Experimental Study onCharacteristics of Cold Flow Field by Gas Reburning Technology with Multi-nozzle

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Abstract

In order to study the gas reburning technology, the cold flow field and mixing efficiency of rising gas in the reburning zone were analyzed after installing another four reburning nozzles on the sidewall of the cold-model based on the prototype of a 350MW boiler. The standard k-ε turbulent model was also adopted to the numerical simulation. The results show that the deflection angle of reburning gas near the center of the furnace was significantly decreased after installing eight nozzles in the reburning zone and a much better mixing efficiency were obtained for the rising gas, that will bring a very valuable and practical reference for the engineering utility.

Key words: Gas reburning technology; Reburning nozzles; Numerical simulation; Air-flow deflection; Covering effect

1. Introduction

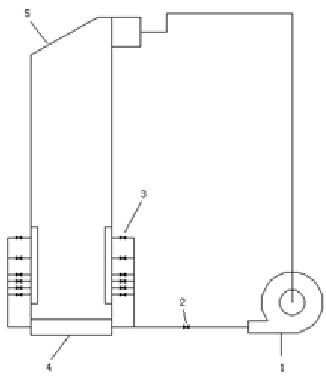
Gas reburning as a low NOx emission technology is suitable for China's national conditions with relatively low cost. The method of this technique is dividing boiler combustion zone into three different sections, and the mechanism of each zones are as follows: The Primary zone, where the coal was burnt fullywith oxygen-enriched combustion to produce a lot of NOx;The reburning zone, where the reburning fuel was injected and make sure the excess air coefficient is less than1.0, thus the CHi, CO, $H_2$and CnHm etc .were produced in the reductive atmosphere,meanwhile the NOx from the primary zone were reducted to N_2;The burning-out zone, where the unburnt fuel gas and coke were burn out in oxygen-enriched combustion [1-2].One of the key points of this technology is to make reburning fuel and flue gas in the furnace mixed fully [3].ProfessorZhang Zhong-xiao studied theeffect of some key factors such as residence time, stoichiometric coefficient, temperature and coal types on NOx formation regulation[4].It showed that prolonging the reburning zone residence time can help to lower the NOx emission and the optimum residence time was 0.6s ; The NOx reduction efficient increased with the increasing of the reburning heat input and the reburning zone temperature, and the effect on low NOx emission was remarkable to different coal types.

In this paper, an improved structure is proposed, another 4 reburning nozzles were added in the center of the furnace wall which has only 4 reburning nozzles in four corners previously. In order to improve air flow fullness inside the furnace and reduce air flow deflection in the purpose of effective reduction NOx, similarity simulation principle wasapplied with velocity characterization instead of concentration and the single phase instead of two phase flow processing. The influence of reburning nozzle numbers on the flow field inside the furnace were studied with the method of numerical simulation and cold-state testing. That can optimize the gas reburning technology and provide reference for engineering application.

2. Introduction of Cold-state Testing Bench

2.1.Testing Device

Cold-state testing benchwasbuiltin the proportion of 1:5 according to the prototype of a 350MWboiler which consists of three parts: boiler furnace, the reburning burner and air distribution piping. The bench system diagram was shown in **Figure1(a).**The whole furnace and the burner components were made of organic glass. The burner components were placed on the furnace wall from the bottom to top were as follows:lower primary air nozzle, lower secondary air nozzle,upper primary air nozzle, upper secondary air nozzle, reburning nozzle and OFA nozzle.



1.Fan 2. Valve 3.Burner 4.Air Chambe 5. Furnace

Figure 1.*Cold-state test bench system*

During the testing, air was selected as the working medium and thermal anemometer as the measuring facility.8 reburning nozzles are distributed on the same cross sectionof the furnace , the reburning nozzles added in the side wall were5 #, 6 #, 7 #, 8 # .The incidence Angle of reburning nozzles in corners was 41.17°.Testing area and measuring point distribution in a corner of the furnace is shown in **Figure2**,X as the nozzle jet axis with the origin at the center of the nozzle, while Y is the horizontal axis along the nozzle, O point is the center of the nozzle.

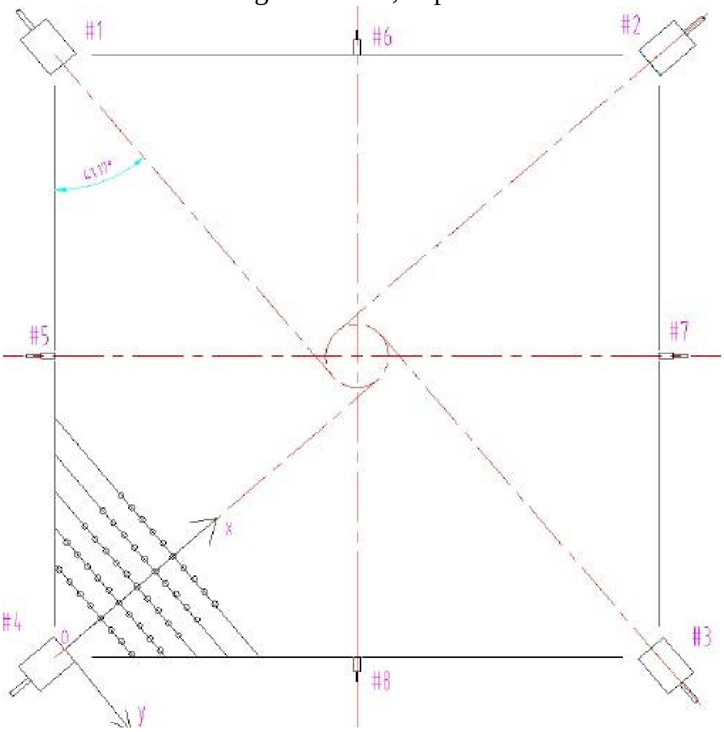


Figure 2 *Test area and the measuring points in corner*

2.2.The Testing Parameters

According to similarity theory, cold modeling calculationwas been built based on operation parameters of the boiler. The parameterswere as follows: the velocity of primary and secondary air was 22m/sand 50 m/srespectively, and the actual velocity of OFA is 64 m/s. The reburning air velocity in cornerswas 100 m/s,80 m/s, Reburning air velocity in the center of the furnace wall is 100 m/s,120 m/s. air velocity of reburning nozzlesin thetestingobtainedwasshown in Table 1.

Table 1 *Reburning nozzles parameters of 1 ~2 operating modes in the test*

Item	*Primary air velocity (m/s)*	*Secondary air velocity (m/s)*	*Reburning air velocity in corners (m/s)*	*Reburning air velocity inthe wall (m/s)*	*Air velocity of OFA (m/s)*
Condition1	*11.4*	*22.6*	*51*	*/*	*29*
Condition1	*11.4*	*22.6*	*51*	*51*	*29*

3.Theory of Experiment and Numerical Simulation

3.1.The Experiment Principle

According to the theory of similarity modeling,cold-state experiment must adhere to the following principles[5]:(1) geometric similarity between the model and the actual object is needed.(2) Under the corresponding conditions, air movement of model and the actual object must be in the automatic modelingarea.(3)The momentum ratio ofeach share airflow of model keep in equalwiththe actual object's.

Due to primary air and secondary air momentum ratio of the model and the actual object is equal[6-7], as follows:

$$\frac{m_{1M}w_{1M}}{m_{2M}w_{2M}}=\frac{m_{1O}w_{1O}+m_{P}w_{P}}{m_{2o}w_{2o}}=\frac{m_{1o}w_{1o}(1+km)}{m_{2o}w_{2o}} \quad (1)$$

In the formula, M represent the model, Orepresent the actual object; 1represent the primary air;2represent secondary air ; mrepresent the mass flow rate ; ωrepresent average velocity of the flowin nozzles; U represent the pulverized coal concentration of the primary air(0.36kg/kg), k selected 0. 8considering different coefficient of pulverized coal flow rate and wind speed.

Secondary air velocity of the model can be calculated according to the Euler number, which adhere theequal between the model and the actual object.

$$w_{2M}=w_{2o}\sqrt{\frac{r_{2o}}{r_{2m}}*\frac{\Delta P_{2M}}{\Delta P_{2O}}} \quad (2)$$

In the formula,△P2M/△P2o representflow resistance of model and the actual object, 2; ρ–density of flow.

Deem the temperature of each nozzle working medium as equal, the flowingformulacan be obtainedtoformula(1) and (2):

$$\frac{w_{1M}}{w_{2M}}=\frac{w_{1O}}{w_{2O}}\sqrt{\frac{r_{2M}}{r_{1M}}\bullet\frac{r_{1O}(1+km)}{r_{2O}}\bullet\frac{f_{2M}}{f_{1M}}\bullet\frac{f_{1O}}{f_{2O}}} \quad (3)$$

Each nozzle parameterof the cold modelwas obtainedaccording to the operation parameters of the boiler.

3.2.Mathematical Model of Numerical Simulation

Gas flow in the furnacewas consideredas the three -dimensional turbulent flow, standard $k-e$ turbulence modelhas good adaptability according to alarge numbers of studies. The gas phase turbulent flow control equations can be obtained under thethree-dimensional rectangular coordinate system, according to the N- S equation, the general form are as follows [8]:

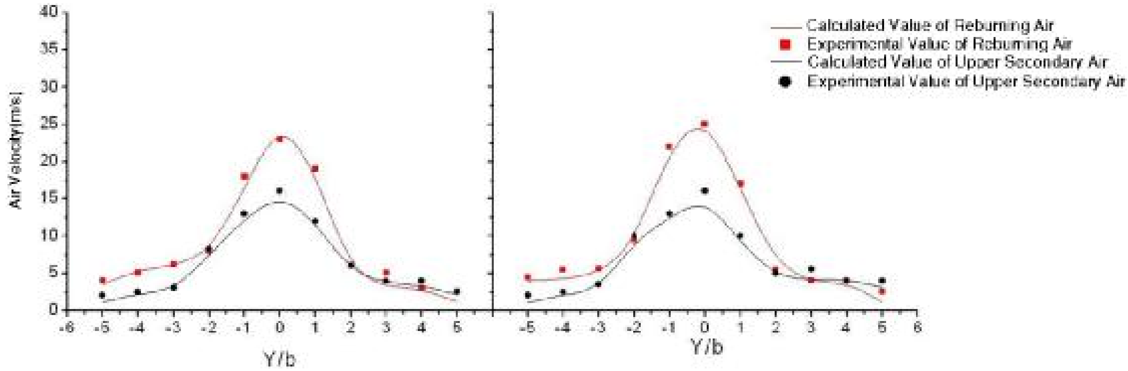
$$\frac{\partial}{\partial x}(rUf)+\frac{\partial}{\partial y}(rVf)+\frac{\partial}{\partial z}(rWf)=$$
$$\frac{\partial}{\partial x}\left[G_f\frac{\partial f}{\partial x}\right]+\frac{\partial}{\partial y}\left[G_f\frac{\partial f}{\partial y}\right]+\frac{\partial}{\partial z}\left[G_f\frac{\partial f}{\partial z}\right]+S_f \quad (4)$$

Inlet boundary condition: the primary airwas 11.4 m/s, and the secondary air was 22.6 m/s. Reburning air is 51 m/s, OFAwas 29 m/s.Outlet boundary conditions: the negative pressure of export of furnace was - 50 Pa, wall boundary conditions: no velocity slip and no quality penetration, the border of the turbulent kinetic energy was $k=\frac{3}{2}\left(I\bar{u}\right)^2$ Turbulent kinetic energy dissipation rate was $e=0.09^{3/4}\frac{k^{3/2}}{l}$,Turbulence intensity was $I=0.16\,\mathrm{Re}^{-1/8}$, turbulence length was $l=0.007L$.

The SIMPLE algorithm was adopted for the numerical simulation in this paper,using thealgorithm to iterative calculation the equations of each variable[9].The method of "speculation - revised" was mainly used in SIMPLE algorithm, computing pressure field on the basis of staggered grid in order to achieve the purpose of solving the momentum equations.

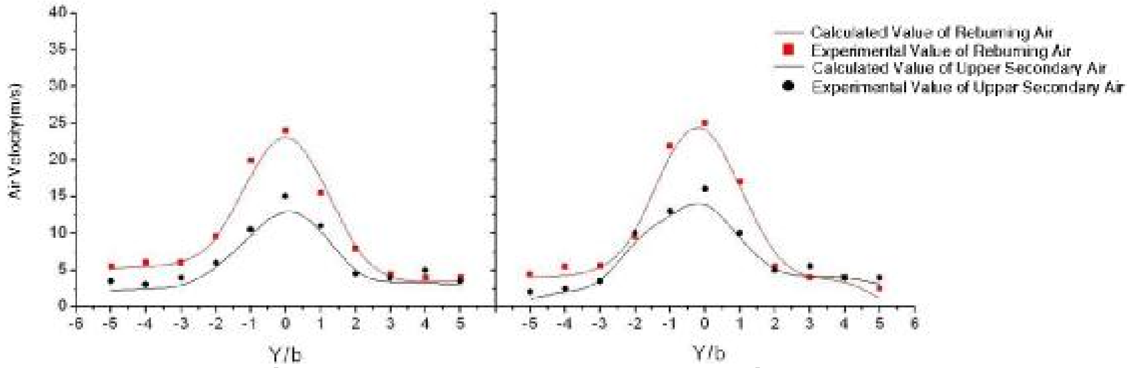
4.Results and Discussion

In order to check the accuracy of the results of the numerical simulation for the cold modelling, the parameter for nozzles of the cold state combustor was adjusted according to **Table 1** and the velocity in all the testing points were measured. All the testing results were compared to the calculatedresults.



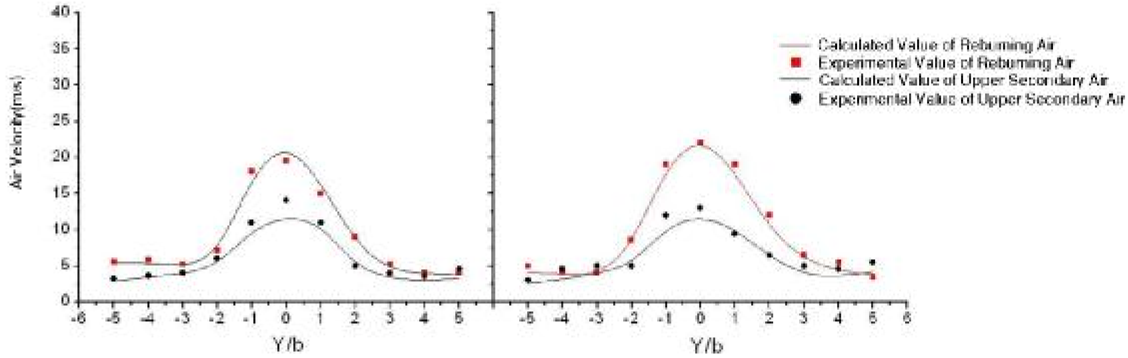
Condition 1 *Condition 2*

(a) X/b=1.0



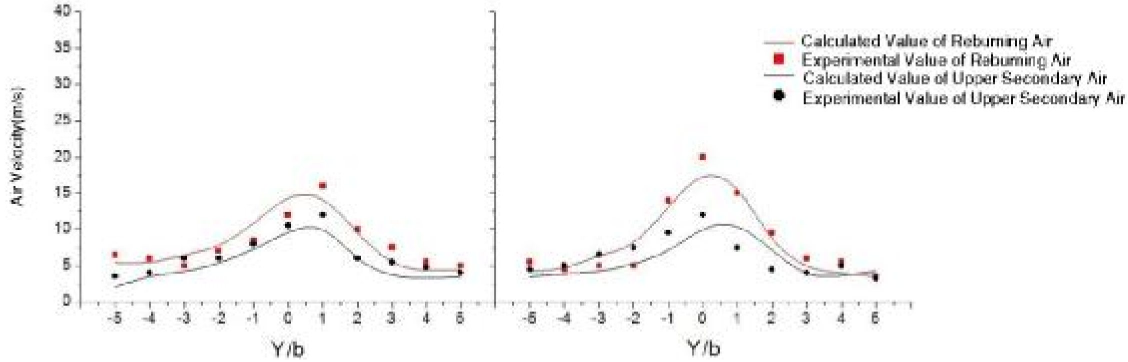
Condition 1 *Condition 2*

(b) X/b=2.5



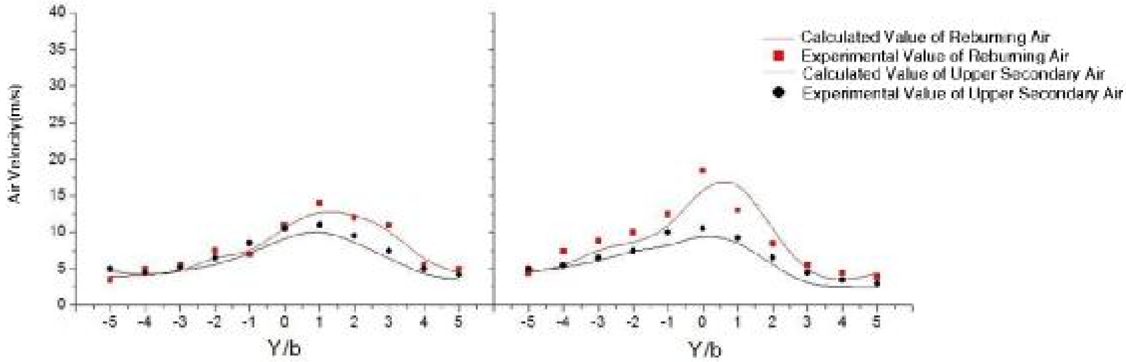
Condition 1 *Condition 2*

(c) X/b=5



Condition 1 *Condition 2*

(d) X/b=7.5



Condition 1 *Condition 2*

(e) X/b=10

***Figure**3.Velocity distribution of reburning air in corners and upper secondary air for Condition 1,2.*

As it shown in Fig.3, the experiment results of the airflow match well with the calculated results in the forehead of the nozzle (X/b=1, 2.5, 5) when the airflow spraying into the furnace with a high speed in condition 1 and 2. While the difference appears at the center of the furnace where is a bit far away of the nozzle, which due to theattenuation and deflection of thereburning gas and the secondary airalong the nozzle axis.

As Fig.3(d) shown,in Condition 1,when the air flow approaching the center of the furnace, reburning gas flow deflected to the furnace wall under the influence of the rotating flow due to the speed attenuation ofthe reburning gas along the jet axis, which peaked at Y/b=1.5. In condition 2, the deviating rate of burning gas flow is slightly smaller compared to condition 1, this is because another four reburning nozzles were added in the furnace, this can bring the additive gas to the airflow in the four corners,so the rigidity of the flue gas was relatively stronger while the deviating rate ofgas flow is relatively smaller in the reburning zone.

According to figure 3 (e), in Conditions 1,the maximum of gas flow is 13.1 m/s,which is significantly lower than the secondary air's speed, socoverage effect of the reburning gas flow is poorer. In condition 2, due to the reburning nozzlesadded in the center of boiler sidewall,the reburning gas flow have enough momentum withthe entrainment effect of surrounding air and can inject into the center of rotating airflow,which have a higher coverage rate to secondary air.

5.Conclusion

(1)A standard turbulence model was used to modeling the cold state aerodynamic field in furnace for three kinds of working conditions, the results from which were matched well to the experiment results.

(2) Where only four nozzles installed in the furnace, the gas flow deflection was serious at the center of the furnace, and the velocity of the reburning gas can't visibly higher than the up secondary gas, and the coverage was poor either. When the reburning nozzles added in and

becomes to eight points injector, the deflection in the center was decreased obviously and with a better coverage of the secondary gas, this can achieve with a fully mixed gas in furnace, thus reducing the NOx.

6. References

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