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Study on a Wet SO_x Scrubber in a Marine Diesel Engine†

SONG ZHOU*, YUANQING ZHU and GUOSHENG GAI

College of Power and Energy Engineering, Harbin Engineering University, Harbin 150001, P.R. China

*Corresponding author: Fax: +86 451 82519852; Tel: +86 451 82568384, E-mail: songzhou@hrbeu.edu.cn

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This paper presents the study on a wet SO_x scrubber in a marine diesel engine and the results of analysis of the scrubber about components and their actions. Models of open cycle seawater scrubber and closed cycle system with alkaline additives were set up using theory of chemical kinetics based on desulfurizing tests. Using the model in the paper and combined with CFD, simulations of a marine desulfurizing scrubber was done, especially focused on the structure of scrubber, sea water flow and fresh air flow on performance of the scrubber and alkaline materials added to SO_x scrubber. This paper also discusses means to reduce scrubber sea water and to collect particles in exhausted seawater. The study in this paper gives a method of reducing SO_x emission from a marine diesel engine, which satisfied the limitation of IMO regulations.

Key Words: SO_x, Scrubber, Model, Marine diesel engine.

INTRODUCTION

With rapid developments of the global economy, international shipping trade has made an unprecedented development. But the SO_2 pollution from marine diesel engines has be grown dramatically, which cause serious environment problems[1]. In some regions, SO_2 pollution from ships is the largest source of air pollution. At present, IMO has developed stringent emission regulations to control SO_2 emissions from ships[2]. Using the low-sulfur fuel is one of most effective means of reducing sulfur emissions[3]. However, the increasing cost of low-sulfur fuels and the stricter emission limits make people to consider the seawater desulfurization[4]. It is a well-established, reliable and cost-effective mean of reducing SO_2 from power plants[5]. But the land-based seawater desulfurization unit is huge and it can not be directly applied to the ship.

Up to now, the study on the structure of seawater desulfurization unit is a quite recent issue. In this paper, a new structure of seawater desulfurization unit was designed. The aim of this work is to optimize internal flow field of the unit using air distribution plate and analyze the droplet distribution.

EXPERIMENTAL

Seawater desulfurization model: The design of seawater desulphurization device is a kind of spray tower, which is widely used in land-based power plant. The unit sprays seawater in the inclined spray type and optimizes the internal flow field by the installation of air distribution plate. The device is shown in Fig. 1.

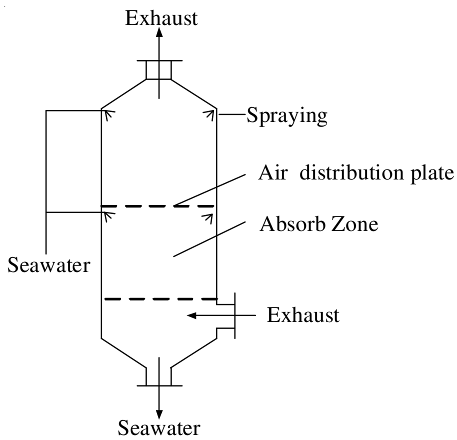

Fig. 1. Structure of desulfurization device

The main body of the desulfurization unit height is 1.5 m, the spray district height is 1m and diameter is 0.6 m. There are two spraying zones, in which each layer is fitted with four nozzles and the spray angle is 45º.

Exhaust gas enters the desulfurization equipment from the inlet and then turn up into the desulfurization zone, where sulfur dioxide is absorbed by the alkaline substances in the seawater. The desulfurization efficiency is dependent on the

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distribution of exhausts and droplets affects. This paper also studied influences of air distribution plate on the flow field and three desulfurization models are shown in Fig. 2.

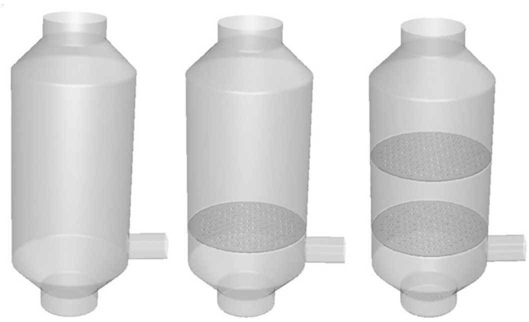

Fig. 2. Three type of desulphurization structure

Gas flow mathematical model: Gas flow in the sea-water desulfurization unit is turbulent flow. In this paper, k-e turbulent model is used, the corresponding transport equations are:

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k\mu_t)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \quad (1)$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial(\rho\varepsilon\mu_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \quad (2)$$

where, G_k is the mean velocity gradient caused by the turbulent kinetic energy k; G_b is buoyancy caused by the turbulent kinetic energy k; Y_M is the contribution of the compressible turbulent pulsation; δ_k is the Prandtl number of kinetic energy; σ_e is the Prandtl number of dissipation rate; S_k, S_ε are user-defined source terms; $C_{1\varepsilon}$, $C_{2\varepsilon}$, $C_{3\varepsilon}$ empirical constants.

Discrete phase model: Numerical simulation of two-phase flow mainly uses two methods: the Euler-Euler method and the Euler-Lagrange method.

In the Euler-Lagrange method, the fluid phase is considered to be continuous phase and solved by the N-S equations directly to get the velocity and other parameters.

Use Lagrange method to describe the dispersed phase, trajectories of dispersed phase determined by integrating the equations of a large number of particles operator. Discrete binomial model assumes discrete item is very thin, neglect the interaction of the particles and the volume fraction of particles on the continuous phase.

The trajectory of the discrete particles is getting by solving the force differential equations of dispersed phase. A variety of forces acted on the discrete particles, such as gravity, drag force and buoyancy. In Cartesian coordinates, the discrete particles force balance equation as follows:

$$\frac{du_p}{dt}-F_D(u-u_p)+\frac{g_x(\rho_p-\rho)}{\rho_p}+F_x \quad (3)$$

where, the $F_D(u-u_p)$ is the drag force of particles per unit mass, C_D is the drag coefficient, F_x is other forces in the x direction.

Boundary conditions: The chemical reaction of the exhaust is ignored and assumed air as the flowing medium. The inlet boundary use velocity inlet and set the speed to 9 m/s, the outlet boundary is outflow, discrete item set to escape. Wall and the orifice set to no-slip condition, near the wall using standard wall functions, discrete item set to escape.

RESULTS AND DISCUSSION

Effects of distribution plate on flow field: Figs. 3-5 shows the flow field situation in desulfurization unit with air distribution plate. It can be seen in Fig. 3 that the gas entered the device internal without air distribution plate horizontally and impacted onto the wall, part of the gas flow upward close to the wall and the main airflow located in the left side of space in the desulfurization unit. With the single air distribution plate, the flow field changed significantly, as seen in Fig. 4. Due to the hindering effect of plate, the airflow can't flow upward directly after contact with the wall, developed exhumation airflow, the main upward airflow transferred to inlet. But the high-speed airflow channel on the right side above the plate is not conducive to the desulfurization reaction. The flow field distribution is more uniform with double air distribution plate are shown as Fig. 5. On the left side of the middle layer turbulence are generated and the right side of the airflow move to the left. Flow field distribution is better than others.

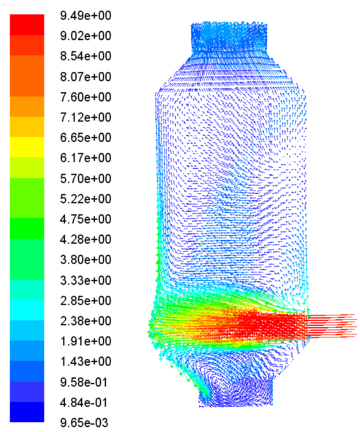

Fig. 3. Gas vector distribution with no-plate

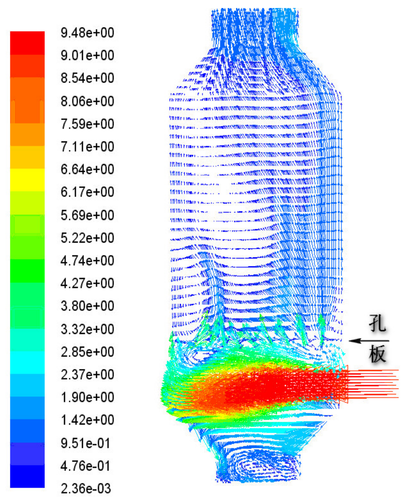

Fig. 4. Gas vector distribution with one-plate

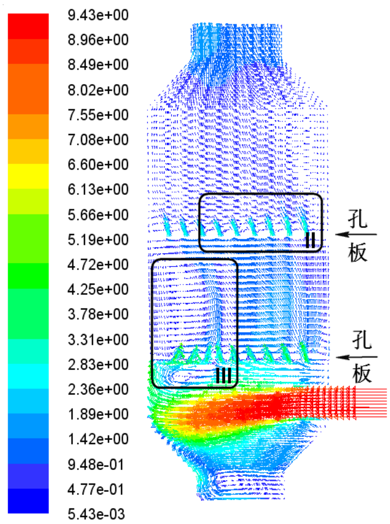

Fig. 5. Gas vector distribution with two-plate

Effects of spraying on flow field: The only flow field analysis is desulfurization spray unit with the two-orifice, because the analysis showed that the gas flow field was better. The vector and velocity of the flow field are shown in Figs. 6 and 7. These figures show that the flow field changed significantly with spraying. The regional jet source oblique below the turbulent region and the main channel of the gas is transferred to the center area of the desulfurization unit. The jet strength and the velocity of the droplets near the nozzle are large. When gas goes to the region along the desulfurization unit, they change the direction and moving with the spray droplets because of the drag effect of the high-speed of particles. The droplet move main below the center position, so a large part of the rising gas around the entire apparatus is transported to the center area of the desulfurization unit, resulting in the central region increased the amount of gas. The gas and upward gas create a turbulent region in the second floor of the unit. Fig. 7 shows that there was no short circuit of gas in the desulfurization equipment. It is conducive to desulfurization reactions because the rate of gas in the edge of desulfurization unit is very low and the speed in the central area is more evenly distributed.

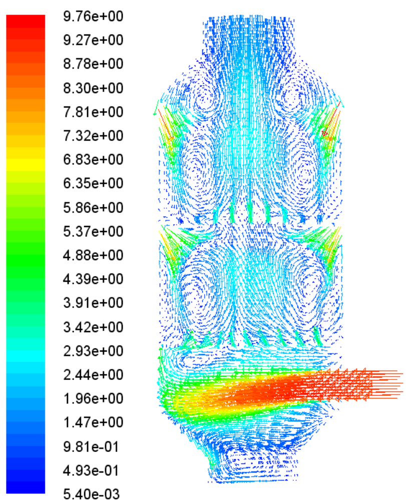

Fig. 6. Gas vector distribution of spraying

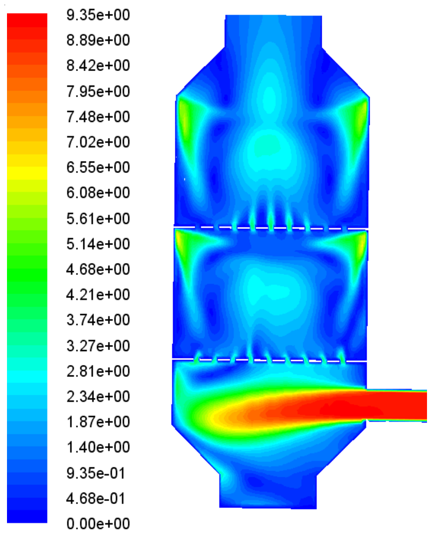

Fig. 7. Gas velocity distribution of spraying

Droplet concentration distribution: DPM model cannot simulate the motion curve of each droplet, but separates the droplet into a number of particles and tracks the distribution trend. Droplet particles enter into the gas flow field from the nozzle, changing the form of flow field, also influenced by gas flow field. The droplets disperse everywhere of the desulfurization region.

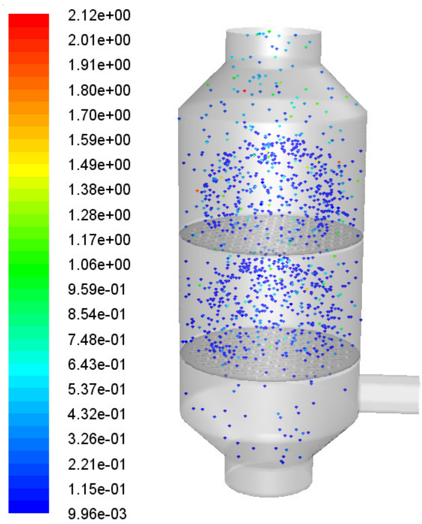

Fig. 8. Droplet space distribution schemes

Fig. 8 shows the distribution of droplets in the device. It is found, droplet distribution presents hemispherical. The drop concentration in the center of each desulfurization area is largely higher than the concentration around. In order to know the particle concentration better, lateral surface is monitored. The size of the device is shown in Fig. 9.

Figs. 10 shows that the drop particle concentration in the top and bottom desulfurization is as respectively. Comparing these two figures, it is found that the particle concentrations of the spray are similar. Because of the same way of spray in the upper and lower levels, the shapes of flow field are similar, resulting in similar distribution of particles.

The concentration and the speed field present the same trend. That means, when the airflow in desulfurization tower begins to move toward the center area and rise, spray droplets concentration in the center increase. The main body of gas flow passes through the area with high concentration of the particles, which is beneficial to waste-gas desulfurization.

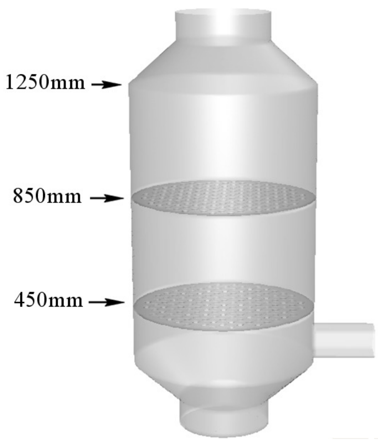

Fig. 9. Desulfurization devices size distribution

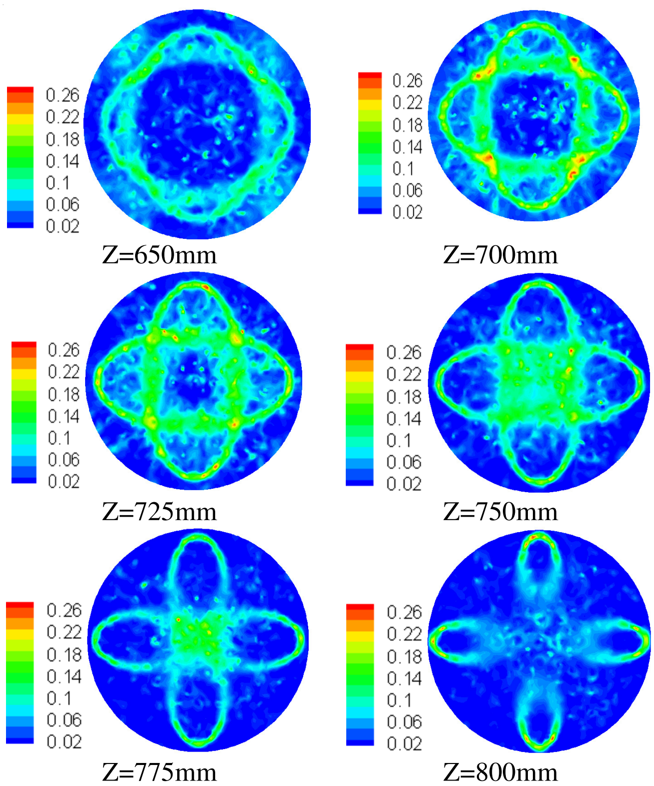

Fig. 10. Concentration distribution of droplet

Through the above analysis, it is found that the system prevents the waste gas from passing from the rare part of the particles and facilitates the main body of the waste gas pass through a thick part of the particle area, improving the efficiency of the waste-gas desulfurization.

Conclusion

Through the analysis of seawater desulfurization unit flow characteristics can be obtained:

(i) Installing two layers of air distribution plate can prevent the escape of gas effectively and optimize the overall flow field.

(ii) The spraying have a great influence of the flow in the unit, the gas entrainment phenomenon is happened near the nozzle and the gas surrounded is thinner than the gas in center.

(iii) The atomized droplet is full of basin space and in the center of unit the concentrations of droplet is higher and the droplet distribution and gas distribution situation is the same.

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