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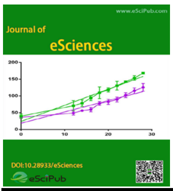

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Study on Decarbonization effect of Ship exhaust Based on Temperature

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ABSTRACT

In order to investigate the effect of temperature of absorption liquid and exhaust temperature of diesel engine on decarbonization efficiency of marine decarbonization tower, the effect of temperature on carbon dioxide absorption efficiency in ship exhaust was studied by means of theory, experiment and simulation. Because of the particularity of the experiment, three exhaust temperatures of 25, 45 and 65 degrees celsius are mainly set up in this paper. The relevant experimental data are collected and analyzed under idle speed, 25% load condition, 50% load condition and 75% load condition, respectively. The experimental results show that under the same load, when the exhaust gas temperature increases, the absorption efficiency shows a downward trend. and the experimental exhaust gas temperature was simulated by Aspen plus software from 35 to 200 degrees celsius respectively. the simulation results show that the absorptivity decreases with the increase of temperature, and the simulation results are consistent with the experimental results, which has a certain reference for the design and operation parameters selection of marine decarburization tower.

Keywords: Ship exhaust; Carbon dioxide absorption; NaOH solution; Aspen plus simulation

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1. Introduction

With the rise of global temperature and the increasing frequency and intensity of extreme meteorological events such as hurricanes, floods and droughts, climate warming has been widely concerned, and reducing CO_2 emissions has become the most urgent environmental problem in the world[1]. It is expected that in the next 50 years, the main body of global energy consumption will still be fossil fuels, with CO_2 emissions accounting for about 80 percent of the total emissions [2-3]. According to the International Energy Agency (2017), global energy-related carbon dioxide emissions increased by 1.4 percent in 2017, and carbon dioxide emissions reached an all-time high of 3.25 billion tons in 2017 [4]. Global CO_2 emissions need to be reduced by more than 60 percent in order to truly curb global climate change. Shipping accounts for about 2%～3% of global CO_2 emissions. If the shipping industry does not control carbon emissions, global ship greenhouse gas emissions are likely to double in 2050. However, if effective means are used to control emissions, emissions may be reduced by 25% to 75% [5]. Reducing CO_2 emissions from ships is of great significance to control global warming and realize green shipping.

Niu Zhenqi, Guo Yancheng et al of Tsinghua University [6] were used to absorb CO_2 in exhaust gas by using MEA solution, NaOH solution and Ammonia micro spray, and the performance of fine spray trapping CO_2 by three reagents was compared. The experimental results show that with the increase of MEA ,NaOH and Ammonia concentration and flow rate, the removal rate of CO_2 is greatly improved. With the increase of the total flow rate of exhaust gas, the removal rate of CO_2 decreased. With the increase of initial temperature, the CO_2 removal rate of ammonia increased. Wang Chuan [7] used aspen plus software and rate-based reaction calculation model to simulate the process of carbon dioxide capture by ammonia method. The effects of absorbent flow rate, temperature and concentration on absorption rate and ammonia loss rate were studied. Storaloff [8] et al studied the feasibility of absorbing CO_2 from air in NaOH spray reactor. In previous years, some scholars have proposed using hydrogen to remove CO_2 from power plant exhaust gas. Diao [9] et al studied the reaction of ammonia absorbing CO_2 by screen plate column. It was found that the efficiency of ammonia removal of CO_2 was over 95%, and the optimum reaction temperature was 33 ℃. Kuntz [10] et al. used spray tower to study the total mass transfer efficiency of MEA- CO_2 absorption process. By comparing the total mass transfer efficiency of packed tower and spray tower, it is concluded that the performance of spray tower is better than that of packed tower, but the experimental data of CO_2 removal rate are not given. In this paper, based on the good absorption ability of NaOH solution to CO_2 gas, the effect of temperature on its absorption efficiency is studied in order to provide guidance for the design and operation parameter selection of marine decarbonization tower.

2.Theoretical analysis of absorption process

2.1 Absorption reaction mechanism

The absorption principle of alkali decarbonization is mainly to absorb CO_2 gas by NaOH solution. The reaction equation is as follows:

$$2NaOH+CO_2=Na_2CO_3+H_2O \qquad (1)$$

When the concentration accumulation of Na_2CO_3 reaches a certain extent, the absorption of CO_2 gas by the solution does not end, because CO_3^{2-} reacts with water to produce HCO_3^- and OH^- ,The solution is still alkaline, in which the ion reaction equation is as follows:

$$CO_3^{2-} + H_2O = HCO_3^- + OH^- \qquad (2)$$

Therefore, the solution at this time has not completely lost the absorption capacity of CO_2 gas, and the absorption process will continue. The absorption process is as follows:

$$Na_2CO_3+CO_2+H_2O=2NaHCO_3 \quad (3)$$

Because of the relative excess of NaOH in the solution, the decarbonization efficiency is studied based on the absorption mechanism of formula (1).

2.2 Mathematical model of absorption efficiency

In order to solve the problem conveniently, the CO_2 in exhaust gas is regarded as ideal gas in this calculation, and the calculation process is as follows: according to the thermodynamic formula:

$$PV = nRT \quad (4)$$

where, P is the gas pressure inside the absorption tower, Pa; V is the volume of gas, m^3; q_v is the gas flow rate per unit time in the exhaust pipe,m^2; τ is time, s; $R = 8.314$, Pa·m^3/(mol·K); T is gas temperature, K. n is the molar number of the exhaust gas,

$$n = m/M \quad (5)$$

Where m is mass of the gas, kg; M is molecular mass, kg/kmol; As a result, the mass of CO_2 can results by Eq.(5)

$$m_{CO_2} = nM_{CO_2} = \frac{PV}{RT}M_{CO_2} \quad (6)$$

3. Absorption Test

3.1 Test method

The 6135 diesel engine in the diesel engine test center of Shanghai Maritime University is used to carry out the real machine test. The influence of sodium hydroxide solution on the absorption efficiency of carbon dioxide emitted by diesel engine exhaust is analyzed by controlling the running load of diesel engine in different temperature range of exhaust gas.

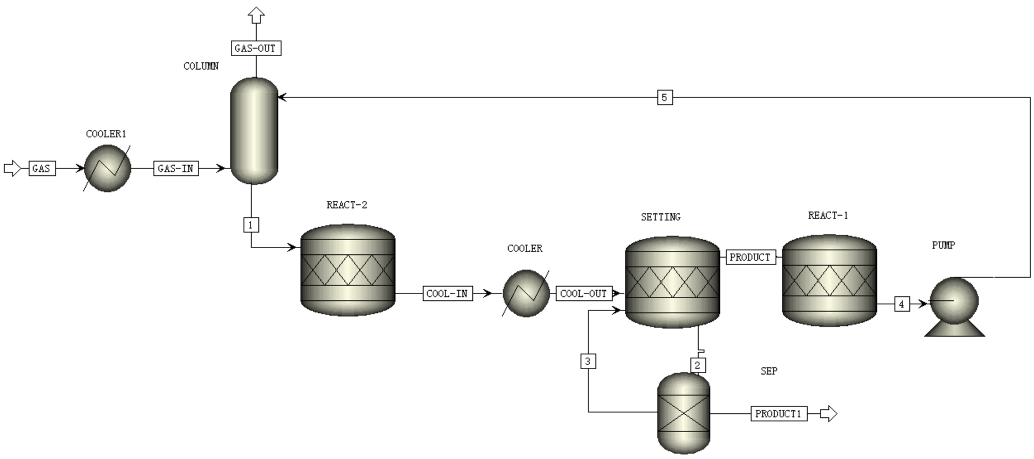

Figure 1. Test flow diagram

Test method: the exhaust gas emitted by 6135 diesel engine in the experiment is too high because of the high exhaust temperature. First, the exhaust gas is cooled, and the exhaust gas enters the condenser cooler1, to reduce the temperature in order to increase the absorption effect of carbon dioxide in the exhaust gas. The cooled gas through the cooler, the column, gas in the absorption tower is absorbed by the absorption liquid transported into the tower by the pump, the rich liquid absorbed by carbon dioxide is discharged from the bottom of the absorption tower into the reactor react-2, cooled by the condenser installed in the reactor, enters the sedimentation tank, recovers the sodium hydroxide in the sedimentation tank, enters the reactor react-1 through the recovered sodium hydroxide, and enters the absorption tower through the pump, The whole process of absorption and recovery of sodium hydroxide is formed.

3.2 Test equipments

In order to ensure the authenticity and reliability of the test, the 6135 diesel engine of Shanghai Maritime University diesel engine test center was used to measure the carbon dioxide composition of exhaust gas by Testo 350 exhaust gas analyzer. The spray tower was selected for the absorption equipment, and the absorption tower was independently developed and designed by our team.

<table>
<tr><td></td><td></td></tr>
<tr><td>Figure 2. 6135 diesel engine</td><td>Figure 3. Testo350 exhaust gas analyzer.</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Fig 4. exhaust coolers.</td><td>Fig 5. 6135 decarbonization tower</td></tr>
</table>

4. Test results and analysis

In order to study the effect of exhaust temperature on CO_2 absorption of diesel engine, marine diesel engine was selected to operate under different working conditions. The exhaust temperature of marine diesel engine was adjusted by cooler to ensure that the exhaust temperature of diesel engine operated at 25℃, 45℃ and 65℃, respectively, and the other experimental conditions remained unchanged. The test results are shown in Fig6.

Figure 6 shows that under idle condition, when the reaction temperature are 25℃, the CO_2 absorption rate in ship exhaust is 27.33%. When the gas temperature reaches 45℃, the CO_2 absorption efficiency in ship exhaust decreases to 21.22%, while when the reaction temperature increases to 65 ℃, the absorption rate decreases to 17.59%. Under 25% load condition, when the gas temperature is 25℃, 45℃ and 65℃, the CO_2 absorptivity is 23.04%,21.62% and 16.46% respectively. Under 50% load condition, when the gas temperature is 25℃, 45 ℃ and 65℃, the CO_2 absorption efficiency is 22.22%,20.09% and 17.26% respectively. Under 75% load condition, when the gas temperature is 25℃, 45℃ and 65℃, the CO_2 absorptivity is 23.59%, 19.30% and 17.48% respectively. It can be seen from the above four groups of test data that when the exhaust gas temperature increases under the same load, the absorption efficiency shows a downward trend, therefore, cooling is beneficial to the absorption of carbon dioxide in the exhaust gas of marine diesel engines.

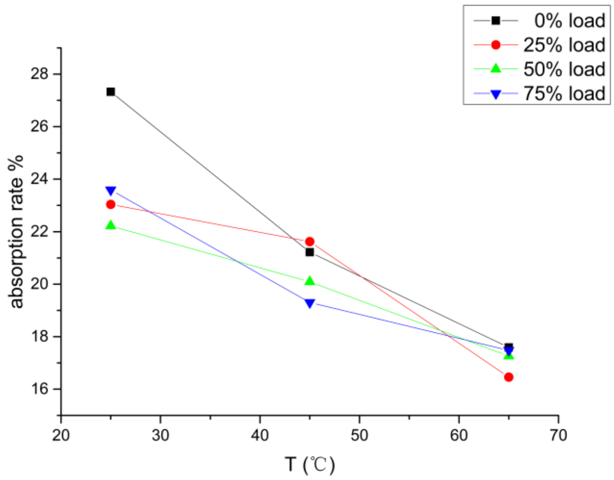

Figure 6. Effect of exhaust Gas temperature on absorption rate under different working conditions

5. Aspen Plus Absorption simulation

On the basis of experimental study on the absorption of CO_2 in ship exhaust gas by NaOH solution, the process is simulated and calculated by aspen plus software, and the simulation flow chart is shown in Fig.7.

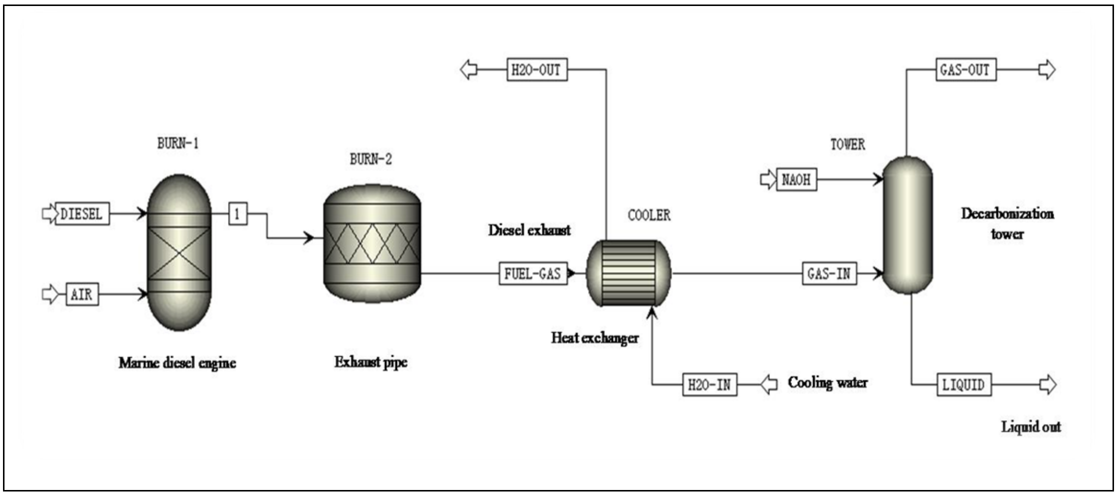

Fig. 7 Simulated flow chart of ship exhaust gas decarbonization.

5.1 Effect of exhaust gas temperature on absorption efficiency.

The simulation results Fig8 show that when the exhaust gas temperature increases, the absorption rate of carbon dioxide decreases, which is the same as the experimental results. Because the simulation experiment is carried out in the ideal state, the simulated absorption rate is slightly higher than the experimental results.

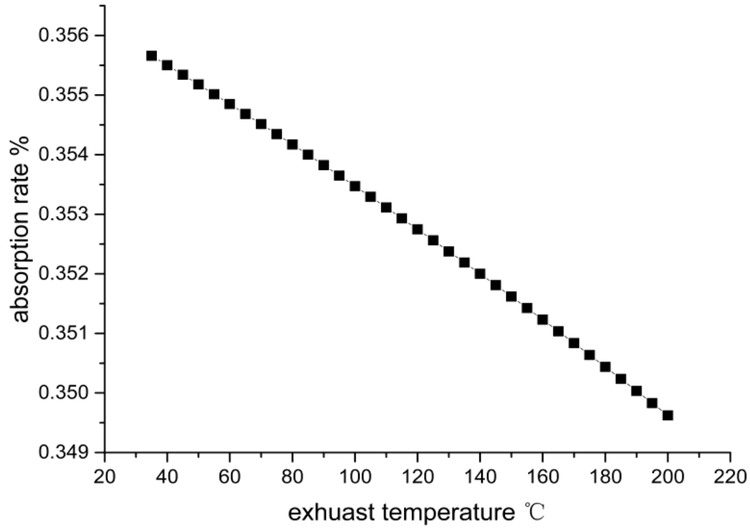

Fig. 8 Simulation of the effect of exhaust gas temperature on CO_2 absorption efficiency

5.2 Effect of temperature of NaOH solution on absorption efficiency

In the simulation, the concentration of sodium hydroxide in 1mol/L and the flow rate of absorption liquid in liquid were selected to study the temperature of sodium hydroxide solution, and the effect on the absorption efficiency of carbon dioxide was analyzed.

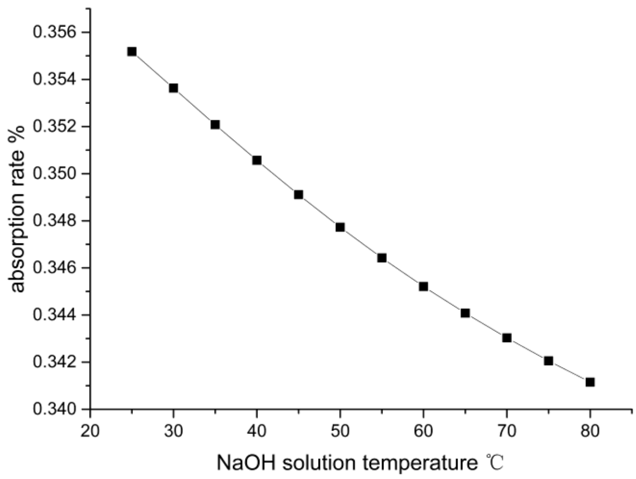

Fig. 9 effect of NaOH solution temperature on CO_2 absorption efficiency

The simulation results from Fig. 9 show that when the temperature of sodium hydroxide solution increases, the absorptivity of sodium hydroxide solution shows a downward trend. Therefore, the absorption temperature should be reduced as much as possible, and then the absorption rate should be improved.

6. Conclusion

In this paper, the influence of temperature on the absorption rate of carbon dioxide in diesel engine exhaust gas is analyzed. Due to the particularity of the experiment, three exhaust temperature ranges of 25°C, 45°C and 65°C are mainly set up in this paper. The relevant experimental data are collected and analyzed under idle speed, 25% load condition, 50% load condition and 75% load condition, respectively. The experimental results show that under the same conditions, when the exhaust gas temperature increases, the absorption efficiency shows a downward trend. The experimental results are simulated by aspen plus software, and the exhaust gas temperature is set at 35°C -200°C respectively. the simulation results show that the increase of temperature is not conducive to the absorption of carbon dioxide. Compared with the experimental results, the effect of exhaust gas temperature on the absorption of carbon dioxide by sodium hydroxide is the same. A simple simulation analysis of the temperature effect of sodium hydroxide is also carried out, and the simulation results can further guide the experiment.

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