Numerical Simulation of Marine Desulfurization Tower based on Cyclone Reaction

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Abstract. The desulfurization tower is the main equipment in flue gas desulfurization system for ship. The traditional spray scrubber tower has the disadvantages of large volume, high energy consumption, difficult installation etc. This paper presents a new desulfurization tower by cyclone principle, and using the Reynolds Stress Model (RSM) and the component Transfer model in fluent software to simulate the strong swirl field and chemical reaction in the tower. The simulation results can observe the concentration distribution, flow field distribution in the cyclone desulfurization tower and the desulfurization effect of cyclone desulfurization tower. Thus providing theoretical guidance for the design and feasibility of cyclone desulfurization tower.

Introduction

In order to control the emission of sulfur oxides from ships, from the 50th MEPC Conference in 2003 to the 65th MEPC Conference in 2013, a total of 16 environmental meetings in 10 years have completed the development and revision of MARPOL regulations for regarding the some special and sensitive sea areas in the world as the ship emission control areas [1]. In order to meet the provisions of the regulations, ships can use different sulfur components of the fuel, so before the ships enter the ship's exhaust emission control area, we need to switch from high-sulfur content fuels to low-sulfur content fuels, However, the low-sulfur content fuel costs higher and there will be more problems in the handover process [2]. Therefore, desulfurization in the discharged flue gas that is the desulfurization treatment of flue gas with the ship flue gas desulfurization system which is increasingly becoming another effective method to satisfy the ship's sulphide emission regulations. Due to the limited space on the ship and the large volume of the traditional spray desulfurization tower, the installation and operation of the desulfurization tower on the ship are so difficult; therefore, this paper proposes a new type of desulphurization tower that utilizes the principle of cyclone separator. The swirling airflow in the tower not only increases the turbulence intensity so that the gas-liquid mixing is more completed and the reaction is more rapid and thorough, but also greatly increases the travel of the flue gas in the tower. Therefore, the flue gas in the desulfurization tower under the limited volume space still has sufficient residence time to fully contact with the alkali solution.

Structure Design of Swirl Desulfurization Tower

The structural parameters of the cyclone desulfurization tower include tower diameter D, flue gas inlet size W×L, flue gas outlet diameter D0, bottom outlet diameter Du, column length H, flue gas outlet insertion depth H0, cone angle θ, and its structural parameters are shown in Figure 1. The specific values are shown in Table 1.

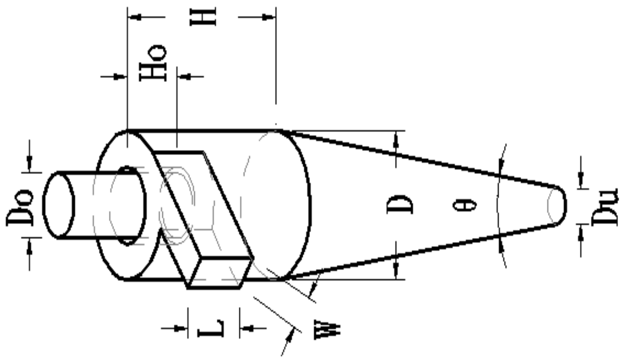

Fig. 1 Structural parameters of Cyclone Desulfurization Tower

Table 1 Structural size of Cyclone Desulfurization Tower

parameters	values	parameters	values
tower diameter[m]	2.5	column length[m]	3.75
flue gas inlet L×W[m]	1.3×0.7	flue gas outlet insertion depth[m]	1.25
flue gas outlet[m]	1.1	cone angle[°]and bottom outlet diameter[m]	15;0.625

Numerical Simulation of Gas-Liquid Two-Phase Flow

Turbulence Model

The flow field in the cyclone desulfurization tower is a flow with high Reynolds number and strong swirling flow. Erdal[3] uses the Reynolds stress model to accurately predict the flow field distribution in the cyclone. This paper uses the Reynolds stress model to simulate the strong swirling turbulent flow field in the cyclone desulfurization tower.

Component Transfer Model

The general finite rate model chosen in this paper can be based on the solution of the mass fraction of the transport equation, according to the user-defined chemical reaction mechanism for chemical reaction simulation. The use of this model is very extensive and it is mainly used to simulate the mixing, transport and reaction of chemical components.

Initial Conditions and Boundary Conditions Settings

The initial conditions of the simulation

The RSM turbulent model was used to solve the transient Reynolds stress equation [4] to calculate the strong vortex flow field in the tower. The energy model and the component transfer model were used to simulate the chemical reactions in the strong vortex flow field. The flue gas temperature is 373K, and the volume fraction of sulfur dioxide is 0.12%. The $CaCO_3$ solution was atomized into tiny droplets at the inlet and mixed into the desulfurization tower at a ratio of 1⁄4 of the molar ratio of SO_2 gas.

The boundary conditions of the simulation

Inlet boundary conditions: inlet boundary type selected speed inlet, flue gas flow Q = 28.49kg/s, inlet flow velocity calculated 25m/s;

Outlet boundary conditions: outflow;

Wall boundary conditions: No slip boundary.

Results and Analysis

Simulation of the Flue Gas Trace in the Swirl Desulfurization Tower

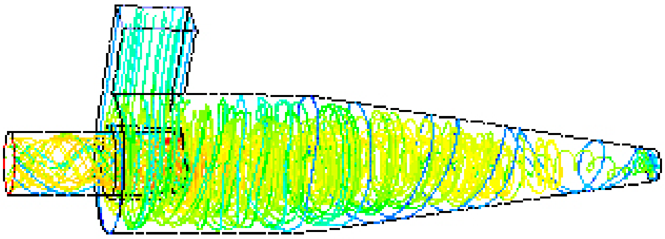

Fig. 2 Smoke trace diagram

Figure 2 is the flue gas trace diagram in the swirl desulfurization tower; it reflects the movement locus of flue gas in the desulfurization tower. It can be seen in the figure that, Flue gas imports into the flue gas desulfurization tower through Flue gas imports, firstly, the flue gas circulates around the inner wall of the tower toward the bottom of the tower, the travel of flue gas is increased, arrived at the bottom and then along the tower in the center of a spiral, until the last from the top of the tower flue gas outlet, further increase the flue gas.

Tangential Velocity Distribution in the Swirl Desulfurization Tower

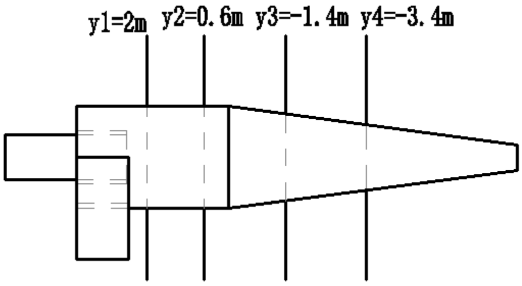

Fig. 3 Sketch of axial cross-sections in Cyclone Desulfurization Tower

In the velocity field of vortex flow reactor, the tangential velocity is the most important [5], because of the tangential velocity not only on the value is much bigger than the speed of the other two directions, and the tangential velocity as the premise of centrifugal force. In favor of observing the tangential velocity distribution of the section, different in hydrocyclone desulfurization pillar and cone respectively take two cross section is analyzed, namely y_1=2m,y_2=0.6m,y_3=-1.4m,y_4=-3.4m, its distribution diagram is shown in figure 3.

Figure 4 is the tangential velocity distribution diagram of the cross section of the swirl desulfurization tower. It can be seen from the figure that the tangential velocity of the flow field in the tower is basically symmetric about the central axis of the desulfurization tower. Velocity along the radial direction from the center, with the increase of the radius increased to a maximum and then gradually decreases, and fell to a smaller area at low speed until the column wall, thus it can be seen that the tower wall and the center axis in tangential velocity for low-speed zone, vortex formed in the two, the tower wall for free vortex, the center axis of the forced vortex, the double vortex at the tangential velocity, the largest about at r=0.5m.

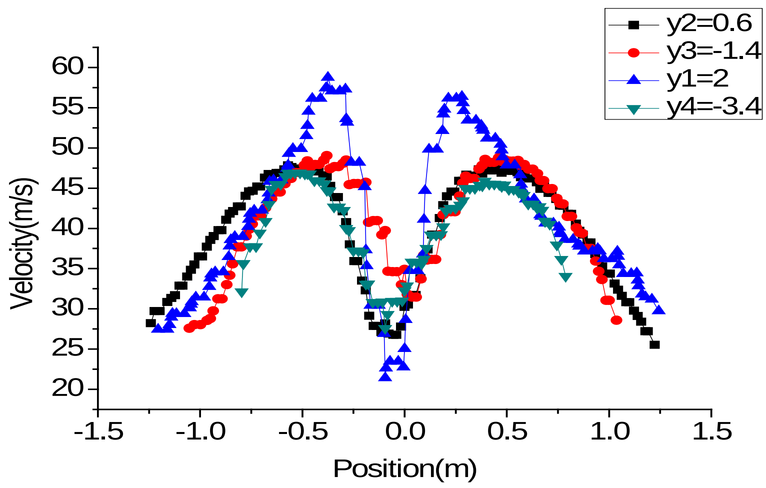

Fig. 4 Axial velocity distribution of different sections in Cyclone Desulfurization Tower

Pressure Field Simulation in Swirl Desulfurization Tower

Figure 5 is the static pressure distribution cloud graph of z=0m and y=3m sections. From figure 7 z = 0 m profile can be seen that along the axial static pressure from top to bottom, the pressure had no obvious change, isobar almost parallel to the center axis, so that the influence of the axial position of pressure is small; From figure 5 y = 3 m section, you can see that the pressure along the radial direction decreases with the decrease of the radius, the highest pressure, the tower wall at the center of pressure, this phenomenon and the theory in the center of a cyclone leads to low pressure gas column. The low pressure zone allows the flue gas to rise along the central axis until it exits the top of the tower.

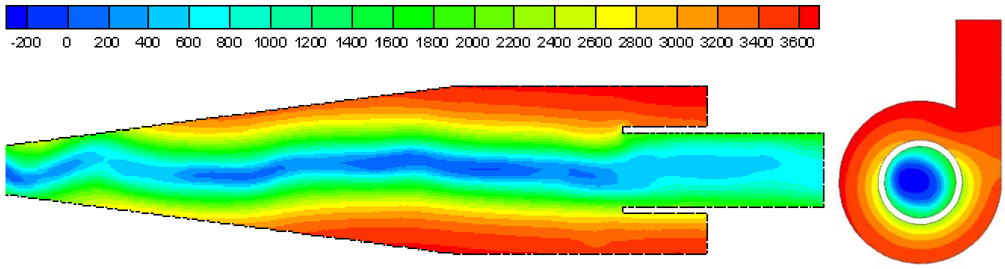

Fig. 5 Static pressure contours distributionat the axial distance of z=0m and the height of y=0m

Concentration Field Simulation in Swirl Desulfurization Tower

SO_2 Concentration Distribution of Swirl Desulfurization Tower

Figure 6 is the SO_2 concentration distribution nephogram at z=0m and y=3m. From z = 0 m profile can be seen in figure 6 tower column section SO_2 concentration changes obviously, From top to bottom, from the tower wall to center, sharply reduced concentration, alkali and SO_2 gas fully contact and reaction, the cone section in SO_2 stability in a very low concentration range; from the section y=3m in figure. 6, it can be seen that the concentration of flue gas decreases sharply after it enters the circulation along the tower wall from the inlet tangential direction, and its change trend presents the form of rotating eddy. Meantime SO_2 almost all absorbed by atomization of the lye, the desulfurization efficiency reached 99.5%.

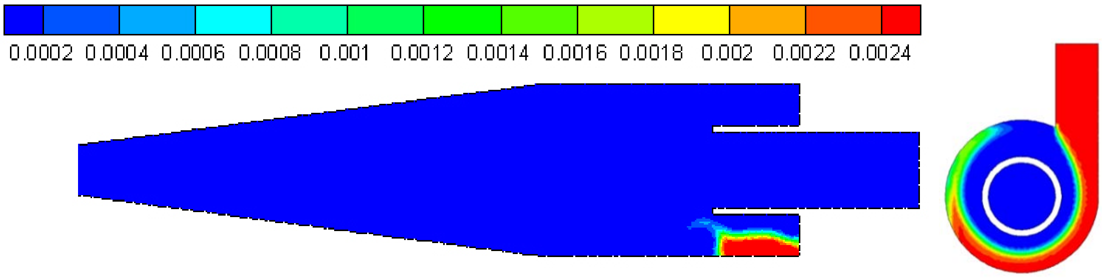

Fig. 6 SO_2 concentration contours distributionat the axial distance of z=0m and the height of y=0m

Concentration Distribution of Lye in Swirl Desulfurization Tower

Figure 7 shows the distribution cloud of alkali concentration at z=0m and y=3m. Within the tower can be seen from the figure 7 lye concentration and SO_2 concentration change trend is consistent by tangential imports into the tower after a rapid decline in circulation after concentration along the column wall, the change trend of rotating vortex pattern.

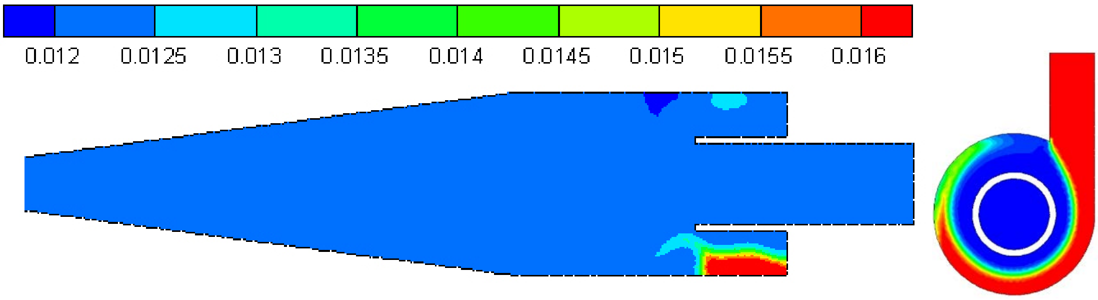

Fig. 7 $CaCO_3$ concentration contours distribution at the axial distance of z=0m and the height of y=0m

Conclusion

In order to better meet IMO about ship sulfur oxide emissions standards, this paper proposes a new desulfurization tower by using the theory of cyclone separator, and by using FLUENT software, the Reynolds stress model and transmission model of components within the tower on strong spin on three dimensional numerical simulations of the flow field and chemical reaction, based on the simulation results can get the following conclusion:

(1) Vortex structure characteristics of the desulfurization tower greatly increased in the tower flue gas trip, so compared with traditional desulfurization reaction tower, vortex desulfurization tower under the condition of the smaller still can ensure the residence time of flue gas in the tower has enough contact reaction fully with lye, so vortex desulfurization tower is more suitable for less available space environment of the ship.

(2) Flow field in the tower of the tangential velocity distribution in line with combination of Rankine vortex characteristics of tower column wall and the center axis in tangential velocity is small, in the two formed the vortex, the tower wall for free vortex, the center axis of the forced vortex, the double vortex at the tangential velocity, the biggest is about at r = 0.5 m.

(3) Axial position has little effect on pressure. The pressure at the center of the tower wall is the highest and the pressure at the center axis is the lowest

(4) SO_2 and alkali liquor after entering the tower, the import tangential concentration along the column wall in circulation in the process of rapid decline, the change trend of eddy current shaped; SO_2 in the tower and a good contact with lye and was almost completely absorbed, the removal efficiency reached 99.5%

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