Numerical simulation of pulverized coal combustion in a tangentially fired boiler SG-130-40-450

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***Abstract*— This paper presents summarized results of numerical simulation of the flow and combustion process in the furnace of a large scale tangentially fired pulverized coal boiler SG-130-40-450 in NinhBinh thermal power plant through ANSYS ACADEMIC RESEARCH CFD software. The characteristics of the flow, combustion, temperature and combustion efficiency as well as particle burnout are studied with emphasised on Vietnamese domestic coal, namely Hongai coal. In addition, the influence of blending coal between Indonesia sub-bituminous coal and Hongai coal on the combustion processes was also considered. The predicted results clearly show that ratio of blending coal have an insigficantly on burning rate. An increase in the blending ratio results the faster volatile burning rate and the lower char burning rate in the same simulated conditions.**

***Index Terms*—Numerical simulation, CFD, tangentially fired boiler, blending coal.**

I. Introduction

In Vietnam, coal has played a role key in power generation. According to Power planning vision to 2050 approved by Vietnam government, thermal power plants will account for 49.3 per cent of the total power production. However, domestic coal resource is being depleted and the quality of coal is also reduced. The shortage of coal used to generate power will be 48 million tons by 2020 [1] and be offseted by importing coal.

Pulverized coal combustion is a complicated phenomenon of chemical reactions and depended highly on various factors such as fuel properties, primary air, secondary air and phasing of air supply, particle diameter [3]. Blending coal enables a better control the coal quality and improves combustion efficiency [11]. Besides, blending coal impacts of chracteristics and behaviours of combustion process due to the change of coal components. Therefore, it is nesscessary to characterize the blending coal combustion.

This kind of analysis can be done either by convential experiment or numerical analysis obtaining from appropriate models using computer. Convential experiment is very expensive, difficult and time consuming for designing and developing the physical models, whilist the availability of high speed computers made it easier to analysis any combustion process by using computational fluid dynamic (CFD) theoretical analysis [3].

The computational fluid dynamics (CFD) of the pulverized coal combustion field is being developed with the remarkable progress in the performance of computers. This method, in which the governing equations of the combustion field are solved using a computer, is capable to provide the detailed information on the distributions of temperature and chemical species and the behavior of pulverized coal particles over entire combustion field that cannot be obtained by experiments. In addition, it facilitates the repeated review in arbitrary conditions for the properties of pulverized coal and the flow field at a relatively low cost [3].

Many CFD studies undertaken of coal combustion relating to tangentially fired furnace, for example [6-10] have shown that CFD provides an accurate tool for predict the behaviour of coal combustion and the results obtainted form these studies are relatively reasonable comparing with the experiment.

The objective of this study is to predict the combustion behaviour of single coal and blending coal when fired in a tangential furnace operated in Vietnam using CFD model. The firstly, the results are emphasised on Vietnamese single coal, namely Hongai coal. Then the influence of blending coal combustion to the combustion process will be assessed in the terms of conversation rate and burning rate of volatile and char.

II. Model Description

A. Boiler geometry and operating conditions

The tangentially fired pulverized coal boiler SG-130-40-450 operated in Ninhbinh thermal power plant was considered in this study. The unit generates 130 tonnes.s^{-1} of steam at 40 bar and 450oC when operating at full capacity. The geometry of CFD model for the boiler is shown in fig.1. The height of the boiler is approximately 24 m and the horizontal cross section in the furnace is 6.6 x 6.8 m. Eight burners are divided into four groups installed in the four corners ranging from lower group A to upper group B. Each burner consists of two coal burners (fuel rich burner and lean fuel burner) with different air to fuel ratios and segregation rate of coal mass flow rate of 9:1. The burners are of low NO_x burner type.

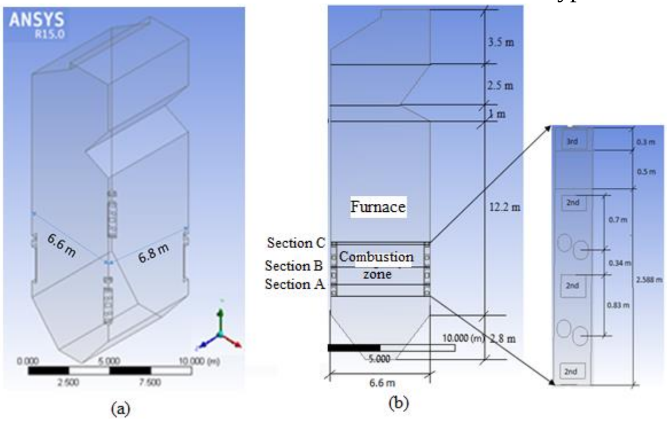


Fig.1. The geometry of boiler SG-130-40-450

The fuels used were Hongai anthracite coal (Vietnamese coal) and sub-bituminous coal (Indonesia imported coal). The properties of them were given in table 1.

TABLE 1. COAL PROPERTIES

Proximate analysis		Hongai	Sub-bituminous
Moisture	%	6.38	20.62
VM	%	7.37	37.45
Ash	%	25.33	9.23
FC	%	60.92	31.7
Ultimate analysis			
C	%	90.06	74.29
H	%	3.4	5.12
S	%	0.91	0.45
N	%	1.52	1.49
O	%	4.11	18.65

Sub-bituminous coal was blended to Hongai coal ranging from 5 to 20% based on mass fraction and injected simultaneously into furnace. In present model, the blending coal was considered simply as one single coal using averaged properties of component coals. All of the cases were simulated in the same operating conditions shown in table 2.

TABLE 2. OPERATING CONDITIONS

Parameter	Unit	Value
Coal consumption	t/h	19.526
Total air flow rate	Nm^3/h	117995
Primary air	%	25
Secondary air	%	48
Over fire air (OFA)	%	27
Primary air temperature	^oC	245
Secondary air temperature	^oC	395
OFA temperature	oC	90

B. Numerical simulation

The model is solved using ANSYS-Fluent 15.0. In Fluent, the governing equations including the mass, momentum, chemical species and energy equations are discretized by using the finite Volume method. The continuity and momentum equations were solved using the coupled algorithm. The grid-independent study is done for all cases. All simulations are run K-ε reliable model for turbulent gas phase. The motion of the representative coal particles was calculated by Lagrangian formulation. The radiative heat transfer among the gas, particles and wall were simulated by DO model. Boundary conditions used are mass flow rate and temperature. Meshing is done in ANSYS meshing. The inlet surface and volume meshing were done with approx. 700.000 tetrahedral element.

The coal combustion process is modelled by the following two step reaction mechanism:

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

$CO + ½ O2 \rightarrow CO_2$ (2)

Here, a, b, c are determined by the coal constituent. A general model of pulverized coal devolatilization and a general model of char combustion were incorporated into the comprehensive model in Fluent. Further details regarding the fluid flow, turbulence models, radiation models, and coal combustion models can be found in [6] [8] [9] [11].

III. RESULTS AND DISCUSSION

A. Flow field and particle trajectories

The velocity distribution and vectors in cross sections along the furnace height are shown in Fig.2. The flows located near the burners show more active than other locations. A clockwise swirling flow formed via coal particles and air injected through the burner ports in found in the center region of the furnace. The swirling flow is stronger in the combustion zone. In the upper region (section D and E), the swirling flow is reduced remarkblely and became very weak. In particular, the flow in the section E tends to move out to the wall of the furnace. Velocity profile in cross section C was shown in Fig.3. It is clear that the velocity of flow concetrates and reachs the maximum in the middle of the wall and the center point of the furnace formed swriling flow.

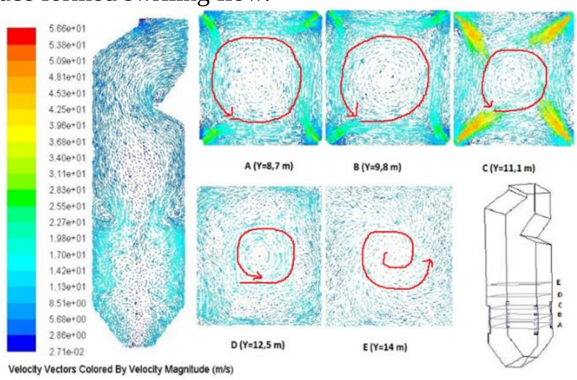


Fig.2. Velocity vectors in different cross sections

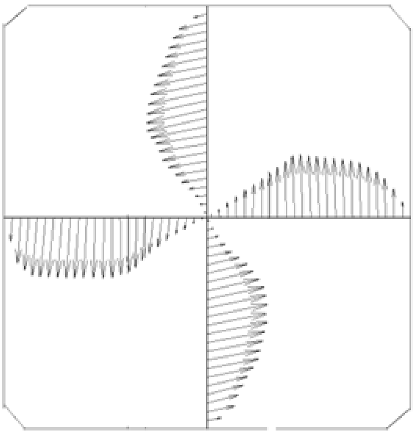


Fig.3. Velocity profile on section C

The residence time and trajectories of the coal particles are illustrated in Fig.4. In order to characterize the trajectories of the coal particles in the furnace, ten coal particles injected through each burner at the two various positions were considered. The motion of particles at two burners is clearly different. The coal particles injected from the lower burner innitially circulate in the bottom of the furnace and the ash hopper, while the coal particles from the higher burner pass around the surface of the swirling flow. As a result, the residence times of coal particles injected from the higher burner are much shorter than the coal particles from lower burner.

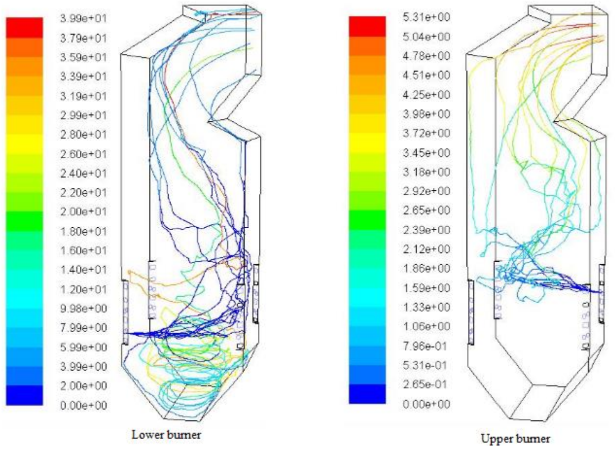


Fig.4. Residence times and coal particle trajectories from two different burners

B. Temperature distribution

The temperature distributions in the cross sections are shown in Fig.5. The temperature of flue gas is relatively high in the center region of the furnace where coal combutions activately takes place. The temperature increases along the height of the furance from section A to section C due to high combustion intensity as shown in Fig.6b. In the upper of the combustion region, there is uniformity of temperature distribution between section D to F and the mean temperature gradually decreases due to convectional and radiation losses to furnace walls.

The change of the flue gas temperature inmediately after injecting fuel into the furnace is clearly shown in cross sections A to C. The temperature of the mixture of primary air and coal particles injected through burners is 245ºC and it increases up to a maximum temperature of 1650ºC in the center region of the furnace. The high temperature is concentrated mainly at the swirling flow formed in the center of the furnace as shown in Fig. 6a and 7. And finally, the flue gas leaves the furnace at an averaged temperature of approx. 1000ºC.

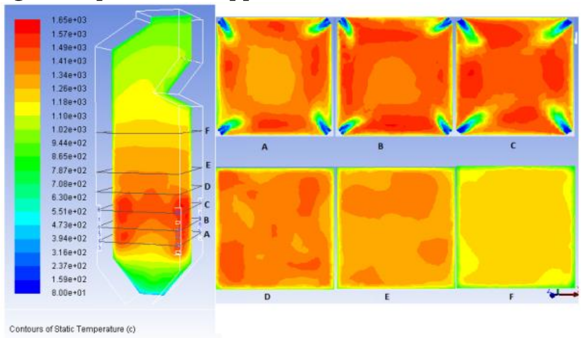


Fig. 5. Temperature distribution

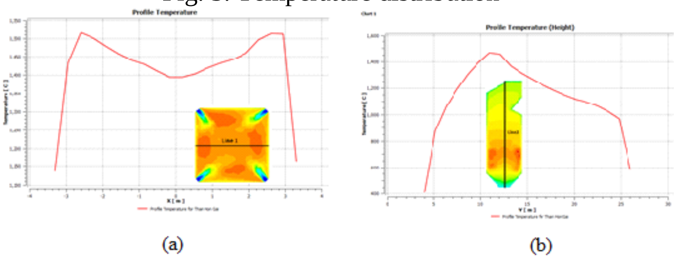


Fig.6. The profile of temperature following the height and width of the furnace

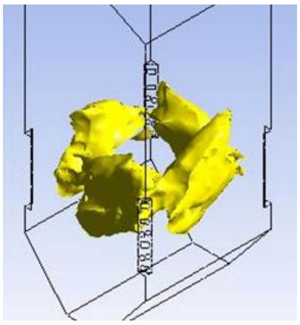


Fig.7. Iso-surface of 1500ºC

C. Species distributions

The mass fraction distributions of O_2 and CO_2 are shown in Fig.8. The O_2 concetration is relatively high near burners. The O_2 contained in the air injected into high temperature zone of the furnace is comsumed quickly during the combustion process. This results the O_2 concentration is reduced rapidly in the volume of furnace. In contrast to the O_2 mass fraction, the CO_2 mass fraction significantly increases as air moves from the burners due to the active combustion processes.

The relationship between temperature and O_2 and CO_2 mass fraction along the furnace height, the vertical line A-B and the diagonal line C-D are presented in Fig.9. It is shown that the high temperature regions in the furnace coughly correspond to the regions of the lower O_2 mass fraction and higher CO_2 mass fraction.

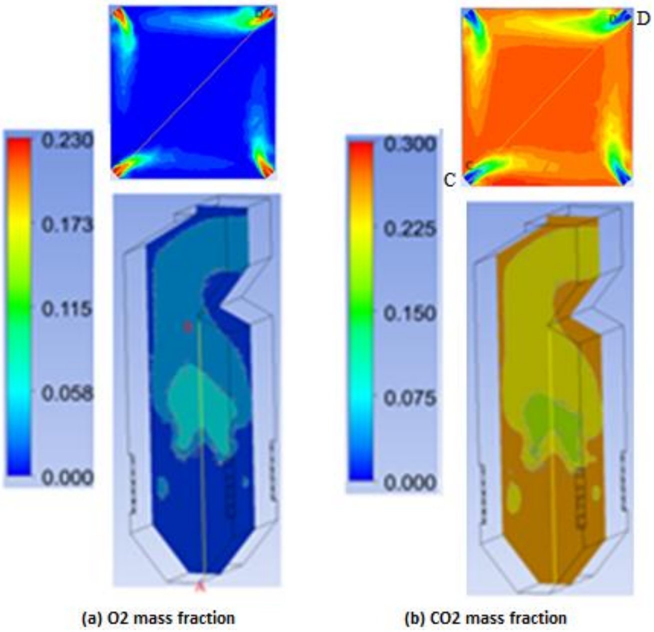
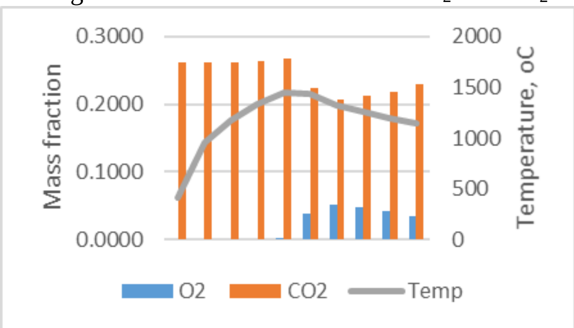
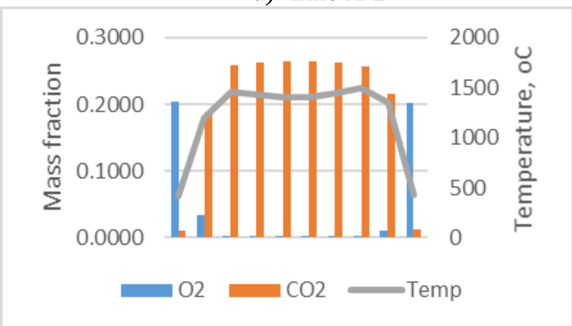


Fig.8. Mass fraction distribution of O_2 and CO_2



a) Line A-B



b) Line C-D

Fig.9. The relationship between temperature and O2, CO2 mass fraction

D. Influnce of blending coal on combustion process

Blending coal has a significantly effect on combustion chracteristics, particularly in terms of particle burnout and burning rate as dispicted in table 3. As the predicted results, volatile matter was converted completely (100%) for all the blending ratios. The ratio of 5% gave the highest char conversion rate with 99.63%. At 10% and 20% of ratio, the char conversion dropped to 99.57% and 99.45, respectively. This can be explained by the fact that when the ratio of blend increased, the volatiles matter was greater and the quality of coal was also improved. As a result, the char conversion rate is highest at the ratio of 5%. The higher volatile matter, the higher primary air needed for completing combustion of volatile during devoltilization process. Thus, this needs an increasing the air supply for whole combustion process. But the operating conditions are remained constant for all cases in this study. This caused the shortage of air for char burning and char convertation was falled. In addition, the volatile burning rate increases when increasing ratio due to high volatile released, while char burning rate is inversely proportional to the blending ratio.

TABLE 3. PARTICLE BURNOUT AND BURNING RATE

Blending ratio	Hongai	5%	10%	20%
VM convertation (%)	100	100	100	100
Char convertation (%)	99.48	99.63	99.57	99.45
Char burning rate $.10^{-5}$ (kg/s)	1.9802	1.93	1.8587	1.8191
VM burning rate $.10^{-6}$ (kg/s)	0.6202	0.7734	0.8863	1.1639

IV. CONCLUSION

The characteristics of the flow, combustion, temperature, species distribution and particle motion in tangentially fired pulverized coal boiler SG-130-40-450 have been numerically investigated. The results shown that, 1) the flow and temperature field have been expressed the phenomenon combustion process took part in the furnace as expected; 2) the residence time of coal particles was enough to ensure the particle burnout; 3) the relation between temperature and O_2 and CO_2 mass fraction has been demonstrated clearly; 4) the particle burnout and burning rate are significantly dependent on blending ratio and air supply.

Further rearearch focused on blending coal to optimise combustion, improve combustion behaviours may be needed under various operating conditions such as flow rate of air and segregation of two component coals into two independent coal streams.

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