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# Integrating multi-objective optimization with computational fluid dynamics to optimize boiler combustion process of a coal fired power plant

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## HIGHLIGHTS

- A coal fired power plant boiler combustion process model based on real data.
- We propose multi-objective optimization with CFD to optimize boiler combustion.
- The proposed method uses software CORBA C++ and ANSYS Fluent 14.5 with AI.
- It optimizes heat flux transfers and maintains temperature to avoid ash melt.

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## ABSTRACT

The dominant role of electricity generation and environment consideration have placed strong requirements on coal fired power plants, requiring them to improve boiler combustion efficiency and decrease carbon emission. Although neural network based optimization strategies are often applied to improve the coal fired power plant boiler efficiency, they are limited by some combustion related problems such as slagging. Slagging can seriously influence heat transfer rate and decrease the boiler efficiency. In addition, it is difficult to measure slag build-up. The lack of measurement for slagging can restrict conventional neural network based coal fired boiler optimization, because no data can be used to train the neural network. This paper proposes a novel method of integrating non-dominated sorting genetic algorithm (NSGA II) based multi-objective optimization with computational fluid dynamics (CFD) to decrease or even avoid slagging inside a coal fired boiler furnace and improve boiler combustion efficiency. Compared with conventional neural network based boiler optimization methods, the method developed in the work can control and optimize the fields of flue gas properties such as temperature field inside a boiler by adjusting the temperature and velocity of primary and secondary air in coal fired power plant boiler control systems. The temperature in the vicinity of water wall tubes of a boiler can be maintained within the ash melting temperature limit. The incoming ash particles cannot melt and bond to surface of heat transfer equipment of a boiler. So the trend of slagging inside furnace is controlled. Furthermore, the optimized boiler combustion can keep higher heat transfer efficiency than that of the non-optimized boiler combustion. The software is developed to realize the proposed method and obtain the encouraging results through combining ANSYS 14.5, ANSYS Fluent 14.5 and CORBA C++.



## 1. Introduction

Coal fired power plants play the dominant role in many countries in the world because of the characteristics of coal fired power plants, such as massive and stable unit power, low cost and short construction period compared with other energy based power generation plants. On the other hand, there is a great need to improve coal fired power plant boiler combustion efficiency and decrease carbon emission. Coal fired power plant boiler combustion is a highly complex process. As the pulverized coal is blown into the furnace and combusts, the volatile matter in the coal is liberated. As the bonds between the coal molecules are broken, and the coal decomposes many gases are contained in the gaseous volatiles

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including $CO_2$, $H_2O$, $N_2$ and small proportions of CO, $H_2$, and many different hydrocarbons ($C_xH_y$). These are mixed with the surrounding air and rapidly burnt with prevailing temperature above the ignition temperature of the volatile mixture [1]. Radiation, convection and conduction occur inside the boiler. Radiant heat transfer is prevalent in the radiation section or core of the furnace. The transfer of radiant energy to the boiler tubes is dependent on the luminosity of the flame and the amount of heat absorbing surface of the boiler [2]. However, slag build-up on the heat absorbing surface such as surface of water walls of a boiler can seriously deteriorate the boiler combustion efficiency.

Slagging in the radiant section of a coal boiler with a high temperature is usually associated with some degree of melting of the ash [2]. In coal fired power plant boilers, slagging can occur on the furnace water walls and the first few rows of superheater tubes. The aerodynamics of the flue gas in the combustion process can convey ash particles to the vicinity of the heat transfer surfaces, and the ash particles can pass to the boundary area by inertia. The ash particles can adhere to the surface of water wall tubes if either the particles or the surface is "sticky" enough to overcome the kinetic energy of the incoming particles, and prevent it from rebounding from the heat transfer surface [2]. Therefore, maintaining an appropriate temperature in the boundary of the furnace and keeping the incoming particles not to melt can decrease slagging. Based on these mechanisms of heat transfer, chemical reactions and slagging, the research proposes a novel method to decrease or even restrict slagging and improve the coal fired power plant boiler efficiency.

Artificial intelligence (AI) technologies such as neural network based methods and multi-objective optimization have been applied in power industry to improve the efficiency of control systems [3–10]. For example, the neural-network-driven computer systems are used to optimize soot-blowing in coal plant boilers to decrease $NO_x$ emissions, improve heat transfer rate and unit efficiency, and reduce particulate matter emissions in coal fired power plants in the United States [11]. NSGA II is one of AI based multi-objective optimization and it is widely used to successfully optimize industry processes [12–15]. However, AI based methods are limited because non-availability of data regarding characteristics of slag build-up. For example, no data from slag measurement can be obtained from coal fired power plants to train the neural networks.

On the other hand, CFD simulation technology is widely applied in power generation industry to analyse and improve combustion processes [16–20], optimize boiler design [21–25], and adjust burner tilt angle offline after overhaul or upgrade occurring in power plants [26].

With the advancement of computer technology and mathematical methodology, integrating AI with CFD technologies can solve combustion related problems. Based on this, the research proposes a new method of integrating multi-objective optimization with CFD technology to improve boiler combustion efficiency and decrease or even prevent serious slagging inside the furnace of a coal fired power plant boiler.

## 2. Modelling of coal fired power plant boiler combustion process

Finite element method (FEM) supported CFD is applied to simulate all the dynamic fields of the flue gas accurately [1,27,28,30–32]. A coal fired power plant boiler model based on FEM is developed. The flue gas property fields such as temperature and density field are analyzed and the results show that the simulation results of the flue gas properties are close to corresponding data from power generation industry and simulation results from other research [29,30].

### 2.1. Geometry of the furnace of coal fired power plant

A three dimensional coal fired power plant boiler furnace model is developed using ANSYS Fluent 14.5 based on the real data of a 1160 t h$^{-1}$ tangential coal fired power plant with a 14.62 m wide, 12.43 m deep and 48.8 m high furnace [33]. The characteristics of flue gas property fields such as temperature and density fields are simulated and analyzed. The results are close to corresponding data from power generation industry and other researchers' simulation results [27,33,34]. The geometry of furnace is shown in Fig. 1.

The positions of each set of four burners located in the same horizontal section are shown in Fig. 2. The center line of burner which is installed in different corners is shown in Fig. 3. The mesh for the geometry is shown in Fig. 4.

The angle of center line can decide the diameter of the tangential flame ball and the data is listed in Table 1. The pulverized coal property data is shown in Table 2 [33], and the burner operating parameters are listed in Table 3. The location of each burner group is denoted using value of $z$-axis as shown in Table 4.

The detailed data of mesh is listed in Table 5. The research combines multi-objective online identification with CFD based model to identify the slagging and fouling inside furnace, and optimal number for mesh node and element is significant, insufficient meshing and over meshing both can negatively influence the identification of the software based on the proposed method.

### 2.2. Modelling the combustion process

Heat transfer including conduction, convection and radiation occurs in different sections of the furnace. In the center of furnace, heat transfers to the metal surface of water wall pipes from flame of pulverized coal burning through radiation. Then the heat transfers to water side of the metal pipes through conduction and the heat can be absorbed by the flowing water or mixture of steam and water by conduction and convection. In the flue gas path, heat is carried to the metal surface of superheater and re-heater. Then the heat can be absorbed by metal pipes of superheater and re-heater through convection. Finally the steam inside the pipes of

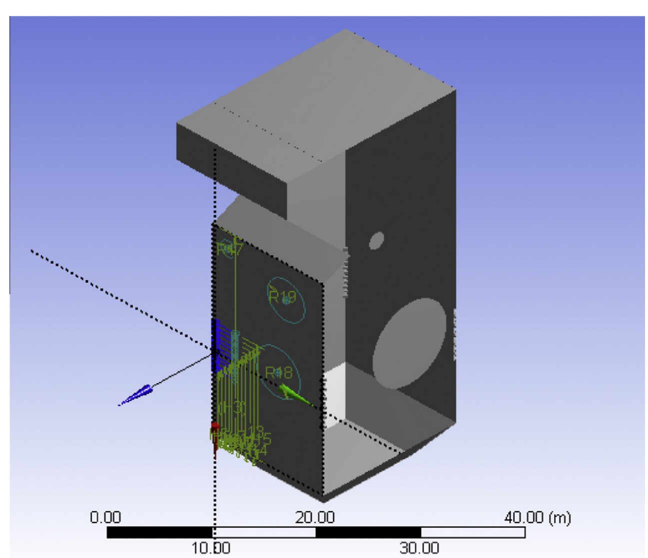


**Fig. 1.** The geometry of boiler of coal fired power plant developed using ANSYS DesignModeler 14.5.

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