PhD Examination Report: Rafal Buczynski

PhD Thesis Title: Investigation of Fixed-Bed Combustion Process in Small Scale boilers

1. **Appraisal of the Thesis.**

This thesis is concerned with the modelling and design improvement of a fixed bed combustor capable of burning either coal or biomass, although only the former is studied here. The thesis consists of eleven chapters is 137pages long including the references.

The first chapter is a general introduction to the topic and is concerned with the role of coal as an energy source in the world and particularly in Poland. Coal is widely used for heating purposes particularly for small domestic appliances and these tend to be inefficient and produce high levels of pollutants. The purpose of the investigation described in the thesis is to increase the understanding of the combustion behaviour and present an improved design. This chapter provides a suitable background.

The second chapter gives an excellent outline of the background relating to the use of small scale coal-fired boilers in Poland. The design of these boilers is given together with the shortcomings in control of emissions and in thermal efficiency. The environmental emission regulations are outlined.

The third and fourth sections briefly outline the objectives and scope of the work and this sets the outline of the work undertaken and reported in the subsequent chapters.

The next chapter, 5, sets out the model that is used for studies of combustion in a fixed bed. This first of all includes an outline of the general features of the decomposition of coal and then gives compilations of physical data relating to thermal conductivity, radiation, specific heat, density and porosity which are necessary for the model. The major chemical processes are then discussed. Devolatilisation and char combustion and gasification are surveyed and the chosen kinetic data give; this data is from a slightly older source but these seem to be adequate. The role of heat exchange between the phases is examined.

Chapter 6 outlines the mathematical model and a Commercial Computational Fluid Dynamics (CFD) software package was used. This is appropriate and commonly the case because of the difficulty of writing such complex software within the time available for study for a PhD. The appropriate continuity and conservation equations are set out as well as the choice of the turbulence and radiative heat transfer model. The establishment of the fixed bed combustion model was then described. The combustor uses a prepared solid fuel which consists of particles with an average size of 2 cm which would give a porous bed. The mathematical model of combustion in such a bed was the established and this is a sound approach. The key issues are the sequence of combustion reactions of the volatiles formed by devolatilisation and the way in which CO is formed as an intermediate and then decays. Secondly the individual reaction around a combusting char particle have to be established and how both CO and CO_2 are formed and their interaction, and the decay in concentration of the former. The structure of the bed is important in relation to the flow of gases through it but also from the point of view of the internal porous structure of the individual char particles and the variations within the fixed bed. There are rigorous sections on the thermal properties of the fixed bed. All these issues covered by the thesis play an important part in the success of the model. Reasonably good sources of data are used although the most up to date references are not always employed.

Validation is undertaken and described in Chapter 7 where the theoretical model is compared against a set of experimental data for an idealised vertical cylindrical combustor. This experimental data comes from a separate PhD study. A considerable number of computed studies are made of the thermal conditions and gas composition in the bed. A detailed comparison is made of calculated and experimental temperatures in the bed and the gas composition. There is reasonable agreement between the results for the temperatures but the CO concentration show deviations. A sensitivity analysis is undertaken pointing to the effect of the kinetics, this is clearly an important factor but the accuracy of the experimental data should also have been examined; but since the data is from within the same institute perhaps this had been done independently. This lack of agreement between experimental and calculated CO concentrations is common feature in many combustion models because of the shortcomings of the chemistry and often because of difficulties in the quenching of gases in the experiments.

Chapters 8 and 9 set out the simulation of the combustion process in a small scale boiler and it is later validated. The model is first set up in terms of the geometry, the combustion conditions and the boundary conditions. Because this is a real burner it is a more complex situation than that set out in the previous chapter for a cylindrical fixed bed combustor.

Much of the difficulty in modelling this system arises from the fact that the solid fuel moves across the grate and interesting results are given for the changes in char, volatiles and moisture along the bed. The combustion of the gases is seemingly easier to model but the accurate prediction of the profiles and exit composition is the sum effect of a considerable number of variables-temperature, velocity as well as the kinetics of combustion of the gases. A sensitivity analysis was undertaken to look at a number of such effects including changing the size of the computation mesh and a number of the physical properties.

Chapter 9 deals with the details of the validation of the numerical model using measurements of temperature, O_2, CO_2 and CO measurements made in various planes in the freeboard which were made available for this study, and the details of these measurements are given in another referenced thesis. Agreement is fairly good except in the case of some of the CO concentrations. All the experimental measurements are subject to error and the thesis contains some discussion about the causes, such as leaks, although the experimental errors are not given. It is concluded that the model is sufficiently accurate to make conclusions about improving the design.

Suggested improvements in the design are outlined in Chapter 10. Particular attention is directed to the deflector whose role is increase the residence time of the gases and to improve mixing. Different positions and shapes were examined and CFD results were obtained for these cases. The air distribution and shape of the combustion chamber were also examined in the same way and a set of results obtained for all the cases.

The final chapter, 11 gives an excellent summary of the results and the conclusions. The outcome is that an optimised boiler has been produced which would significantly reduce the emissions of CO and increases the efficiency. This is a substantive outcome of the work described in the thesis.

The compilation of references at the end of the thesis give a good coverage of the field. It particularly deals with the German and Polish literature with perhaps less emphasis on the Scandinavian and US publications. However there does not seem to anything missing of a significant nature. There are a few minor errors, for example Ref 44 is incomplete and does not follow the style of the other references, Ref 51 should be Malte

In my opinion the thesis contains a significant amount of original result of a high standard. The thesis is well written, the results are presented in a clear way and it is well illustrated with good diagrams.

Overall Assessment

My overall conclusions are that this is a very good piece of work and much of it would be worthy of publication in scientific Journals.

I therefore conclude that the Thesis meets the standard necessary for the PhD to be awarded.

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