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Application of Numerical Simulation to Analyze and Evaluate Reaction of Combustion inside Boiler of Thermal Power Plant

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Abstract

In Vietnam, according to the master power plan number 7+, in 2016, the demand of power generation capacity is approximately two times higher than the annual GDP growth rate, and must ensure the efficient use of the domestic hard-to-burn anthracite coal and imported coal. Therefore, coal-fired thermal power has been playing an important role in the national electricity supply. The thermal power plants in Vietnam, especially the old power plants are facing frequent changes in the quality of coal supply from domestic and imported sources, thus the implementation of tests to check and optimize the operating parameters whenever there is a change in coal sources quality, before actual operation, is very important and necessary for the efficient and continuous operation of the plants. The application of numerical simulation technology helps to shorten the testing time and optimize operational parameters, greatly reduces annual costs for testing, and helps optimize design and testing with advantages thanks to the intuitive, clear and highly accurate evaluation results. It is clear and highly accurate. Therefore, this study carried out the application of numerical simulation on CFD (Computational fluid dynamics) to analyze and evaluate coal burning process and heat distribution in SG 130-40-450 boiler with the important criteria for evaluating the efficiency of combustion process in the boiler of the thermal power plant: reaction rate, distribution of combustion products, movement and existence time of coal particles

Keywords: *CFD, reaction, numerical simulation, coal combustion, boiler, thermal power plant.*

1. Introduction

Coal-fired thermal power is of great importance to energy security in Vietnam, and always accounts for a high proportion in the electricity production structure, which is clearly shown in to the master power plan number 7+, in 2016, accordingly, by 2030, coal-fired thermal power will account for 55% of the total capacity [1], with the capacity increasing from 26000 MW (in 2020) to 55300 MW (in 2030). Besides, by 2030, the shortage of coal for electricity production will reach 83 million tons and must be offset by imported coal [1].

With the large share of the generation capacity of the thermal power plants in the national power supply, and the generation capacity increases rapidly year by year, and the fluctuations in coal quality, the efficient use of coal in the thermal power plants is of great significance in the operation of the

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national power system. Analysis and assessment of coal combustion and heat distribution in the boiler is an important step to build options to optimize the boiler operation to improve coal efficiency, reduce costs of fuel and save time. Due to implementation of traditional experimentation methods is very expensive, it takes a long time to build a physical model, the process of controlling and operating the combustion process is very complicated, but thanks to advancement of numerical technology, the computer helps to analyze and research the combustion process is much easier through the CFD combustion theory calculation tool, which helps reduce costs and save time.

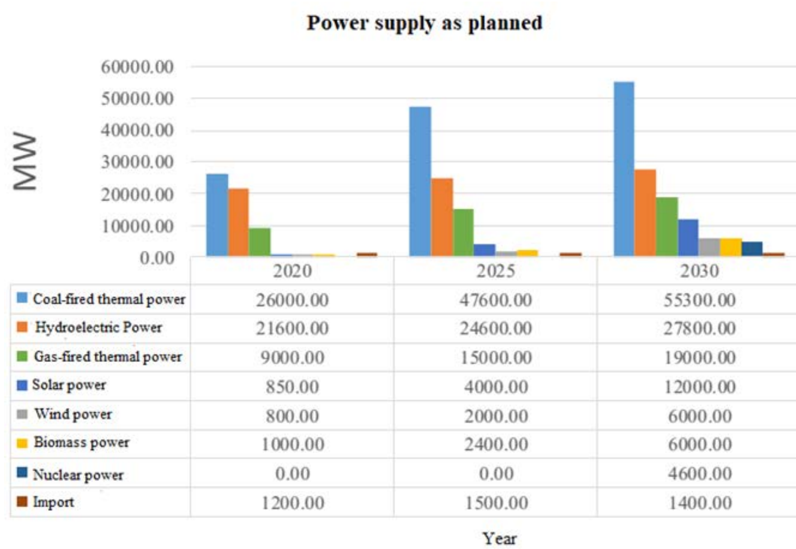

Figure 1.1: Planning of power supply in Viet Nam up to 2030

As we all know, conducting experiments is very expensive and takes a lot of time, thus the authors have used CFD numerical simulation model to analyse and evaluate the efficiency of coal combustion and heat distribution inside the boiler. The results show the temperature field and other critera of combustion to analyse and evaluate the efficiency of combustion process to build options of optimal operation for coal used in operation, in order to limit and reduce the adhesion of slag in the combustion chamber, or select the most optimal parameters to do experiments [3-6] with minimum cost and the shortest time.

CFD software is a powerful tool to simulate the coal powder combustion process in the boiler, assessing the combustion chamber structure to calibrate and optimize coal combustion process. In combustion industry and energy production industries, the CFD numerical simulation models mentioned in [2] has been wirely applied. Simultaneously, there are also many scientific studies on the combustion of coal powder using CFD tools, especially including studies on the combustion process of coal powder of tangent injection nozzle boiler by T. Asotani et al., 2008. [6], Choeng Ryul Choi and Chang Nyung Kim, 2008 [8], Zhao Feng Tian et al., 2009 [17], Cristiano V. da Silva et al., 2010 [9], studies of mixed effects coal to combustion in a boiler chamber, RI Backreedy et al., 2005 [16], Y.S.

Shen et al., 2006 [15]. Other uses of CFD in the study of the formation of NOx in coal combustion were presented in B.R. Stanmore, 1999 [12], M. Xu et al., 2000 [13], Z.Q. Li et al., 2002 [7].

The purpose of this study is to do application of numerical simulation model to analyse and evaluate combustion process of coal, heat distribution and determine coal complete burning efficiency of boiler SG-130-40-450 of Ninh Binh thermal power plant in Vietnam.

2. NUMERICAL SIMULATION OF COAL POWDER COMBUSTION PROCESS

2.1 Calculation domain and boundary conditions

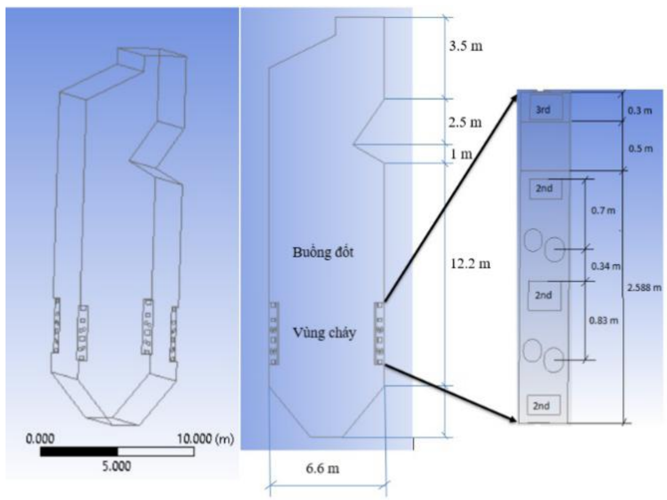

Figure 2.1: Model of combustion chamber of boiler SG 130-40-50

Figure 2.1 shows the calculated domain of the combustion chamber model of the tangent injection nozzle boiler SG 130-40-450 with dimensions of height x width x depth are 26 x 6.6 x 6.8 m. The boiler uses 8 low-NOx burners located in the combustion area of the boiler chamber at the four corners of the combustion chamber. Each burner cluster consists of 2 low-NOx burners, and coming between are secondary air vents, third air vents are located at a distance of 0.5 m above the secondary air vents. Each low-NOx burner is divided into 2 taps conforming for two concentrated and dilute streams. The concentrated stream with a ratio of air and coal (A/C) approximates 1 formed internally near the center of the combustion chamber ensures ignition is premature and stable and thus reduces mechanical incomplete combustion losses (q4). The dilute stream with very small A/C ratio, the combustion occurs in strong oxidation zone but low temperature to limit the formation of NOx and at once separate the hot smoke stream at the combustion center and the fire chamber wall to give ability to control and help limit the phenomenon of slag in the fire chamber.

Table 2.1, table 2.2 and table 2.3 below are properties of coal and boundary conditions.

Table 2.1: Technology composition and heat value of coal

Technology composition		Unit	Hon Gai Coal
Moisture	H_2O	%	6.38
Volatile matter	VM	%	7.37
Ash	A	%	25.33
Fixed carbon	FC	%	60.92
Low heat value	Q_{th}	kJ/kg	21,844
High heat value	Q_c	kJ/kg	22,768

Table 2.2: Chemical composition of coal

Chemical Composition	Element	%
Carbon	C	61.5
Hydro	H	2.32
Oxy	O	2.81
Nitrogen	N	1.04
Sulphur	S	0.62
Ash	A	25.33
Moisture	M	6.38

Table 2.3: Boundary conditions for the simulation model

Items	Unit	Value
Coal consumption	t/h	19.526
Total of air supply	Nm^3/h	117.995
Primary air rate	%	25
Secondary air rate	%	48
Third aire rate	%	27
Primary air temperature	^0C	245
Secondary air temperature	^0C	390
Third air temperature	^0C	90
Separation rate of concentrated and dilute stream	-	9/1

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2.2 CFD Model

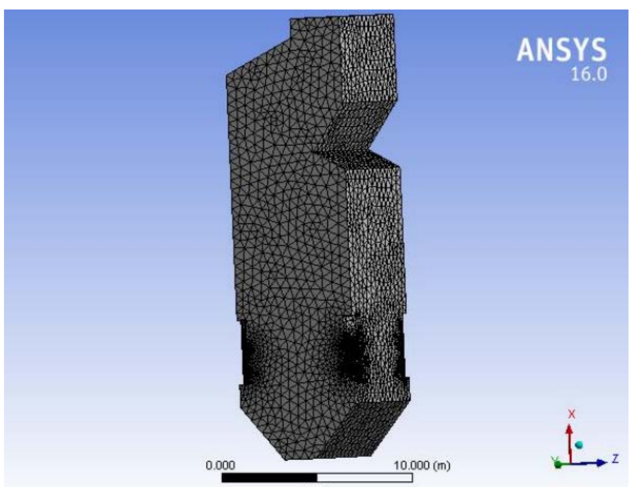
In this study, the authors used ANSYS ACADEMIC RESEARCH CFD software version 16.0 to simulate coal powder combustion process, using basic equations such as continuity equations, momentum equations, energy equations, tangled equations, chemical reaction equations which are discrete by finite volume method [4]. The coupled algorithm represents the pressure-velocity correlation, the swirling motion model of k-epsilon Realiable, the radiation model of Discrete Ordinate Method (DOM) and the gas phase reaction flow model of Eddy Dissipation used in all simulation cases. All models are stationary and ignore the influence of gravity. The movement of coal particles is calculated according to Lagangian formula [3,11]. The removal of volatile matter and coke burning occurs when coal particles are injected and mixed with the air stream in the combustion chamber [9]. The process of escaping volatiles is modeled by first degree single model and the rate of escaping and burning volatiles is described by Arrhenius [3,11,14]. The combustion between volatile matter and air is calculated by Eddy dissipation model. The two-step reaction mechanism is as follows:

$$Coal + aO_2 \rightarrow bCO + cH_2O \qquad (1)$$

$$CO + ½\,O_2 \rightarrow CO_2 \qquad (2)$$

In which a, b, c are reaction factors, depending on the composition and properties of coal.
The coke combustion process is calculated according to kinetics/diffusion-limited model. The surface reaction rate is calculated based on kinetics rate or diffusion rate [6,8,14]. Details of the models are presented in Fluent 16.0 User's guide.

Figure 2.2 shows meshing model and meshing parameter of the simulation model



ID	Items	Value
1	Element type	Tetra
2	Number of elements	341,613
3	Number of intersection	63,319
4	Skewness	1.8786e-4 ~ 0.792
5	Orthogonal Quality	0.29496 ~ 0.99578

Figure 2.2: Meshing model of boiler SG 130-40-50

3. RESULTS AND DISCUSSION

3.1. Reaction rate

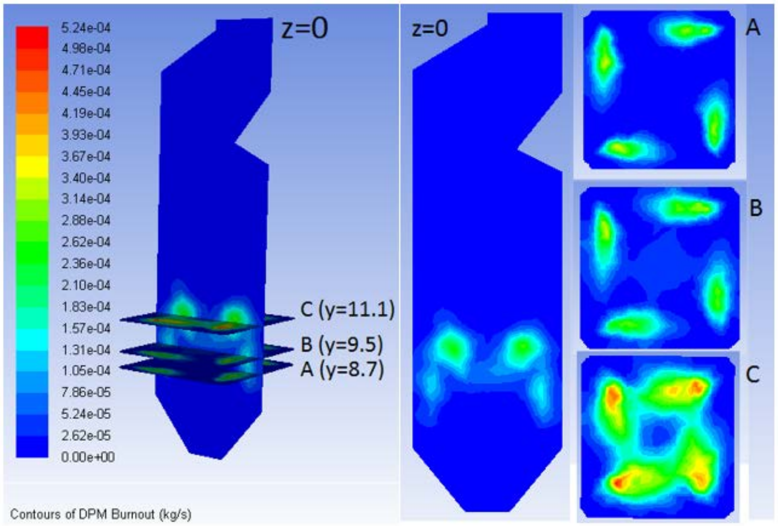


Figure 3.1: Reaction rate at each survey plane

According to the simulation results on 3 cross-planes passing through the burner, the distribution of combustion reaction rate is quite similar, the regions with high combustion reaction rate is concentrated near the 4 corners of the furnace wall. This distribution is explained by the fact that these regions are located on the direction of the coal powder flow, the tangent structure of the coal powder flow makes the coal powder flow into a vortex. In the direction of motion, the density of the coal powder mixture is large, so when the combustion occurs, the combustion reaction occurs very quickly. The locations of these zones of high combustion reaction rate are at a distance from the burner face. This is explained because when the coal powder mixture is sprayed into the combustion chamber and encounters high temperature, the process of drying, heating, and escaping volatiles will take place first, then the combustion reaction will occur. As the height of the combustion chamber increases, the vortex narrows and narrows, along with the better mixing of coal powder and air, so the high combustion reaction rate zone is located in the center of the furnace, above the burners.

The position of cross-plane C through the level 3 injector gives the highest rate because here the excess of air is the most and the place of combustion and this place has also a good condition to mix Oxygen and fuel.

3.2. Distribution of combustion products

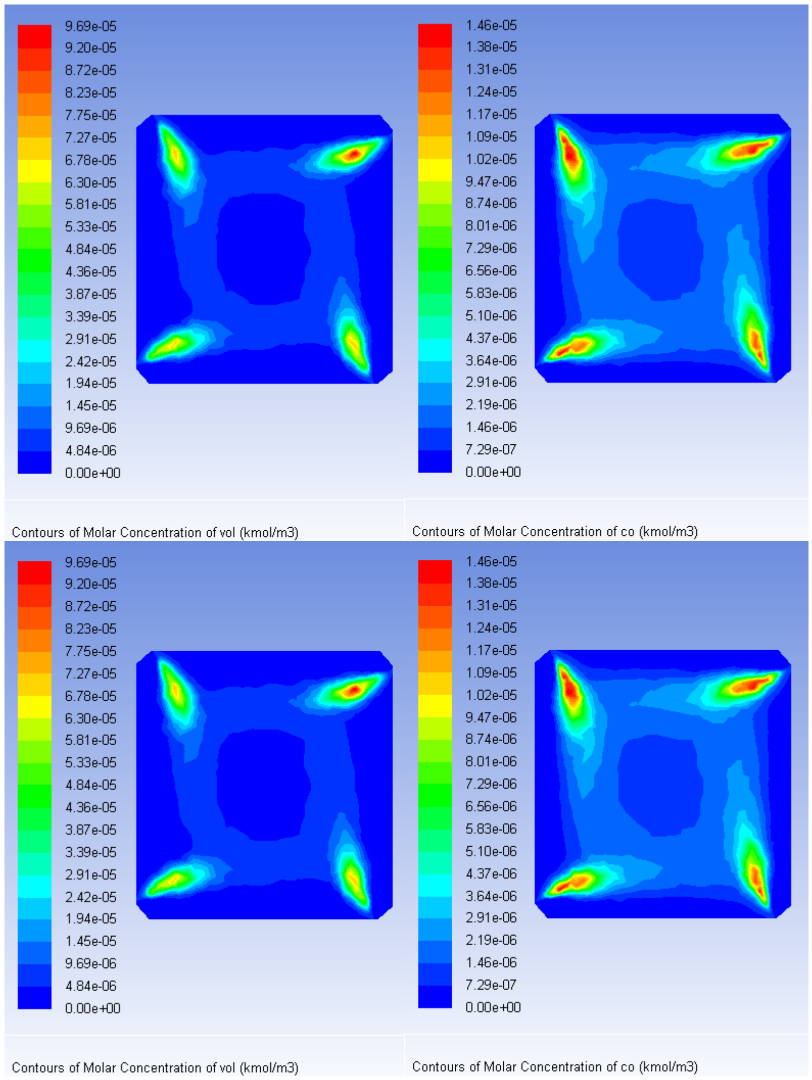


Figure 3.2: Distribution of combustion products

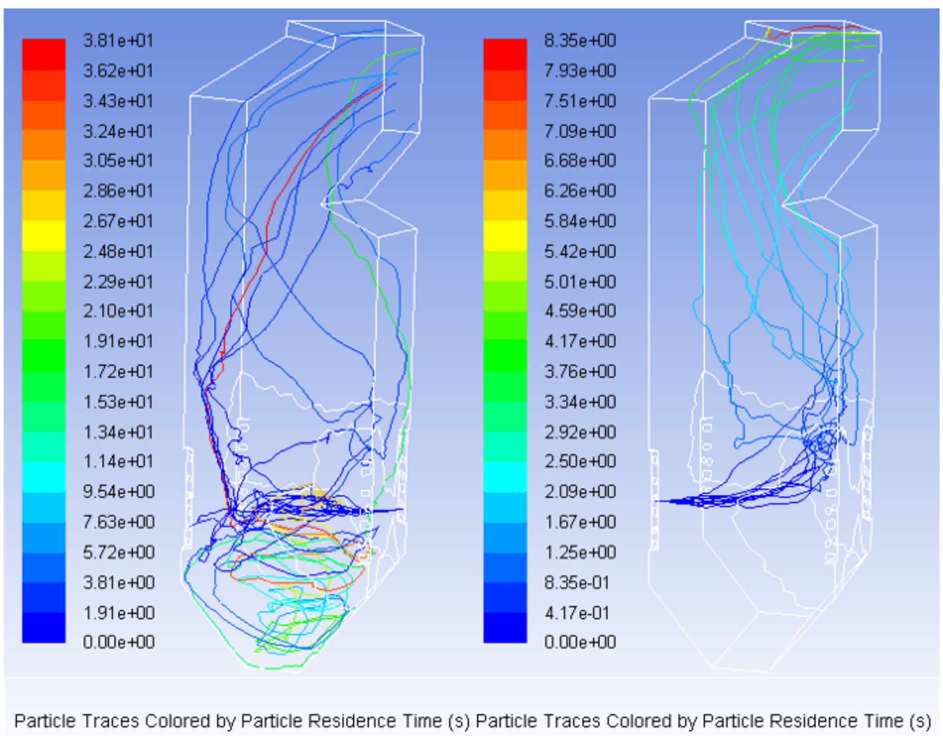
We can see that the molar concentration of volatiles is concentrated in the 4 corners of the burners. The distance to the burners is the phase where the coal particles after being sprayed are dried and heated. After that, a new phase of volatile discharge occurs. The amount of volatiles produced will immediately react with the oxygen in the incoming air flow. So, the molar concentration of the volatile substance at the other position is almost zero.

The molar concentration of CO is also highly concentrated in the area around the burner, the remaining regions are almost zero because of the coking combustion process, the combustion products not only form of CO_2 but also form of CO (reconversion process) because at high temperature, the oxidation of the particle surface occurs too quickly while the amount of oxygen is not enough (coal powder and oxygen cannot be completely mixed), so the combustion product is CO before being further oxidized to CO_2.

The molar concentration of CO_2 is also quite evenly distributed, only at the outlet of the burner with low concentration because the input air is mainly N_2 and O_2. CO_2 is a combustion product of coal combustion, so there is a high concentration of CO_2 around the fire.

In contrast to the distribution of CO_2, the molar concentration of O_2 is highest at the mouth of the burner, then gradually decreases. This is explained that because the input air has a large O_2 composition, when entering the combustion chamber according to space and time, the amount of O_2 decreases gradually according to the combustion reactions.

3.3. Movement and existence time of coal particles



Nozzle of 1 at height of 8.7 m Nozzle1 at height of 9.8 m

Figure 3.3: Movement and existence time of coal particles

Observing the results in the figure right above, we can see that the motion trajectory of the spray particles from 2 nozzles of different heights is quite different.

Due to the turbulent motion as well as the region at the bottom of the furnace without a smoke outlet, some of the particles are trapped down and then in the direction of the smoke going up.

The nozzle trajectory at higher. Because at the same time, the high-temperature combustion product flow is directed towards the outlet, creating a general trend towards the outlet, so this position is no longer swirling then down to the bottom of the furnace. They are upward of the smoke exhaust and have a more stable rate.

4. Conclusions

The study has applied the CFD numerical simulation model to analyze and evaluate reaction rate, distribution of combustion products, movement and existence time of coal particles of the combustion inside the boiler.

The simulation results show that the operation status of the SG 130-40-450 boiler with the current fuel is good in the criteria of reaction rate, distribution of combustion products, movement and existence time of coal particles

The simulation results are in accordance with actual operating results at the thermal power plant with high accuracy. However, with analysis and evaluation based on simulation models show that the operation of the boiler can be even more optimized to increase more the coal complete combustion efficiency of current coal such as optimizing the ratio of primary air and secondary, or doing nozzles adjustment which the authors will do in next time.

The simulation results give us a visual view of reaction rate, distribution of combustion products, movement and existence time of coal particles inside the boiler, which would be difficult and costly to implement on a real model. Application of numerical simulation model is a significant meaning to help optimizing the boiler design and operation parameters whenever there is a change in fuel or technology with the intuitive, clear and highly accurate evaluation results, and shortening the testing time and optimize operational parameters, greatly reduces annual costs for testing.

The results obtained from the study through the CFD numerical simulation will give orientation of the experimental process of testing coal, design or any technical improvement in the actual model which is operating at the plants.

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