CHAPTER 2
LITERATURE SURVEY AND EXISTING TECHNOLOGY

2. LITERATURE SURVEY AND EXISTING TECHNOLOGY

2.1 LITERATURE SURVEY

A literature survey had been carried out regarding similar work that might have been done in other leading countries on this topic and compared to the South African scenario. Confirmation had to be obtained concerning the originality of the criteria of the hypothesis, i.e. to optimise the combustion air flow as stated in Chapter 1.4. The main emphasis was on the thermal efficiency, of the whole unit, for different coal qualities similar to and as wide in range as that of Lethabo coal, with calculation from especially the direct side too. The combined effect of the losses were to be minimised and the air flow not just optimised for single aspects such as minimum NO_x. Also other variables such as pf fineness and burner swirl setting were to be kept constant. Surveys and searches were carried out internationally under numerous combinations of keywords of which the following were the most important:

Thermal efficiency, overall efficiency, unit efficiency, boiler efficiency, maximum efficiency, losses, direct, indirect calculation, steam flow - air flow, optimum air flow/quantity, total air flow, excess air, primary, secondary, tertiary air flow, oxygen percentage, macroscopic, coal quality, low grade, low volatile, low heat in volatiles, moisture, pf fineness, etc.

2.1.1 Germany:

The survey was done through Utility Consultants International GmbH[39] (UCI). Seventeen of the doctorate studies were selected for evaluation according to this project's criteria. Here follows an abstract evaluation of a selection of some of the most applicable ones:

- Reference[29]: This paper concentrated on the swirl in the burner and its effects on the ignition and combustion of pulverised fuel.
- Reference[40]: The formation of CO_2 relative to the CV of the coal was evaluated for spot market buying. The flame temperature was an important parameter and only the boiler was evaluated.
- Reference[41]: This was a study of the acceptance testing and efficiency calculation according to the DIN standard, for the boiler efficiency only.
- Reference[42]: This was a study of modifications on firing equipment (burners, etc.) of the total air flow difference for different NO_x reduction on 20 operational boilers. It was found that one formula or patent was not possible for all boilers and all coals. Each individual case had to be optimised separately.
- Reference[43]: The cost of thermal efficiency was compared against the cost of air pollution, due to the air flow optimisation. The optimum total air flow quantity criteria was shifted from efficiency to air pollution and the cost thereof. The design of combustion parameters and burners were evaluated to suit. Only the boiler was evaluated and the coal type was not mentioned. This project was

probably the closest to the one in this thesis, but still not the same criteria.

- Reference[44]: This study involved the staged air regulation of total air for low NO_x burning.

- Reference[45]: This was a study of the staging of the air that prevents incomplete burn-out. The pf fineness is evaluated and the minimisation of the coarser particles are used to overcome the mentioned disadvantages.

- Reference[46]: The results of a small pilot scale test rig presented problems in its full scale application. The results were of qualitative value only. They concerned NO_x reduction.

- Reference[47]: This study involved the comparison of efficiency gains vs NO_x reduction of low volatile coal on a power station. The priority was the evaluation of the highly stressed boiler components. This power station has a combined cycle gas turbine and the low volatile coal originates from the gasification of the coal to supply the gas turbine.

- Reference[48]: This study involved the NO_x reduction in natural gas, oil, and bituminous coal fired boilers at Mannheim Central Power Station.

- Reference[49]: The priority in this study was the evaluation of NO_x reduction by changes in the combustion process. Even so-called optimised boilers must be reviewed.

- Reference[50]: This study involved the chemical modelling of CV calculation from the elemental analysis of coal and fuel oil.

- Reference[51]: A simulation mathematical model that calculated the environmental aspects too, not only the efficiency of the boiler.

The specific issue that was evaluated was front wall firing in the boiler.

- Reference[52]: This was a study of the combustion of low volatile coal to reduce NO_x emissions. It was achieved by blending the coal with a high hydrogen volatile content coal. The evaluation of low and high concentrate mixtures were compared to establish combustion criteria for the power station.

- Reference[53]: The variation of the staging ratios as well as the total air flow quantity to reduce gaseous emissions on swirler, chaingrate and normal pf burners.

- Reference[54]: This study of burner and milling equipment on NO_x reduction had the conclusion that such a low value as 200 mg/STD m^3 can not be reached without catalytic reduction and a very small pf fineness.

- Reference[55]: This study used bituminous coal analysis to predict ignition and burnout. Seems a laboratory or microscale type of study in the category of drop tube furnace experiments.

2.1.2 United Kingdom:

- Reference[9]: This is the procedure for testing on power stations which prescribes the indirect losses method in detail.

- Reference[14]: This book has several chapters on the separate efficiency testing of boilers and turbines. Various direct efficiency methods are discussed such as traditional density determination. The difficulties thereof are highlighted and therefore not advocated.

- Reference[26]: This standard also covers testing methods on fossil fired power stations. No simultaneous testing of boiler and turbine is covered.

- Reference[27]: This performance analysis has the priority of metal temperature excursion due to combustion air flow as well, but no specific cognisance of the coal quality differences as well as turbine side effects were given.

- Reference[31]: This paper covers the research done on the effects of coal quality on low NO_x burners.

- Reference[56]: This paper covers recommendations for the future regarding the cleaner combustion in pf burners with pollution as priority.

2.1.3 United States of America:

- Reference[34]: The effects of coal quality on power plant performance and the costs are reported. Overall, the conclusion is made that the availability of the plant is proportional with the coal quality, and availability is made up from efficiency and reliability. No simultaneous testing of boilers and turbines were covered. The coal quality range that a power station can burn is covered implicitly but not as in the case of tied collieries with varying qualities, especially that of Lethabo coal.

- Reference[36]: This Normative Reference covers the prevention of explosions in multiple burner furnaces in general (all fuels). It concentrates on the economiser oxygen values and air fuel ratios, especially during start-up conditions.

- Reference[37]: This Normative Reference covers the prevention of explosions in multiple burner furnaces fired by coal. It states that the oxygen in flue gas guidelines should be followed, unless otherwise proven by test, but no specific criteria is given. The emphasis is on the boiler alone.

- Reference[38]: This research report on boiler optimisation supported some of the detailed findings of this project e.g., that the reheat steam temperature decreased when the air flow is reduced below a certain value but, overall the testing criteria had few commonalities with those mentioned in **Chapter 1.4**.

2.1.4 Australia:

- Reference[32]: In this presentation, feedback was given regarding coal combustion in Australia. There were single commonalities regarding testing and coal quality evaluation, but not Overall regarding the main criteria mentioned in **Chapter 1.4**. (Certain explanations of the results in **Chapter 6** were based on research done by this reference, e.g., the percentage NO_x produced from the nitrogen in coal as opposed to thermal NO_x.)

- Reference[57]: This book treats the norms of testing and characterisation of brown coal in that country. In chapter 8 the theory of combustion is treated inter alia. Chapter 12 covers the combustion more specifically in industry application. No common ground regarding the standards for testing and coal classification (although of totally different quality than that of Lethabo) could be found.

- Reference[58]: This paper covers work that concentrates on the burner in isolation with the main emphasis on NO_x formation.

2.1.5 Japan:

- Reference[59]: This standard states the Japanese coal buying criteria. There was common ground regarding the reactivity ratio used in Chapters 6 and 7 (the ratio of fixed carbon to total volatiles as used by engineers and financial merchants and not the hydrogen to total carbon as used by academics and power industry), but no information on testing criteria.

2.1.6 South Africa:

- Reference[2]: This study attempted an optimisation of the total air flow according to the suggested criteria except without segregated coal supply but blended coal. The sliding targets of the computer program used were also not customised for the power station.

- Reference[3]: This study was limited to the burner in isolation with a wide range of different volatile contents in coal, all at the same CV, to produce the Burner Stability diagram (**Figure 4.4**). The goal was to determine the minimum burner load for specific coal qualities.

- Reference[4]: This is the guaranteed efficiency test of Lethabo boiler which utilises the indirect losses method of evaluating certain contractually defined losses only.

- Reference[5]: This study optimised Lethabo Boiler 1 only according to the least excess air criterion and with blended spec. coal and utilising the indirect losses method only.

- Reference[60]: This study optimised the Matimba Boiler 4 only according to the least excess air criterion and utilising the indirect losses method only.

- Reference[30]: This was a drop tube furnace laboratory type test that determined the deflagration properties of Lethabo coal as a function of temperature and oxygen concentration.

2.2 OPTIMUM COMBUSTION AIR FLOW CRITERIA

In section 2.1 the literature which was evaluated showed common denominators with the criteria set in Chapter 1.4, but none had enough properties to categorise itself as a similar study. Certain of the variables that were deliberately fixed in this study, varied in those evaluated, such as the burner swirl and the pf fineness size. In many of the studies the emphasis fell on other priorities, such as the varying flame temperature due to air flow variation, the staging of the air rather than the total air flow requirement, the degree of burnout only as a loss, front wall firing and superheater metal temperature excursions, etc.

There were studies where the efficiency was a criterion, but more often than not it was compared against the cost of air pollution as a higher priority. The above mentioned refers to the present European high standards but in South Africa little can be done to change the gaseous emissions by changing the air flow. A lot depends on the coal quality and the tied colliery scenario. The gaseous air pollution emission rates in South Africa is not the critical problem, although slightly higher than the stricter European emission limits. The greater concern is the particulate emissions, which is more efficiency and air flow dependable. The gaseous emission rates against air flow variations can be seen in Chapter 6. In South Africa the total air flow has greater impact on the efficiency and the combined effect of the losses. Therefore the air flow tests in Europe were focused on NO_x reduction as the priority.

No evidence could be found regarding the testing of the combined boiler and turbine as a unit. In all the tests in the studies, the prescribed standards, etc., the focus was on testing of the boiler in isolation. Many of the studies also focused on the testing of components of the boiler such as the burners and mills. Some of the tests were also not full scale but performed on a pilot scale test rig. One study was performed on a combined cycle which is a total different case, despite the varying coal qualities tested due to the gasification of the coal.

The fact that more than one of the German studies found that universal criteria is not possible, but that each case must be optimised individually (even so called optimised boilers), supports the findings of this study. Each plant has its own characteristics and range of coal quality that can be burnt, under different settings (and air flows).

2.3 THERMAL EFFICIENCY COMPUTER PROGRAMS

Concerning computer software, there was no resemblance in the philosophies to those used in these studies and those set in the criteria for the execution of this project. This project's criteria required a direct calculation method to be developed and then that the STEP program be customised according to the optima obtained from those project results. The STEP program balances the direct and indirect efficiency calculation methods by minimising the unaccountable losses. It can be considered optimisation modelling but not process/plant modelling. STEP also utilises polynomials to slide targets for the efficiencies and losses.

Amongst the studies evaluated, there was one which used the DIN standard to calculate the boiler efficiency of an acceptance test. Two other studies, also from Germany, compiled chemical and mathematical models, one of the CV calculation from elemental analysis and the other the environmental impact combined with the boiler efficiency. ESKOM has a modelling program, Coal Quality Impact Model (EPRI-CQIM) that evaluates the techno-economic impact of variance in coal quality, but only at full load and the other data is extrapolated proportionally.

All the other studies, including those carried out in ESKOM, utilised the indirect losses method[9] for the boiler only. Although the STEP program monitors the whole plant on the direct and indirect methods, it was not used as such to optimise plant (and combustion air flow) in the UK. More detail about available computer software and the philosophies thereof can be found in Chapter 3.7 and Appendix I.

2.4 COAL QUALITY AND CHARACTERISATION

In the studies evaluated in section 2.1, there were those that investigated combustion behaviours with change of the coal quality. There was a study that evaluated the ratio of low volatile content coal blended with coal of a higher volatile content. Another study investigated the impact of combustion with change in CV of the coal. These projects all had the blending of coal as the predominant feature (except reference[3] in South Africa), whilst the philosophy in this thesis concentrated on segregated (blockburning) coal supply.

Some of the other references performed tests with coal totally different to that of Lethabo (and even South Africa in some cases) such as higher CV bituminous coals and brown coals. The Lethabo coal has a distinctive variability in its volatiles (see Chapter 3.8, 4.1 and 7.3). Many of the other countries in the studies have a coal quality policy considering spot market buying of coal. Lethabo falls in the category of a power station with a tied colliery, just with a significant difference in quality of the seams in the mine.

The Japanese reference use the same definition for coal reactivity as in this study after comparison of the different definitions (Chapter 6.4, Figures 6.29 to 6.33) were made.

2.5 PREVIOUS AVAILABLE TEST RESULTS

The applicable test data that could be used as reference or comparison purposes in this study were the following:

- The Lethabo boiler[4] and turbine[61] guarantee efficiency tests.
- The Lethabo Lean Coal tests[3].
- The Lethabo excess air reduction tests[5].
- The Lethabo coal deflagration tests[30].
- The Lethabo air flow optimisation tests[2].

These tests also did not comply exactly with all the criteria as set out in section 1.4.
