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Design, Calculation and Experimental Analysis on Packed Tower of Marine Exhaust Gas Scrubbing Desulfurization

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Due to the regulation of fuel sulfur content in IMO ECA will be implemented in 2015, the research on the exhaust gas scrubbing desulfurization system suitable for marine power plant is very important. Considering the limited space and stable requirements of ship, packed tower was selected as the absorption equipment of scrubbing system and NaOH was used as absorbent. Firstly, this paper finished the scheme of packed tower, including absorption process, operational condition, absorption and packing. Secondly, the paper finalized the design and calculation of packed tower structure and auxiliary components, including the selection and calculation of tower structure size, supporting device of packing, liquid spray device, inlet and outlet device of gas and liquid. Finally, a scrubbing desulfurization test-bed of marine diesel engine was built according to the design result. Tested by the built scrubber system, this paper analyzed and obtained the influence of pH of absorbent on desulfurization efficiency.

Keywords: NaOH, Scrubber, Marine diesel, Sulfur oxide, Desulfurization efficiency.

INTRODUCTION

Restrictions on international emission regulations become more stringent on SOx emissions, raising higher requirements for exhaust gas scrubbing system in efficiency[1]. The application of exhaust gas washing desulfurization technology on board currently has existedin in foreign countries and the technology is relatively mature[2-4], while domestic research for the washing desulfurization of flue gas on board is relatively weak. So coming up with a ship desulfurization equipment with independent intellectual property is of great significance[5].

EXPERIMENTAL

Laboratory experiment process of absorption tower is shown in Fig. 1. Exhaust gas from the diesel engine was cooled through shell-and-tube heat exchanger and entered the packed tower, fully contacting absorb liquid that was sprayed from the nozzle-type shower and finishing the mass transfer process in the packing layer. The gas after washing was exhausted through the outlet of the packed tower after drying by the defogger. The packing layer, a supporting grid plate, spray device of nozzle type and a defogger is installed in the packing tower. The waste water after washing was cooled by the plate heat exchanger and was circulated to cool the waste water in the packing tower.

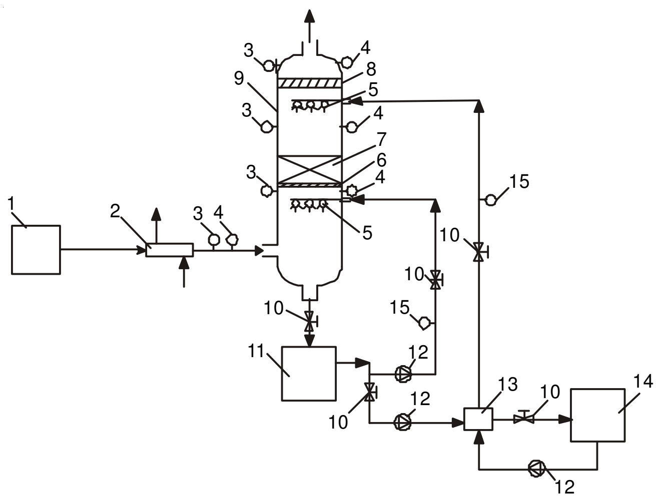

Fig.1. Flow chart of desulfurization experimental device

The desulfurization washing experimental system is shown in Fig. 2, including the tower body, diesel engine, shell and tube heat exchanger, plate heat exchangers, absorbing liquid storage devices, instruments and pumps.

Fig. 2. Desulfurization system device

RESULTS AND DISCUSSION

In this experiment, the stainless steel saddle ring was selected as the packing, controlling that the intake air temperature is 50 °C, absorbing liquid temperature is 25 °C, liquid gas ratiois 1.5 L/m^3, the intake air flow is constant. Then the pH value of the absorbing solution is adjusted by adjusting the ratio of the concentration of NaOH and water, respectively, do experiments with the desulfurization efficiency of the different pH value of absorbing solution, the experimental results are shown in Fig. 3.

As shown in Fig. 3, when the pH value of the absorbing liquid is in the range from 7 to 10, the desulfurization efficiency is significantly increased with the increase of pH value; when the pH value is in the range from 10 to 12, the growing trend of the desulfurization efficiency flattens and the desulfurization efficiency goes up to 98 % when the pH value exceeds 10.

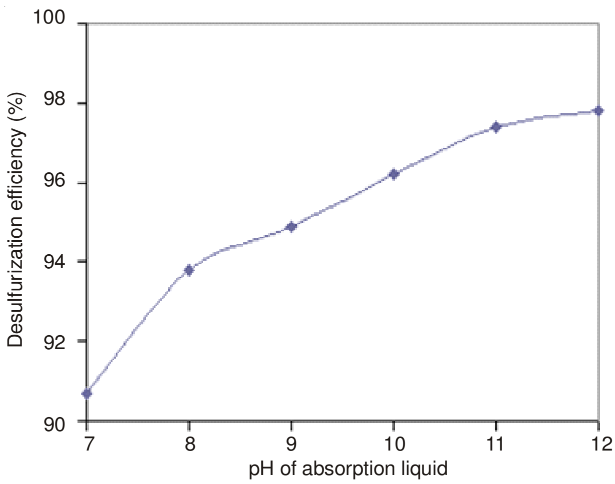

Fig. 3. Change of desulfurization efficiency with the pH value of absorption liquid

Sodium sulfite (Na_2SO_3) generated by the absorbing liquid is strong base weak acid salt, the aqueous solution is alkaline due to hydrolysis, which exists the ionization equilibrium in aqueous solutionbelow:

$$Na_2SO_3 = 2Na^+ + SO_3^{2-}$$

$$SO_3^{2-} + H_2O = HSO_3^- + OH^-$$

$$HSO_3^- + H_2O = H_2SO_3 + OH^-$$

Sodium bisulfite ($NaHSO_3$) is fully ionized to Na^+ and HSO_3^- in water and HSO_3^- can be not only ionized, but also hydrolyzed.

HSO_3^- ionization:

$$HSO_3^- = SO_3^{2-} + H^+$$

HSO_3^- hydrolysis:

$$HSO_3^- + H_2O = H_2SO_3 + OH^-$$

The partition coefficient of H_2SO_3, HSO_3^- and SO_3^{2-} in the solution of is controlled by the pH of solution. The equilibrium relationship of the sulfur-containing component is shown in Fig. 4 according to ionization equilibrium.

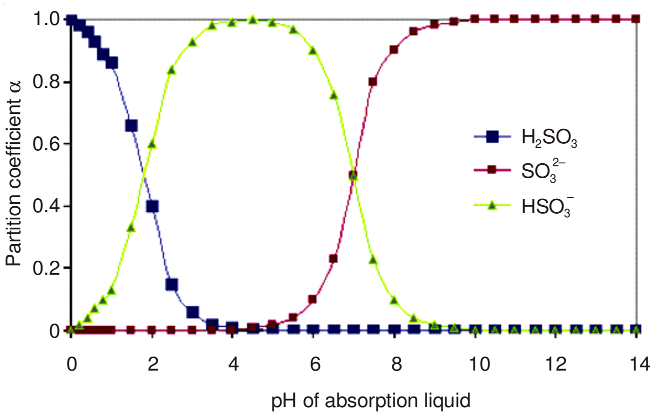

Fig. 4. Distribution curve of H_2SO_3, HSO_3^-, SO_3^{2-} under different pH

Fig. 4 shows, when the pH of absorbent liquid is gradually decreased, SO_3^{2-} in the solution continues to be converted to HSO_3^- and the effective ingredients SO_3^{2-} in the absorbing liquid decreases, resulting in lower desulfurization efficiency. While at high pH values, the concentration of OH^- is higher, the chemical reaction rate is faster, the enhancement factor of the liquid phase mass strengthens, so that the mass transfer resistance of the liquid phase is greatly reduced and ultimately the desulfurization efficiency rises.When the pH dropped to about 6, the large number of HSO_3^- exists in the solution, but HSO_3^- does not have the ability to continue to absorb SO_2, along the chemical reaction, the mass transfer resistance of the liquid phase gradually increases, so the efficiency of desulfurization decreases fast. When the pH is less than 5, due to the chemical reaction is close to completion, the phenomenon that SO_2 further dissolves in the absorption solution belong to physical absorption, the desulfurization efficiency is less than 20 % at this time. The concentration of H_2SO_3 in the absorbing liquid rises, while H_2SO_3 is unstable. At this time a small amount of SO_2 escapes from the absorbing waste liquid by desorption, producing a pungent smell.

In this experiment, the pH value is in the range of 7 to 12. From Fig. 4, when the pH value is within the range of from 7 to 10, the concentration of the solution OH-rapidly increases, SO_3^{2-} in the solution is the dominant with the ability to absorb SO_2 gradually increasing, reflecting that the efficiency of desulfurization increases; and when the pH value is within the range of 10 to 12, the concentrationof SO_3^{2-} in the solution reaches the upper limit and therefore the absorption capacity reaches the upper limit, reflecting that the desulfurization efficiency has no significant increase.

In practice, as long as the pH reaches to 8 or more during the operation and can meet the requirements of the desulfurization, extortionate pH value will increase the investment in equipment and cause strong corrosion of the apparatus. Thus, according to the results of this experiment, the suitable range of the packed tower scrubbing liquid's pH valueis from 8 to 10.

Conclusion

The desulfurization efficiency is increased with the increase of the pH value of the washing solution and the desulfurization efficiency is significantly increased with the pH in the range from 7 to 10; when pH ranges from 10 to 12, the growth trend of the desulfurization efficiency flattens and the desulfurization efficiency goes up to 98 % when the pH value exceeds 10. The results of this paper can provide design reference and theoretical guidance for further design of ship closed-loop scrubbing desulfurization equipment.

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