IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Design of Mixed Scrubbing and Desulfurization System for a Marine Engine

To cite this article: Fangyong Wang and Hao Guo 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **472** 012098

Design of Mixed Scrubbing and Desulfurization System for a Marine Engine

Fangyong Wang[1*] and Hao Guo[2]

1.College of Engineering & Technology, Northeast Forestry University, Harbin, Heilongjiang, China, 150001
2.College of Power &Engineering, Harbin Engineering University, Harbin, Heilongjiang, China, 150001
Email: wfy166@163.com

Abstract. Along with the rapid development of the shipbuilding industry, the control of SO_x in the exhaust gas discharged from marine power plants has become increasingly strict. Unlike NOx emissions, sulphur oxide are derived from fuels, and economic and practical considerations need to be considered while looking for alternative fuels and low-sulfur fuels. Therefore, post-treatment of emissions is the best means to control SO_x. In order to meet the new IMO emission control standards, a more stringent exhaust gas desulfurization system should be designed. In this paper, the design of the mixed ship exhaust gas desulfurization system is studied. The absorption principle and the respective characteristics of the seawater method open desulfurization system are analyzed. The spray tower was selected as the desulfurization absorption equipment, and the seawater was used as the main absorbent to calculate the size data of the spray tower, the spray device and the size of the gas inlet and outlet. A set of specific exhaust gas desulfurization systems was designed for the design of liquid handling equipment, piping and pumps.

1. Introduction

With the development of ships industry, the proportion of SO_x from marine power plant accounting for total global emissions increases year by year, with enable the usage of high-sulfur heavy fuel oils (HFO) [1]. In order to prevent atmospheric pollution from ships, according to the regulations of International Maritime Organization (IMO), from 2015 beginning, for the ships sailing in sulfur controlled area (SECA) the sulfur content of fuel oil shall not exceed 0.1%wt; by 2020, the global worldwide sailing ship in non-SECA, the fuel sulfur content shall not exceed 0.5%wt. In accordance with the comparative analysis of ships SOx emissions performance technologies, ships exhaust gas emissions after-treatment technologies are the most economic and feasible [2-3]. Therefore, it is necessary to improve the existing equipment and processing technology or to design a new mixed marine tail gas washing and desulfurization system.

The wet scrubbing system is more widely used than the dry scrubbing system. It is the main desulfurization system currently researched and applied in foreign countries. At present, Wärtsilä, Clean Marine, MAN, Aalborg, etc. have mastered their core technologies in this respect [4-5]. After February 2012, Wärtsilä's exhaust scrubber desulfurization system incorporates Hamworthy's technology, and several vessels have already installed or ordered the ship's exhaust scrubber desulfurization system developed by Wärtsilä.

2. Reaction Mechanism

When the desulfurization system starts to operate, the initial absorbent gradually contacts and reacts with SO_2, and the pH of the absorption liquid continuously decreases. When the pH value of the absorbent is lower than the limit value and the required desulfurization efficiency cannot be satisfied, the system automatically discharges the portion. The absorbent is simultaneously added with a fresh absorbent to automatically adjust the pH to maintain a high desulfurization efficiency. During the whole absorption process in the scrubbing tower, various reversible and irreversible chemical reactions occur in the contact zone. The chemical reaction process is very complicated, and water dissociation and sulfite mainly occur during the period. Oxidation produces sodium sulfite, sodium bisulfite and a small amount of sodium sulfate.

1. Absorption reaction

$SO_2(g)+H_2O \rightarrow SO_2(l)+H_2O$(mass transfer)

$SO_2+H_2O \rightarrow H_2SO_3$ (dissolved)

$SO_2+H_2O \rightarrow H^++HSO_3^-$(ionization)

$H_2SO_3 \rightleftharpoons H^++HSO_3^-$(ionization)

2. Neutralization reaction

The sodium hydroxide absorbent maintains a certain pH value, and will neutralize the product formed by the absorption of sulfur dioxide in the flue gas in the previous step, and the neutralized reaction in the spray tower after the neutralization process is again sprayed in the desulfurization closed cycle. The tower absorbs sulfur dioxide, and the following is the chemical equation for the neutralization reaction.

$NaOH \rightarrow Na^++OH^-$

$2NaOH+H_2SO_3 \rightarrow Na_2SO_3+2H_2O$

$Na_2SO_3+ SO_2(l)+ H_2O \rightarrow 2NaHSO_3$

$NaOH+NaHSO_3 \rightarrow Na_2SO_3+H_2O$

$Na^++HSO_3^- \rightarrow NaHSO_3$

$2Na^++CO_3^{2-} \rightarrow Na_2CO_3$

$H^++CO_3^{2-} \rightarrow H_2O+CO_2\uparrow$

3. Oxidation reaction

The absorbed part of HSO_3^- is oxidized in the absorption zone of the absorption tower with oxygen in the flue gas. More of the part of HSO_3^- is completely oxidized in the slurry tank below the spray tower and the air. The reaction equation is as follows:

$HSO_3^-+1/2O_2 \rightarrow HSO_4^-$

$HSO_4^- \rightleftharpoons H^++SO_4^{2-}$

3. Hybrid Desulfurization Tower Structure Design

3.1. Exhaust Gas Properties

The model selected in this paper is the MAN 6S50 diesel engine as the supporting diesel engine model. When designing the exhaust gas mass flow, the maximum exhaust gas flow should be fully considered. After data inquiry, the mass flow rate of the exhaust gas is finally determined to be 82500 kg/h.

The absorption target of this paper is the exhaust gas produced after the combustion of the fuel with a sulfur content of 3.5%. After the test, the concentration of SO_2 in the exhaust gas after combustion of the fuel with a sulfur content of 3.5% was measured and further measured. Below are some other data of the exhaust gas.

Exhaust gas density: $1.293 kg/m^3$,

Smoke molar mass: 29g/mol,

Smoke viscosity: 2×10^{-5}Pas.

3.2. Spray Tower Structure Size Calculation

The structural size calculation of the spray tower mainly consists of two parts, one is the tower diameter calculation of the spray tower, and the other part is the tower height calculation of the spray tower. The diameter of the spray tower can be calculated from the exhaust gas intake flow rate and the empty tower gas velocity as follows:

$$D=\sqrt{\frac{4V_s}{\pi u}} \quad (1)$$

Where: *D* - a diameter, m.

Volume - flow of exhaust gas under *Vs* operating conditions, m^3/h.

U - gas velocity of mixed gas, m/s.

In the design process, the rationality of the design and the operability of the processing should be considered. Therefore, the final design of the spray tower diameter is 2.5m.

3.3. Spray Tower Height Calculation

The height of the spray tower is composed of many sections. The design is mainly for the height of the absorption zone, the height of the defogging zone, the height of the slurry pool and the height of the gas inlet pipe. The rest can be increased or shortened more or less according to the actual situation of the design. .

(1) Design of the absorption zone of the spray tower

The flue gas containing sulfur dioxide passes through the spray tower to average the total sulfur dioxide absorption in the tower to the inner volume of the tower within the height of the absorption zone, which is the average volumetric load of the absorption tower, and the value is expressed as the average volumetric absorption rate. The symbol ξ indicates.

$$\xi=3600\times\frac{64}{22.4}*\frac{273}{273+t}u*y_1\eta/h \quad (2)$$

Where: η- SO_2 absorptivity,

h - Height of absorption zone in H tower,

u- gas velocity u(m/s),

Y_1- the molar fraction of the solute in the gas entering the tower.

According to the design experience, the average volumetric absorption rate ξ should be selected between 5.5 and 6.5kg/ (m^3.s). Take ξ=6.0kg/ (m^3.s).

$$h=\frac{3600\times\frac{64}{22.4}\times\frac{273}{273+75}\times4.0\times1.12\times10^{-3}\times97.2\%}{6.0}=5.86 \quad (3)$$

(2) Design of the height of the defogging zone of the spray tower

The mist eliminator designed in this paper has two-stage defogger. The first-stage demister and the uppermost spray layer are 1m, and the distance between the first and second demister is 1.5m. The secondary demister and the upper spray tower is one meter, so the final demister height design height h_2=3.5m.

(3) Design of spray tower pulp pool height

In the design process of the slurry tank, the volumetric capacity should be designed from the volume, so that a certain amount of liquid is stored at the bottom of the bottom of the slurry. Therefore, the capacity of the slurry tank V_1 can be designed according to the ratio of the liquid to gas ratio *L/V* and the residence time of the slurry. To determine, the formula is as follows:

$$V_1=\frac{L}{V}\times V_N\times t_1 \quad (4)$$

Where: *L/V* - operating liquid to gas ratio,

V_N - Fume gas standard state wet volume,

t_1 - slurry residence time.

$$V_1 = \frac{7.38\times\frac{65893.27}{3600}\times120}{1000} = 16.21\mathrm{m}^3 \quad (5)$$

$$\mathrm{S}=\pi\mathrm{D}^2=5.826\times\pi=18.30\mathrm{m} \quad (6)$$

$$\mathrm{h}_3=\frac{V}{S}=\frac{16.21}{18.30}=0.886m \quad (7)$$

The result is rounded upwards, and the final designed pulp pool height h_3=0.9m.

(4) Design of spray tower flue gas inlet height

The height of this part should be consistent with the caliber of the inlet flue gas pipeline, and should be appropriately increased on the basis of the known flue caliber. The final design of the gas inlet height h_4=1.1m.

Based on the above four parts analysis, it is concluded that the overall height of the spray tower is mainly composed of the four parts, the height of the absorption zone, the height of the defogging zone, the height of the slurry pool and the inlet height of the flue gas.

$$\mathrm{H}=\mathrm{h}_1+\mathrm{h}_2+\mathrm{h}_3+\mathrm{h}_4 \quad (8)$$

Finally, the overall height of the spray tower is H=11.5m.

When the spray tower flue gas inlet device is designed, the velocity of the gas entering the spray tower is about 10-20m/s. Generally speaking, the higher the gas entering the tower speed can promote the absorption of the absorbent more effectively and improve the overall spray tower. Desulfurization efficiency, so this design takes gas into the tower speed of 20m/s. When designing the seawater liquid inlet, it should be calculated according to the designed liquid velocity. According to the pipe material standard, the liquid velocity in the pipe is generally between 1.8m/s and 2.4m/s. In this design, the inlet speed of the absorbent is 2m/s.

4. Results

The ship hybrid exhaust gas desulfurization system is an effective measure to control the emissions of SOx. In this paper, the design and research of the mixed exhaust gas desulfurization system is carried out. The emission control of the exhaust gas of the 10MW model is studied, and a set of scrubbing desulfurization system is designed, the conclusion is as follows:

1. The material balance between the seawater method and the sodium-alkali method is obtained. The designed liquid-gas ratio of the seawater method is 7.38L/m^3, and the designed liquid-gas ratio of the sodium-alkali method is 2.8 L/m^3, which is calculated according to the liquid-gas ratio. The scrubber has a diameter of 2.5m.

2. The height of scrubber is divided into four parts, which are calculated as the height of the absorption zone 6.0m, the height of the defogging zone is 3.5m, the height of the pulp pool is 0.9m, the inlet height of the flue gas is 1.1m, and the overall height of the spray tower is calculated to be 11.5m.

3. The spray device is selected as a pressure atomizing nozzle, the flue gas flow rate is 3.5m/s, the seawater liquid inlet pipe diameter is 0.3m, and the NaOH solution inlet pipe diameter is 0.23m.

References

[1] Cordoba, Patricia Status of Flue Gas Desulphurization (FGD) systems from coal-fired power plants: Overview of the physic-chemical control processes of wet limestone FGDs [J]. Elsevier journal, 2015.
[2] Caillahua, Mariella Cortez, Moura, Francisco Jose. Technical feasibility for use of FGD gypsum as an additive setting time retarder for Portland cement [J]. Elsevier journal, 2018.
[3] Yu, Jicheng, Lu Jia,Kang Yong. Removal of sulfate from wet FGD wastewater by co-precipitation with calcium hydroxide and sodium aluminate [J]. Energy&Fuels, 2015.
[4] MAN. Emission Project Guide, 2017.6.
[5] Wartsila. Wartsila-Environmental Product Guide, 2017.