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Numerical Study on the Effects of Flue-Gas Inlet Type for the Flue-Gas-Desulfurization Wet Scrubber

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Wet scrubber is the most common reactor of limestone/lime wet flue-gas-desulfurization (WFGD) system. For investigating the effects of its inlet format and inlet obliquity on heat and fluid flow, the commercial software Fluent 6.3 is used to simulate 12 cases which are the combination of the three inlet formats and four inlet obliquity. The demister and spray system are simplified as a layer of porous jump and face injection source respectively. A parameter called velocity non-uniformity of scrubber velocity is introduced to estimate the velocity uniformity in the scrubber. By comparing the slurry evaporation, velocity non-uniformity and pressure drop, it is proposed that, for single inlet, the 15° and 20° obliquity are recommended in priority while for double inlet, 120° double inlets with 15° inlet obliquity is the best choice.

1. Introduction

Most of the sulfur in coal is oxidized to sulfur dioxide in the combustion process and is discharged with the flue gas emissions. A series of restrictions have been published to control sulfur dioxide emission because sulfur dioxide not only causes damage to health of human-being but also contributes to acidification of soil and water. Gansley (2008) overviewed Wet FGD system and operation of WFGD. WFGD is the most widely used method and wet scrubber is the most common reactor. Dudek SA and Rogers JA (1999) discussed the various physics presented in wet scrubber that include two-phase fluid flow in the absorption zone, collection of liquid in the demister, transient interactions between gas and liquid, evaporation of water, chemical interactions between the flue gas and the reagent slurry and so on. Gas and slurry flow field in it directly determines the degree of mass transfer, heat transfer, and reaction. In order to save occupancy area of wet desulfurization systems, double inlets and flue duct layout can be adopted by putting wet scrubber directly on the location of original main flue gas. It is necessary to investigate the effects of flue-gas inlet type on heat and fluid flow of the wet scrubber.

Lin Yongming et al. (2005) reviewed progression of study on and application of CFD in large-scale wet flue gas desulfuration system. Scholars as M.K.Akbar et al. (2003) and Zhong Yi (2008) have developed a lot of models including motion of slurry drops, absorption of SO_2, dissolution of limestone and crystallization of gypsum. However it is difficult to describe all the processes in WFGD system by mathematic models. Thus, as

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a trial we intend to numerically study the effects of flue-gas inlet type on the heat and mass transfer in the flue-gas-desulfurization wet scrubber. The commercial software Fluent 6.3 is used to simulate 12 cases which are the combination of the three inlet formats and four inlet obliquity.

2. Physical system and assumption simplification

The object of this study is wet scrubber in 300 MW coal-fired power plants. The flow of flue gas and slurry concentrate in absorption zone while the flow in reactor zone is relative stable and has little influences on the absorption zone. So only the flow in absorption zone is studied for simplification.

Demister plays two major roles in flow in wet scrubber: eliminating the droplets carried by flue gas and causing loss on pressure. The internal structure of demister is full of wavy elements and is too complicated for model building. The demister is simplified as porous jump boundary layer as Lin Yongming (2006) did.

The wet scrubber used in this study has approximately 180 spray nozzles. It would be helpful to find a way to simplify the burdensome setting for nozzle. 90° hollow spray nozzle can cover a circular region of two-meter diameter one meter below spray location. Draw all the spray cover regions one meter below nozzles and it can be seen as Figure 1 that the cover regions almost uniformly bestrow the whole section of the wet scrubber. For simplification, only the downward velocity is considered in simulation, and we assume slurry is sprayed uniformly at the surface one meter below real location with the velocity of $\sqrt{2}/2$ times the actual velocity.

There are still some other assumptions as follows.

1) The flue gas is considered as incompressible Newtonian fluid;
2) The solid particles in the flue gas are ignored;
3) The absorption process of SO_2 is not considered;
4) The spray liquid is treated as pure water;

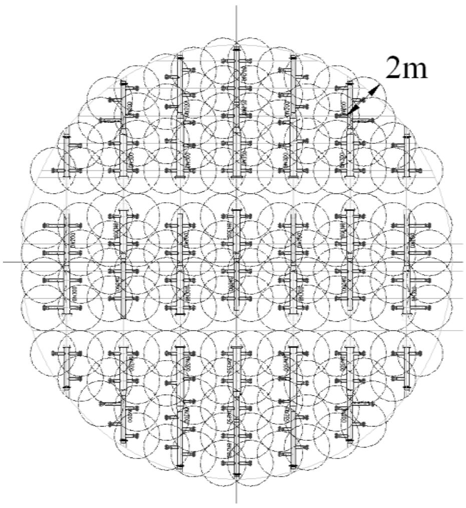


Figure 1: Cover effect drawing at 1m under spray nozzle level

5) The droplet size of spray droplets is uniform.;
6) The break and merge of droplets are not considered;
7) The wall of wet scrubber is adiabatic.

3. Numerical simulation

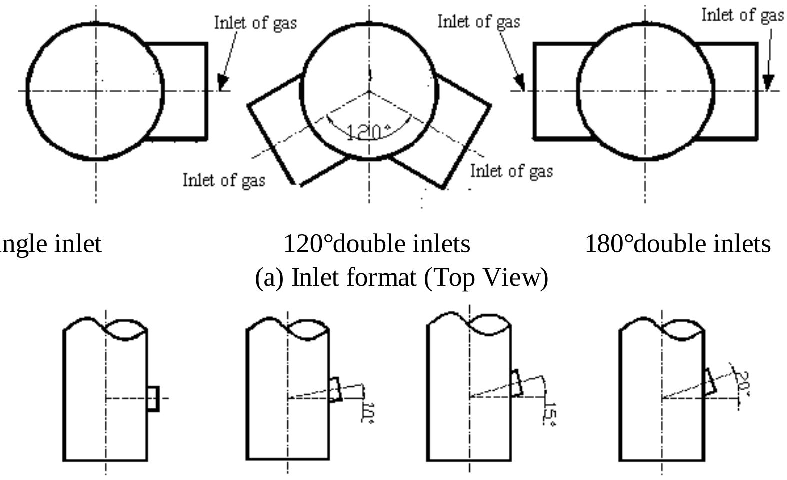
Spray liquid are well-distributed in flue gas in the form of discrete droplets, and the rate of liquid and gas is less than 10%, so it is appropriate to use Euler-Lagrange method to solve this kind of problem. Flue gas is considered as continuous phase using Euler method while spray droplets are considered as discrete phase using discrete phase model(DPM).

3.1 Computing environment

Computer specifications: Inter Core 7200, 2.53GHz frequency, 5GB RAM. Operating system is Microsoft Windows XP Professional x64 Edition Version 2003 Service Pack 2. The mesh is generated by software Gambit 2.3.16 and numerical simulation is realized by software Fluent 6.3. In order to reduce the computational time, the numerical simulation use a dual-core parallel computing.

3.2 Geometrical conditions

In order to investigate effects of inlet type on flow characteristic of wet scrubber, twelve cases are studied in detail, which are the combination of the three inlet formats (single inlet, 120°double inlets, 180°double inlets) and four obliquity (0°, 10°, 15°, 20°). The sketch of inlet format and inlet obliquity is shown in Figure 2. The model parameters are as shown as table 1.



single inlet 120°double inlets 180°double inlets

(a) Inlet format (Top View)

0° obliquity 10°obliquity 15°obliquity 20°obliquity

(b) Inlet obliquity

Figure 2: The inlet type of Flue-Gas-Desulfurization Wet Scrubber

Table 1 Model geometrical parameter

Items	Diameter of wet scrubber	Height of wet scrubber	Size of double inlets	Size of single inlets	Outlet diameter
Unit	m	m	m^2	m^2	m
Value	12.5	22.2	4.4×4.6	9.2×4.4	6.3

3.3 Model setting

The total mass flow rate of spray droplets is 4596.9 kg/s admeasured averagely on three spray levels. The downward velocity of injection droplets is 7.07 m/s. The diameter of droplets is set to 0.002m and the temperature of droplets is 321.15 K.

The component of flue gas are SO_2,CO_2,O_2,H_2O,N_2 with mass percentage of 3.24%, 18.59 %, 6.04 %, 4011 %, 68.02 % respectively. The destiny of the mixture is calculated as incomprehensible-ideal-gas. The specific heat, thermal conductivity and viscosity of the mixture are calculated by mass-weighted-mixing-law. The volume rate of flue gas is 548.7 m^3/s.

The Demister is simplified as porous jump layer with a height of 2.025m and pressure-jump coefficient of 13.065. The boundary conditions for flue gas inlet and outlet are set to velocity and outflow respectively. Inlet, output and bottom surface are set to escape face in DPM. The spray pipes are set to wall-jet in DPM.

The structured grid is taken to mesh the inerratic region such as inlet, demister and main part of absorption zone. The region near spray pipe and outlet are meshed with non-structured grid. Five same cases were calculated with grids from 4.5 million to 9.5 million. It shows that the velocity stabilizes when grid number reaches about 7.5 million. So the grid of the model is controlled at 7.5 million approximately.

4. Results and discussion

The rule of naming different cases is using “angle between inlets-inlet obliquity” method to mark specific conditions. When inlet is single, the angle between inlets is expressed as “0”. For example, "0-15" stands for case of single inlet with 15°obliquity, and "180-15" stands for case of 180° double inlets with 15° obliquity.

4.1 Effects of inlet type on evaporative capacity

Evaporative capacity is obtained by calculating the difference in water capacity between inlet and outlet. Spray droplets evaporate after being heated by hot flue gas. The larger the evaporative capacity is, the more possibly the flue gas and droplets contact. Figure 3 shows remarkable changes in evaporative capacity of 180° double inlets, and this may be arose by change of flow pattern. The evaporative capacity increases with the increasing of inlet obliquity under the condition of 120° double inlets. The average evaporative capacity value at single inlet is 14.40kg/s which have small discrepancy from the practical value 14.39 kg/s. Consequently the calculated evaporative capacity can be referred for the design of wet scrubber.

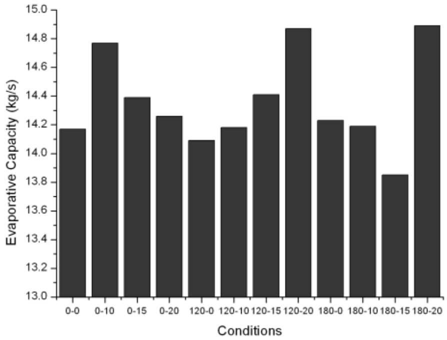


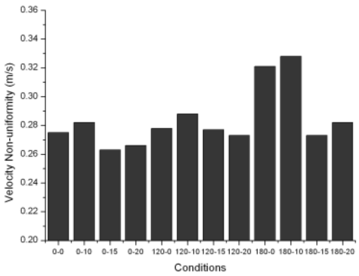
Figure 3: Evaporative capacities at different conditions

4.2 Effects of inlet type on velocity non-uniformity

Define velocity non-uniformity to describe uniformity of velocity distributions at different cross sections whose expression is shown in Equation (1).

$$\tilde{v} = \sqrt{\sum_{i=1}^{N}\left[\left(v' - \bar{v}\right)^2 A_i\right] / A_0} \tag{1}$$

v' represents grid velocity with unit $m \cdot s^{-1}$; $\bar{v}$ represents mean velocity of a cross section with unit $m \cdot s^{-1}$; A_i represents grid area with unit m^2; A_o represents whole cross section area with unit m^2. Average velocity non-uniformity at different cross section in absorption area which is taken every 0.5m and obtain the assemble velocity non-uniformity in wet scrubber whose value is listed in Figure 4. An even flow field lend itself to improve desulfurization effect. Except cases of “180-0” and “180-10”, assemble velocity non-uniformity value at most of cases is between 0.26 and 0.29. The value at 15° or 20° is smaller than the value at 10° or 0°. This means that the velocity distribution may be more uniform under high obliquity.



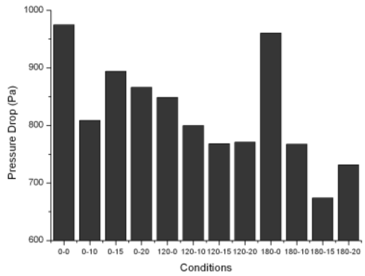


Figure 4: Assemble velocity non-uniformity *Figure 5: Pressure drop*

4.3 Effects of inlet type on pressure drop

Pressure drop is obtained by calculating the pressure difference between inlet and outlet that reflects the flow resistance in wet scrubber. As can be seen from Figure 5, the change of pressure drop under different obliquity for 180° double inlets is the largest. The reason of big change may be arosed by big vortex generation because of direct bump of two flue gas. The 180° double inlets are not commended. The variation law of pressure drop is directly opposite from variation law of evaporative capacity. The pressure drop increase with increase of inlet obliquity under the condition of 120° double inlets.

Appropriate evaporative capacity, small velocity non-uniformity, low pressure drop are qualifications for good inlet type. Considered three parameters comprehensively, cases of “0-15” and “0-20” are better among conditions at single inlet and case of “120-15” is the most suitable condition at double inlets.

5. Conclusions

Using CFD commercial software Fluent, the flow and heat transfer in wet scrubber are simulated, and three parameters are introduced to evaluate the flow characteristic. Inlet obliquity of 15° and 20° for single inlet is preferred. Double inlets with 180° angular separation is not recommended. Double inlets with 120° angular separation with 15° inlet obliquity is the best choice when double inlets are adopted.

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