygen ranging from ± 5,6% average for the LH and RH for the highest down to ± 3,2% for the lowest air flow tests. (The O_2 corrections for the day were LH +0,5 % and RH +0,45 %)

- This resulted in the CO monitor readings maintaining a steady low average value of ± 20 - 50 ppm for the first four tests, but increased to > 100 ppm in the last test. The respective LH and RH values of air flow, economiser oxygen and CO monitor reading again gave evidence of a well balanced combustion process in the furnace.

- The CV correction panel indication also stabilised at ± 0,7 which also corresponded with the low quality coal indication.

Even on the high air flows the pyrometers already showed low flame temperatures. During the last (ie. fifth) tests two pyrometers started flickering, rendering the sixth test too risky to conduct.

5.4 THE HIGH GRADE COAL TESTS

The high grade coal were tested the third week. An adjustment to the CV correction and the boiler master control was necessary due to the much higher CV of this coal and the different capability of the load demand in relation to the amount of mills needed. The high grade coal also had relatively high total moisture, but that did not seem to make much difference to the CV due to the fact that the combustion gave an all-over impression that this coal was in a higher category.

5.4.1 The High Grade Coal 630 MW Tests

These tests were performed on 16^{th} May 1994 and included:

- H / 630 / 21 / 11h45
- H / 630 / 18 / 13h15
- H / 630 / 15 / 14h15
- H / 630 / 11 / 15h15
- H / 630 / 8 / 16h15
- H / 630 / 5 / 17h15

where the coding system is as explained in Chapter 4.

- The mill configuration included 5 mills in service, with A mill on stand-by and B and E mills biased up to 60% and 55% respectively.
- The total air flow panel reading ranged in equal intervals for the six tests from ± 620 - 525 kg/s. The correction factor being as in Table 5.1.

- This air flow resulted in the economiser oxygen ranging from 3,8% to 1,1% for the average of the LH and RH values. (The O_2 corrections for the day were LH +0,4% and RH +0,4%)

- This resulted in the CO monitor readings maintaining a steady low average value of ± 20 - 35 ppm for the first four tests, but significantly increasing to 60 ppm for the fifth and > 800 ppm on the last test. The respective LH and RH values of air flow, economiser oxygen and CO monitor reading gave evidence of a well balanced combustion process in the furnace.

- The CV correction panel indication stabilised at > 1,0 which corresponds with high quality coal indication.

- Large red hot clinkers formed during the first two tests with the highest air flow and fell down into the ash hopper. Frequent inspection of the platen super heaters, the walls in the burner vicinity and the ash hopper with a tinted heat shield was carried out. Fortunately nothing appeared damaged and the conclusion was drawn that the tests could continue and the situation was solved satisfactorily with the prescribed sootblowing regime that night.

- A small amount of brittle clinkers formed during the last test with the lowest air flow. Samples of both the clinkers which formed with the high air flow which had a solid glassy appearance as well as the dull brittle clinkers which formed during the low air flow, were sent to the ESKOM Technology Research and Investigations laboratory for analysis. A comprehensive report was issued which explained the difference in the fluxing agents formed by the different oxygen levels, resulting in the two types of clinkering and the virtual absence thereof in the mid-range (Blenkinsop[28]).

5.4.2 The High Grade Coal 550 MW Tests

These tests were performed on 17th May 1994 and included:

- H / 550 / 28 / 09h00
- H / 550 / 24,5 / 10h15
- H / 550 / 21 / 11h15
- H / 550 / 17 / 12h15
- H / 550 / 13,5 / 13h30
- H / 550 / 10 / 15h30

where the coding system is as explained in Chapter 4.

- The mill configuration included 4 mills in service, with A and F mills on stand-by and B mill biased up to 58%.
- The total air flow panel reading ranged in equal intervals for the six tests from ± 565 - 475 kg/s. The correction factor being as in Table 5.1.
- This air flow resulted in the economiser oxygen ranging from 5,0% to 2,1% for the average of the LH and RH values. (The O_2 corrections for the day were LH +0,4% and RH +0,4%)
- This resulted in the CO monitor readings maintaining a steady low average value of ± 20 - 40 ppm for the first four tests, but significantly increasing to > 100 ppm for the fifth and > 800 ppm on the last test. The respective LH and RH values of air flow,

economiser oxygen and CO monitor reading gave evidence of a well balanced combustion process in the furnace.

- The large red hot clinkers again formed during the first two tests with the highest air flow but not in as great a quantity as in the 630 MW tests. Frequent inspection of the platen super heaters, walls in the burner vicinity and the ash hopper with a tinted heat shield indicated that all was in good order. The situation was solved satisfactorily with the prescribed sootblowing regime at night.

5.4.3 The High Grade Coal 500 MW Tests

These tests were performed on 18^{th} May 1994 and included:

- H / 500 / 32 / 10h00
- H / 500 / 28 / 11h00
- H / 500 / 24 / 13h00
- H / 500 / 19,5 / 14h00
- H / 500 / 15 / 15h00
- H / 500 / 11 / 16h00

where the coding system is as explained in Chapter 4.

- The mill configuration included 4 mills in service, with A and F mills on stand-by and B mill biased up to 58%.

- The total air flow panel reading ranged in equal intervals for the six tests from ± 545 - 445 kg/s. The correction factor being as in Table 5.1.

- This air flow resulted in the economiser oxygen ranging from 4,7% to 2,1% for the average of the LH and RH values. (The O_2 corrections for the day were LH +0,5% and RH +0,6%)

- This resulted in the CO monitor readings maintaining a steady low average value of ± 30 - 40 ppm for the first four tests, but significantly increasing to > 50 ppm for the fifth and > 400 ppm on the last test. The respective LH and RH values of air flow, economiser oxygen and CO monitor reading gave evidence of a well balanced combustion process in the furnace.

5.4.4 The High Grade Coal 450 MW Tests

These tests were performed on 19th May 1994 and included:

- H / 450 / 33 / 09h45
- H / 450 / 29 / 10h45
- H / 450 / 25 / 11h45
- H / 450 / 20,5 / 12h45
- H / 450 / 16,5 / 13h45
- H / 450 / 12,5 / 15h00

where the coding system is as explained in Chapter 4.

- The mill configuration included 4 mills in service, with A and F mills on stand-by and B mill biased up to 58%.

- The total air flow panel reading ranged in equal intervals for the six tests from ± 510 - 405 kg/s. The correction factor being as in

Table 5.1.

- This air flow resulted in the economiser oxygen ranging from 5,7% to 2,5% for the average of the LH and RH values. (The O_2 corrections for the day were LH +0,4% and RH +0,4%)

- This resulted in the CO monitor readings maintaining a steady low average value of ± 20 - 30 ppm for the first five tests, but significantly increased to > 750 ppm on the last test.

5.4.5 The High Grade Coal 400 MW Tests

These tests were performed on 20th May 1994 and included:

- H / 400 / 37 / 00h00
- H / 400 / 32,5 / 00h50
- H / 400 / 27,5 / 01h45
- H / 400 / 23,5 / 02h35
- H / 400 / 18 / 03h45
- H / 400 / 14 / 05h00

where the coding system is as explained in Chapter 4.

- The mill configuration included 3 mills in service, with A, F and E mills on stand-by and B mill biased up to 55%.

- The total air flow panel reading ranged in equal intervals for the six tests from ± 455 - 370 kg/s. The correction factor being as in Table 5.1.

- This air flow resulted in the economiser oxygen ranging from 6,0% to 3,4% for the average of the LH and RH values. (The O_2 corrections for the day were LH +0,5% and RH +0,5%)

- This resulted in the CO monitor readings maintaining a steady low average value of ± 30 - 55 ppm for the first four tests, but significantly increased to 150 during the fifth test and > 400 ppm on the last test.