

Application of Numerical Simulation to Analyze and Evaluate Combustion Process, Heat Distribution and Coal Complete Combustion Efficiency of Boiler in Thermal Power Plant

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Abstract: In Vietnam, coal-fired thermal power has been playing a important role in the national electricity supply. 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. 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, which 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. 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: temperature field, velocity field, coal complete combustion efficiency.

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

I. INTRODUCTION

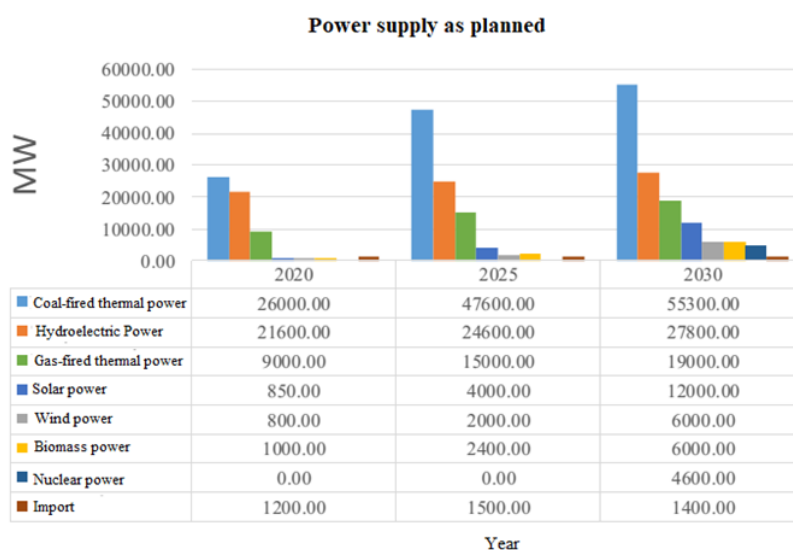


Figure 1.1: Planning of power supply in Viet Nam up to 2030

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 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 analyse and research the combustion process is much easier through the CFD combustion theory calculation tool, which helps reduce costs and save time.

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 criteria 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 widely 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], ChoengRyul 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 NO_x 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 combustion efficiency of boiler SG-130-40-450 of NinhBinh thermal power plant in Vietnam.

II. NUMERICAL SIMULATION OF COAL POWDER COMBUSTION PROCESS

2.1. Calculation domain and boundary conditions

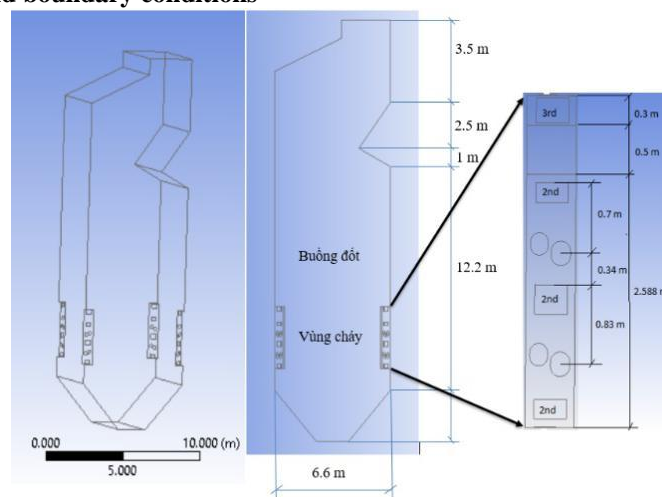


Figure 2.1: Model of combustion chamber of boiler SG 130-40-50

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-NO_x 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-NO_x 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-NO_x 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 centre 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 NO_x

and at once separate the hot smoke stream at the combustion centre 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 ₂ O	%	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

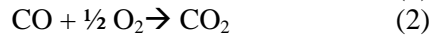
Items	Unit	Value
Coal consumption	t/h	19.526
Total of air supply	Nm ³ /h	117.995
Primary air rate	%	25
Secondary air rate	%	48
Third aire rate	%	27
Primary air temperature	°C	245
Secondary air temperature	°C	390
Third air temperature	°C	90
Separation rate of concentrated and dilute stream	-	9/1

2.2. CFD model

2.2.1. Calculation model and numerical method

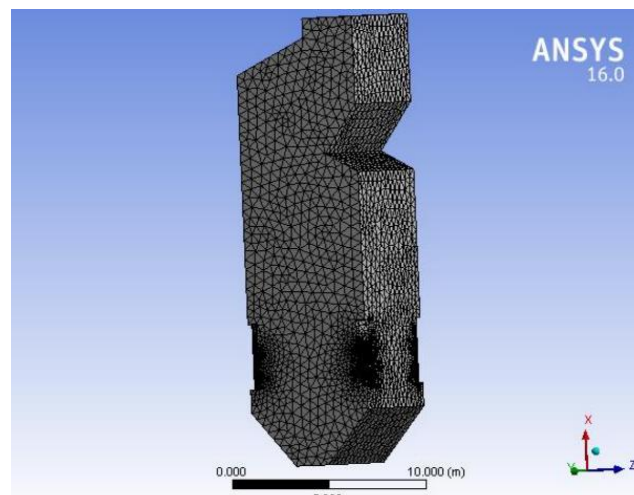
In this study, the authors used ANSYS ACADEMIC RESEARCH CFD software version 16.0 to simulate coal powder combustion process, using basic equations such as continuity equations, momentum equations, energy equations, tangled equations, chemical reaction equations which are discrete by finite volume method [4]. The coupled algorithm represents the pressure-velocity correlation, the swirling motion model of k-

epsilon Realisable, 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 Lagan Gian 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 modelled 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:



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

2.2.2. Solution process

The study uses a solution process to ensure the quick convergence of the solution, while ensuring the accuracy of the results [14], namely 5 steps as follows:

1. Solve the problem only with air stream without coal particle injection by starting the simulation calculation process with 300 loops for the unresponsive flow.
2. Initialize the reaction flow simulation of the problem by patching the temperature in the reaction zone and running 1 iteration step to ignite the flame.
3. Calculate the simulation process with 500 loops for reaction flow.
4. Activate the Discrete Ordinates radiation model and calculate the simulation with 500 iterations
5. Activate the radiation interaction between coal particles and simulate calculations until convergence of 3000-4000 iterations.

III. RESULTS AND DISCUSSION

3.1. Temperature field

Figure 3.1 and table 3.1 below show the heat distribution results in the boiler.

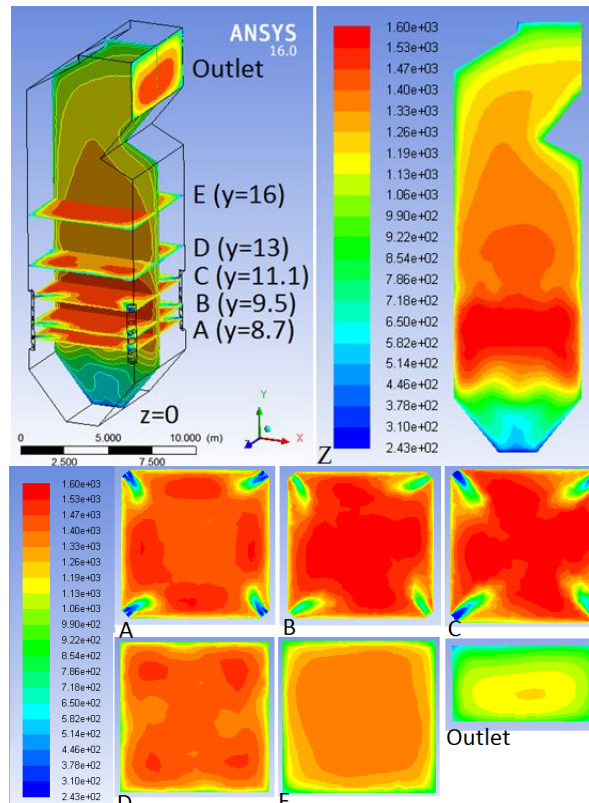


Figure 3.1: Temperature field for each survey plane

Table 3.1: Details of temperature on each plane

Cutting planes	Temperature ($^{\circ}\text{C}$)			
	Max	Min	ΔT	Average
A	1,540.99	220.00	1,320.99	1,372.26
B	1,569.91	610.01	959.90	1,445.55
C	1,605.21	88.00	1,517.21	1,395.70
D	1,495.37	908.07	587.30	1,393.23
E	1,397.14	618.51	778.63	1,314.92
Outlet	1,200.19	471.63	728.56	1,054.73

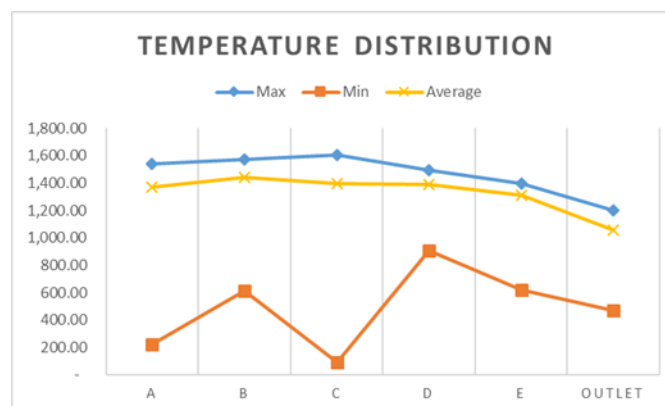


Figure 3.2: Temperature distribution on each plane

Observing the simulation results of the above temperature field, we can see that according to the height of the boiler, the temperature has a quite clear stratification. The temperature between section A and section D has a high temperature and gradually decreases towards the top and bottom of the boiler.

The highest temperature is at the combustion chamber centre shown in C plane of Figure 3.1 and Table 3.1 above with the temperature is over 1600 °C. The minimum temperature of plane A and C has markedly low value because these are areas of locating burner nozzles and air inlets.

Average temperature increases with the height of the combustion chamber from the plane A to C due to increase of combustion intensity. When exiting the burning zone (Plane D to F), the temperature decreases due to radiation and convection heat exchange between the air stream and the combustion chamber wall.

The average temperature of flue gas before going out of the combustion chamber is 1054.73 °C higher than the value measured at the actual boiler of the plant in the same location is about 30 °C. Thus, the results of the model are acceptable.

3.2. Velocity field

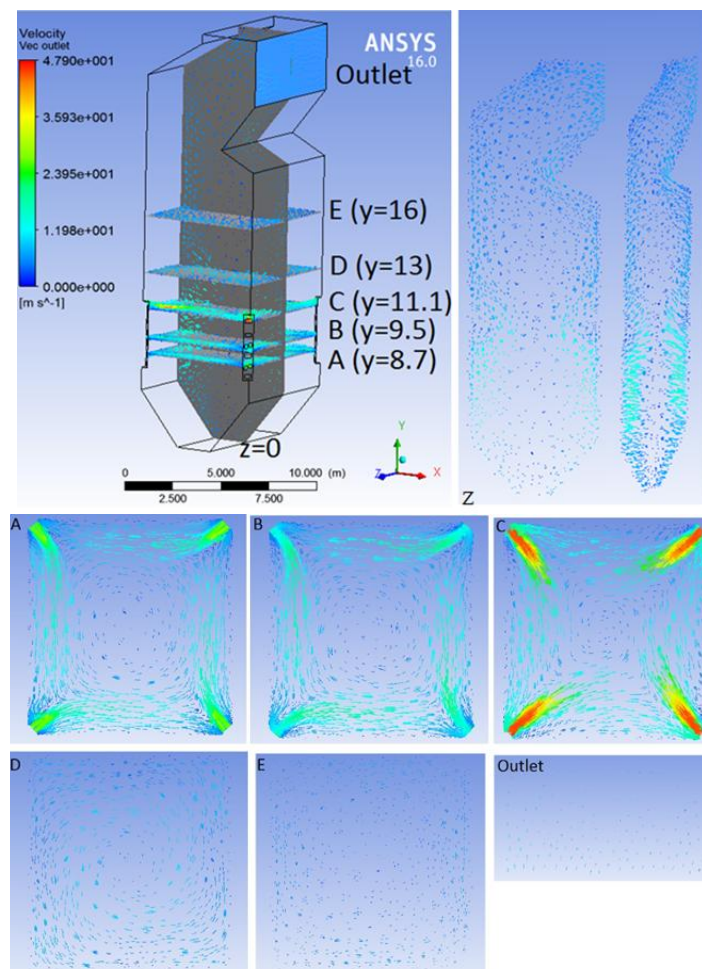


Figure 3.3: Velocity field for each survey plane (m/s)

The results show the highest velocity is at the burner nozzle, then gradual decrease of velocity due to diffusion and friction inside the boiler chamber, there are some local vortex phenomena a few locations. Thanks to the arrangement of the nozzles in a tangential direction that creates a vortex at the chamber center (combustion center) to increase the Coal burning efficiency when at here will form a fireball with very high temperatures. The size of the fireball will depend on the design to increase the efficiency of burning.

The velocity is nearly zero at the chamber wall, the velocity increases gradually when entering the combustion chamber center and reaches maximum value at area between the combustion chamber center and the wall, then decreases gradually as it enters the center.

In the upper part of the boiler, the velocity is evenly distributed because the dynamic force of the motion is only the lift force due to the temperature difference.

3.3. Determination of complete combustion efficiency

Complete combustion efficiency is determined based on the efficiency of use of oxygen for combustion reactions, doing as following:

Determine the amount of oxygen needed for combustion:

According Table 2.3, coal consumption (B) is 19.526 ton/hour is equal to 5.424 kg/s

According to [20][21][22]:

- The amount of oxygen needed for complete combustion is

$$V_{O_2}^0 = 1.866 \frac{C_{ar}}{100} + 0.7 \frac{S_{ar}}{100} + 5.6 \frac{H_{ar}}{100} - \frac{O_{ar}}{100 \times 1.428}; \left(\frac{m_{tc}^3}{kg} \right)$$

- The amount of oxygen needed to completely burn the amount of coal (B) is

$$V_{O_2}^{0'} = B \times V_{O_2}^0 = 5.424 \times 1.26217 = 6.84602; \left(\frac{m_{tc}^3}{s} \right)$$

- The density of oxygen in standard condition is

$$\rho = 1.346 \text{ kg/m}^3$$

Combining with chemical properties of coal used in Table 2.2, result of calculation of the amount of oxygen needed to completely burn the amount of coal (B) is:

$$G_{O_2}^{0'} = V_{O_2}^{0'} \times \rho = 9.21475 \text{ (kg/s)}$$

Determine the amount of oxygen used for combustion from the simulation model

The total of oxygen delivered to the model for the combustion:

$$G_{O_2} = 9.22760 \text{ (kg/s)}$$

The amount of oxygen does not participate in the combustion process obtained at the outlet of the simulation model:

$$G_{O_2}^{\text{outlet}} = 0.76937 \text{ kg/s}$$

Thus, the actual amount of oxygen involved in the combustion reactions are:

$$G_{O_2}^{\text{pu}} = G_{O_2} - V_{O_2}^{\text{outlet}} = 8.45823 \text{ (kg/s)}$$

The complete combustion efficiency is determined based on based on the efficiency of use of oxygen for combustion reactions, thus, coal complete combustion efficiency is

$$\eta = \eta_{O_2} = \frac{G_{O_2}^{\text{pu}}}{G_{O_2}^0} = \frac{8.45823}{9.21475} = 91.79\%$$

The coal complete combustion efficiency of 91.79 % is an acceptable efficiency, however this efficiency can be further improved by optimizing some parameters such as the ratio of primary air and secondary air to improve the coal complete combustion efficiency.

IV. CONCLUSION

The study has applied the CFD numerical simulation model to analyze and evaluate temperature and velocity fields inside the boiler, use the results of models to determining the coal complete combustion efficiency of the boiler with high accuracy.

The simulation results show that the operating status of the SG 130-40-450 boiler with the current fuel is good, with the temperature and velocity field meet the technical requirements, and with a good combustion efficiency. 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 which the authors will do in next time.

The simulation results give us a visual view of the temperature and velocity field 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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