1 Introduction

1.1 Motivation

Currently, the world's energy demands are still expected to increase due to economical growth. Special attention has to be paid to this situation due to increasing energy prices in the future and the requirement for sustainable energy supplies. In addition, global warming related to CO_2 emissions is also an important issue in the development of new energy solutions. Coal together with other fossil fuels such as gas and oil are currently, and will remain for sometime, the main source to meet increasing worldwide energy demands. However, a major disadvantage of using fossil fuels as an energy resource is the emissions of species such as NO_x, SO_2, CO_2, etc. The combustion of fossil fuels inevitably produces large amounts of carbon dioxide. Based on the 2006 WEO Reference Scenario, energy-related CO_2 emissions will rise by 98% above 1990 levels by 2030 [53]. On the other hand, emission regulations are getting more stringent. The problem can be solved by an efficient use of the fossil fuels for energy generation that will lead to the reduction of emissions from global warming gases and a higher efficiency of power generation.

As an alternative, biomass may replace coal partly or entirely in power generation plants. Biomass is gaining increasing interest as a renewable energy resource for two main reasons: 1) biomass is an attractive fuel due to its CO_2-neutrality, which may lead to reduced environmental damage, 2) utilization of biomass may save valuable energy resources. Also, another reason is that there is a great surplus of agriculture production due to a process-intensive plantation technique in some European countries. For example, in Denmark there is a fairly large surplus of straw, and it has been used for power generation in utility boilers as well as for heat production in small scale furnaces, e.g. at individual farms. On the other hand, Germany is one of the countries which makes great efforts to encourage biomass utilization: a new renewable energy ordinance (EEG) is sanctioned which obliges electricity distributors to buy electricity from renewable energy sources at an increased reimbursement. Even demolition wood is regarded as biomass in this ordinance. This ordinance shall make firing biomass profitable, so that the large potential of available biomass can actually be explored [29].

Though the use of biomass for power generation has been practiced for a number of years, there is far too little biomass to replace coal globally. In terms of energy conversion efficiency, biomass as a single fuel is still unable to satisfactorily replace coal as an energy resource. As an option co-firing biomass with coals may be implemented in existing large-scale firing systems. Some power plants in Denmark, Holland and Austria utilize biomass co-combustion with coal for electricity production. In existing pulverized coal fired boilers, this technology offers several environmental benefits such as reducing SO_2 and CO_2 emissions. In addition, co-combustion of biomass such as wood, straw, and energy crops with coal in full scale boilers for power generation is a means of high energy-efficient utilization at comparatively low investment costs.

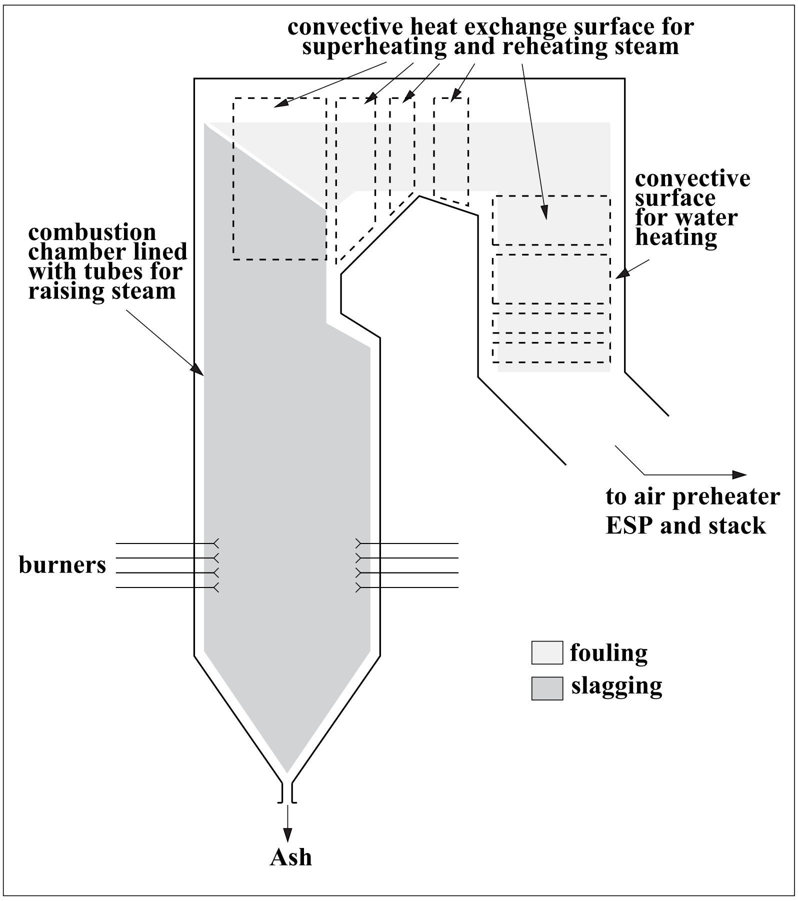

Figure 1.1: Schematic illustration of slagging and fouling regions in typical pulverized fuel boilers [16].

However, co-firing biomass with coals will lead to a higher tendency of deposit formation on the heat transfer surfaces. Uncontrolled deposits causes some operational problems including corrosion as well as slagging and fouling. Fig. 1.1 shows schematically conventional pulverized fuel (pf) fired boiler configuration with regions of slagging and fouling. It can be seen from the figure that slagging represents the deposit formation within the furnace where the heat transfer process is dominated by radiation, whereas fouling refers to the deposit formation in the convective passes of the boiler. These problems cause a reduction in heat transfer rates from the flue gas to the steam circuit causing a decrease in plant efficiency. Unscheduled plant shutdowns are necessary due to unmanageable forms of detrimental deposits causing a deterioration in plant availability. The operational problems are mainly due to the high amount of volatile potassium in biomass, which is vaporized during combustion. The vaporized potassium may react with ash particles prior to or after the condensation process. This may lead to partly melting of the ash particles which promotes the deposition process on the heat transfer surfaces. Alternatively, the vaporized potassium may condense on cooled tube surfaces, afterwards creating sticky surfaces that accelerate deposit build-up. A typical view of deposit formation on superheaters in a coal-fired furnace is shown in Fig. 1.2. The shape of deposits may be similar to that found in a co-firing system. An illustration of a deposit shape with biomass co-combustion in a 0.5 MW semi-industrial pulverized-fuel combustion facility can be found in [29]. In order to prevent or at least to reduce such problems, there have been

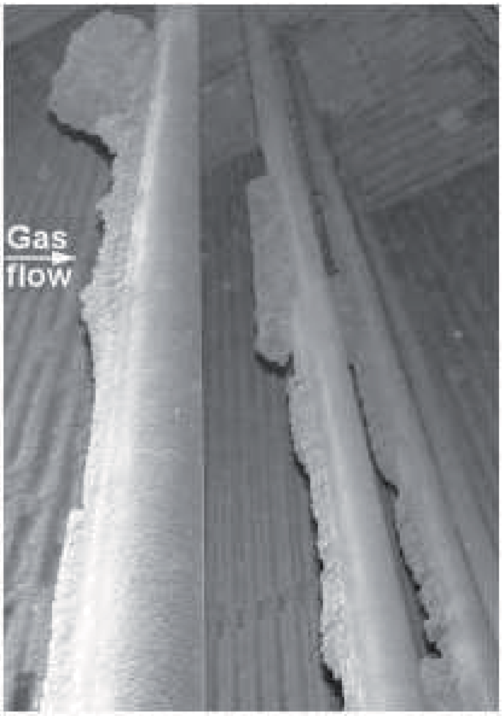

Figure 1.2: View of deposit on superheaters [111].

continuous efforts in both industrial and academic areas in order to predict slagging and fouling tendency. For that purpose, there have been several methods ranging from the most simple indices, based on traditional coal analysis, to advanced models dealing with the fundamental deposition mechanisms [56, 84]. The first methods are the empirical approaches and only valid in a very narrow band of coal rank and they cannot, with any confidence, be utilized for co-firing biomass with coals. The latter ones which consider the physical and chemical processes taking place are much more suitable for general applications.

To predict heat transfer degradation from the flue gas to the steam circuit, it is required to consider the most important processes concerning the mineral transformation and subsequent ash deposition as well as heat transfer through the deposit. For this purpose, the mechanistic approaches of deposit formation in coal fired boilers have been developed [82]. Even though the mechanisms were developed for coal, they are also applicable for biomass fired boilers [6]. Also, the mechanistic descriptions can be applied to a co-firing system, which is different in the relative importance of the mechanisms.

In the recent years, numerical modelling of combustion processes in conjunction with Computational Fluid Dynamics (CFD) has become a very efficient tool and is hence widely applied in predicting flow field, temperature, flue gas composition, and particle aerodynamics inside furnaces achieving a high local resolution and reliability. Furthermore, a comprehensive investigation of the deposition process can be performed by incorporating deposition models into the CFD codes. This approach is especially attractive because it may produce a reliable prediction with reduction in cost and time compared to a purely experimental approach. Based on this situation, the 3D-combustion simulation code AIOLOS has been developed at the Institute of Combustion and Power Plant Technology (IFK) at University of Stuttgart since the late 1970s, which mainly deals with pulverized-fuel combustion processes. More detailed information about the simulation code is available in [60, 98].

1.2 Objectives and Arrangement of the Current Work

Biomass contains a relatively high amount of potassium which significantly affects the deposition process in case of the co-firing technology. In order to predict such effects, this work focuses on two important processes, one is the release of alkali during combustion, and the other is the effect of the released alkali on the deposit build-up. A relatively detailed model is proposed in this work in terms of the alkali release. To the best of the author's knowledge this may be the first time that the detailed model is involved in the prediction of deposit build-up in case of the co-firing system. Models for these processes are developed and integrated into AIOLOS. In these models, the released alkali contributes to the formation of deposit layer via condensation process, and the condensible alkali has effect on the sticking probability of ash particles on the deposit surface. The deposition mechanisms for ash particles depending on the particle sizes and geometry as well as a heat transfer model are utilized in order to build a comprehensive deposition model in the furnaces [90]. For validation purposes, two experimental results are used in this work. One is the experiments which were performed on an atmospheric-pressure drop tube reactor by Reichelt [85], and the other is the experiments which were performed on the 0.5 MW semi-industrial pulverized-fuel combustion facility by Heinzel [42].

Chapter 2 deals with the general aspect of CFD simulation of reacting flow, and the relevant features of solid combustion modelling compared to the deposition models are briefly summarized. A fully coupled Eulerian/Lagrangian approach as an alternative to Eulerian framework in order to model the behaviour of a two-phase flow involving flue gas and particles is described.

In Chapter 3 alkali metals behaviour in coal as well as in biomass are presented and discussed. The heterogeneous and homogeneous reactions for the alkali species are described. Transport and deposition mechanisms of the released alkali and that of ash particles are addressed. A brief discussion about sticking probability especially with the inclusion of the effect of the condensible species as well as the models of heat transfer through the deposit is presented. Strategies for implementation of the models into the 3D-combustion simulation code AIOLOS are discussed.

Evaluations of all models are presented in chapter 4. Simulation results concerning the alkali release and subsequent deposition process are presented and discussed by comparing them with the experimental ones. The results regarding the deposition process are presented, both for a case with 100% biomass and for several co-firing cases with low thermal shares of biomass.

Chapter 5 presents conclusions of the work and recommendations for future work.