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Co-firing of biomass and slagging in industrial furnace: A review on modelling approach

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A B S T R A C T

Co-firing biomass is the principle means of mitigating the future energy crisis and reduction of pollutant emissions by expanding the use of renewable energy. On the other hand, slagging combustion is another important topic in power plant industries where major advantages are the reduction in the disposed of unused mineral content in the environment, enhanced energy efficiency, diverse fuel flexibility and higher percentage of lower-carbon content slag residues for applications. In order to determine the detailed information of different processes and reactions inside the furnace, combustion phenomenon, predicting the flue gas emissions, proper mixing of the fuels, chemical reactions, particles combustion, and the trajectories of particles, experimental investigation is not well enough. These limitations provide the scope to implement numerical modelling of biomass combustion and slagging. A number of researchers developed various code/model to investigate these phenomenon. In the present studies, different numerical studies performed are reviewed, grouped and summarized based on the fuel processing technology, burnout performance, emission level, environmental aspect, ash information and deposit characteristics, effect of co-firing ratios and adoption of oxy-fuel co-firing. Overall, this review highlights the possible impact of co-firing of biomass with coal and slagging combustion under different conditions on the boiler performance which will guide the researchers to further investigations.

1. Introduction

Co-firing: Co-combustion of coal and biomass represents a sustainable, renewable energy option that promises reduction in net CO_2, SO_x and often NO_x emissions, as well as in the anaerobic release of CH_4, NH_3, H_2S, amides, volatile organic acids, mercaptants, esters, and other chemicals leading to several societal benefits [1–5]. Knowledge about the performance of biomass combustion [6–8], its emission [9–13], and firing, ashing, slagging and fouling [14–16] is still quite limited. The primary goal for researchers working in this field is to develop a possible way to convert the biomass to thermally efficient and eco-friendly energy and its subsequent mechanism. An experimental investigation is considered to be the most appropriate method for this kind of study. But, an experiment is not only an expensive and lengthy process but is also technically challenging and sometimes interrupts the regular operation of the plant. However, experimental methods are important, but may often be inadequate to analyse the detailed phenomena inside the boiler, especially for an industrial furnace. Lab scale analysis was another supplementary method which is extensively accepted in order to solve this type of problem. However, there are some limitations in the lab scale compared to full scale analysis based on different parameters and related physics. Detailed information of different processes and reactions inside the furnace, combustion phenomenon, predicting the flue gas emissions, proper mixing of the fuels, chemical reactions, particles combustion, and the trajectories of particles are not possible to track in experimental investigation. These limitations provide the scope to implement numerical modelling of biomass combustion.

Slagging: Slagging is a process of combustion in which ash component is heated (at a temperature above the ash fusion temperature) and becomes molten, and thus deposited along the furnace refractory wall. This molten ash forms a layer called slag. The slag layer has substantial consequences on performance of coal based power plants. The principle advantage of slagging is the reduction in the disposed of

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unused mineral content in the environment, improved energy efficiency, broader fuel flexibility and higher percentage of lower-carbon content slag residues for applications [17,18]. But, only few attempts are taken to investigate the slagging issue [19,20]. It is important to identify the amount and position of the slag as well as its motion. It is difficult to solve the problems on site unobtrusively and with reasonable effort. The answer is mathematical modelling, which leads to slag formation modelling. In recent years, a number of attempts have been made to utilize computational analysis to model the ash formation and transport process in pulverized fuel combustion system [21–30]. Computational modelling is a way to investigate the performance of slagging to better understanding this process. Modelling may provide detailed investigations overcoming limitations in experimental work.

CFD modelling: Computational techniques provide the opportunity to investigate in detail, the combustion phenomena and contaminant development inside the furnace. But the success of computational analysis largely depends on the appropriate numerical technique and the physical/chemical models employed. In order to understand combustion as well as co-combustion issues and related problems associated for direct firing of biomass, modelling and analysis is must. Modelling of the biomass-pulverized coal co-firing process requires theoretical as well as numerical bases. It is essential to validate the model against experimental data. CFD modelling of biomass combustion and co-combustion with efficient turbulent model, and precise model predicting particles' trajectories and chemical reactions on different boilers are demonstrated in the literatures [31–37]. Though some CFD analysis has already investigated for different types of biomass for light weight biomass, a validated and efficient numerical model is still needed for the further investigation of biomass combustion.

CFD models for coal combustion have been developed based on theoretical as well as experimental investigations [38–41], including all the stages of the combustion. Computational modelling of combustion of biomass particle is found as a major challenge due to some limitations. Though a number of researchers and groups are working in this field, still there have been a very few number of modelling study for biomass combustion using detailed combustion models [42]. Many numerical models developed for fossil fuel combustion have been modified to apply to biomass combustion or co-combustion modelling. In addition, there are a number of available commercial CFD models and codes. Only few codes provided the features for the special effects of biomass combustion [31,36,43–48].

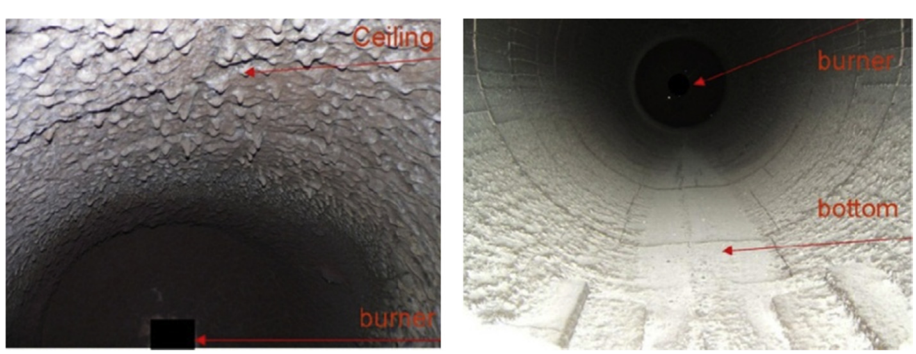
In the present study, two important topics such as co-firing biomass and slagging combustion in industrial scale furnace were highlighted on the basis of numerical modelling. The main objectives of this study are to explore the fundamentals of slag flow modelling and to analyse the present scenario of modelling biomass combustion technology, tools developed for the prediction of slagging behaviour of the fuel ash in combustion applications. Overall, this paper provides an extensive review of the fundamental aspects and emerging trends in numerical modelling of slag formation and co-firing of different types of biomass fuel in industrial furnace. The attempts in modelling published so far are reviewed, grouped and summarized which will guide the researchers to further investigations.

2. Modelling of slagging in industrial furnace

It is proven that coal is the main fossil fuel energy source in the world. But, it contains various inorganic contents such as SiO_2, TiO_2, Al_2O_3, CaO, MgO, Na_2O, K_2O, P_2O_5, Mn_3O_4, SO_3, Fe_2O_3 etc. During the combustion of coal in power plants, these mineral contents are deposited as slag [14]. Fig. 1 shows a typical slag layer formed in a 5 MW combustion test facility [49]. The deposited slag thickness is not uniform in the ceiling wall Fig. 1(a) and the bottom wall Fig. 1(b) of the furnace. This slag layer has a significant effect on performance of coal based furnace and provide numerous advantages [17,18]. The deposited slag layer also works as a coating which prevents the heat loss in the gasifiers. But slagging reduces the overall efficiency of the furnace; excessive slagging reduces reliability and safety because of corrosion. For designing and optimization of the slagging combustor, it is imperative to investigate the related process occurring inside the furnace. In last decade, research has been concentrated into the effects of oxy-fuel combustion by CFD [50–53]. But limited attempts are taken to investigate the slagging issue. It is very important to know the amount and location of the slag as well as its dynamics.

2.1. Modelling of slagging

As discussed above that slagging combustion is a complex process in combustion technology. Several continuous processes are involved such as slag deposition, slag flow, wall burning etc. A basic schematic illustration of the slag formation on a typical refractory wall and membrane wall is presented in Fig. 2. This figure illustrates the fundamentals of slag layer formation and associated mass and heat transfer processes. When molten ash particles hit the refractory wall, based on the capturing criteria, they are captured and deposited on the wall.



(a) (b)

Fig. 1. The slag formed in the 5 MWth oxy-coal combustor [49], (a). at ceiling wall, (b). at bottom wall.

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