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Prediction model for desulphurization efficiency of onboard magnesium-base seawater scrubber

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ABSTRACT

In this study, we developed a prediction model for desulphurization efficiency of onboard magnesium-base seawater scrubber. The effect of various parameters, including liquid to gas ratio (V_L/V_G), pH value and empty container velocity (v_e), on desulphurization efficiency of magnesium-base seawater scrubber was studied using the MiniTab 15 software. Specifically, central composite design coupled with response surface method was used in this model. A prediction model for desulphurization efficiency of magnesium-base seawater scrubber was presented. Analysis of variance of the quadratic model indicates that the model could be used to navigate the design space. The parameters of V_L/V_G and pH are most effective factors affecting the desulphurization efficiency. Within the variation range, v_e has limited influence on desulphurization. The scrubber can be handled at the flow rate of more than 1×10^4 m^3/h. We observed that desulphurization efficiency is more than 90% under the optimized conditions of V_L/V_G at 10.39 L/m^3, pH at 7.66 and v_e between 0.66 and 0.75 m/s.

1. Introduction

Pollution caused by exhaust gas, especially the SO_x composition, from marine diesel engine has become a global concern in recent years (Huang et al., 2008; Lin, 2002). Two sets of emission and fuel quality requirements are defined by Maritime Agreement Regarding Oil Pollution (MARPOL) (73/78) Annex VI: global requirements and more stringent requirements applicable to ships in SO_x Emission Control Areas (SECA). The sulfur limits and implementation dates (Table 1) were needed to control the SO_x emission.

Generally, two pathways can be used to reduce the SO_x emissions from the ships in the SECA and globally. Low sulfur fuel can be used in ships, which can reduce emissions from the sources. If low sulfur fuel is not available, alternative treatment method of onboard scrubbers is also allowed. For example, instead of using 1.5% sulfur fuel in SECAs, ships can install an exhaust gas cleaning system or use any other method to limit SO_x emissions to ≤ 6 g/kWh (as SO_2). Ma et al. (2012) pointed out that a scrubber system using current heavy fuel oils has the potential to reduce SO_x emissions with lower well-to-wake energy consumption and greenhouse gas emissions than switching to production of low sulfur fuels at the refinery. The Exhaust Gas Cleaning Systems (EGCS) market is being driven by regulatory requirements to reduce SO_x emissions of ships.

Seawater is obtained conveniently for maritime vessels. Therefore, much research had already been conducted on seawater scrubber for marine exhaust gas desulphurization (An and Nishida, 2003; Caiazzo et al., 2012a, 2012b, 2013a, 2013b). Some others focused on fresh water doped with caustic soda and spray-dry method (Anttila et al., 2008; Scala et al., 2005). An extensive survey (SOCP, 2011) of the available scrubbers provided by Ship Operations Cooperative Program (SOCP) revealed that scrubbing technologies were generally categorized as either wet or dry systems. There was essentially one option for the dry system (chemisorptions with $Ca(OH)_2$ or $NaHCO_3$) whereas the wet system had at least three variants including open loop system, closed loop system and hybrid system (Table 2).

All the technologies were reported to be suitable to fulfill MARPOL Annex VI fuel sulfur limits for 2016 (Hombravella et al., 2011), whereas the inherent disadvantages should be taken into consideration. The closed loop system was noted for high desulphurization efficiency, however, the operation cost was relatively high for expensive NaOH (0.2€/kg). The seawater scrubber seems to be the most economical way, but the large quantity of wastewater turns out to be a bottle-neck (Andreasen and Mayer, 2007). The $CSNO_x$ method was reported to absorb SO_x as well as NO_x and CO_2, but there was no comparable reference on land. Without further empirical evidence, it would be premature for owners to commit to this solution. The hybrid system means switching to open loop system or closed loop system at open sea or sensitive sea, which inevitably possesses both

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advantages and disadvantages of open and closed loop system. Compared with wet scrubbers, dry scrubbers have lower investment costs but higher running costs, and require more installment space.

Table 1
MARPOL Annex VI fuel sulfur limits.

Date	SECA (%)	Global (%)
Sulfur limit in fuel		
2000	1.5	4.5
2007 2012	1.0	3.5
2015 2020[a]	0.1	0.5

[a] Alternative date is 2025, to be decided by a review in 2018.

Table 2
Main marine scrubbing technology.

Technology	Characteristic	Company
Closed loop system	Fresh water addition of NaOH	Wärtsilä
Open loop system	CSNO$_x$-ultra-low frequency electrolysis system	Ecospec
	Seawater scrubber	Hamworthy Krystallon
	Seawater scrubber & MES EcoSilencer	Marine Exhaust Solutions
Hybrid system	Switch to open or closed loop in different areas	Aalborg Industries
Dry system	Calcium hydroxide: ⌀2–8 mm spheres	Couple Systems DryEGCS

To balance efficiency and costs, a novel wet scrubber system with MgO and seawater (M&S) as desulfurizer was established (Zhu et al., 2011).The running cost of M&S scrubber technology is relatively lower with the use of natural alkaline of seawater and MgO (0.1€/kg). In addition, the wastewater production of M&S scrubber is far less than the open loop system. The preliminary experimental data has shown satisfactory desulphurization efficiency (Tang et al., 2012). In order to optimize this system, a prediction model for desulphurization efficiency of M&S scrubber was established tentatively and the effect of different parameters on desulphurization efficiency would be discussed.

2. Material and methods

2.1. Magnesium-base seawater scrubber

We independently designed a wet scrubber system and applied this system for flue gas desulphurization on Binghe container ship, which belongs to China Ocean Shipping Company (COSCO) Container Lines Co., Ltd. The flow chart of M&S scrubber system is shown in Fig. 1.

The flue gas exhausted by the main engine was partially led to the wet scrubber system via a bypass pipe (Fig. 1). In the spray tower, the black flue gas was cooled, cleaned and exhausted. $Mg(OH)_2$ slurry, prepared in the hydration reactor with MgO powder (200 mesh, Yingkou, China) and seawater, was fed to adjust the pH value of spray liquid. The liquid to gas ratio (V_L/V_G) and flux of flue gas were adjusted by control a spray pump and a fan. The flux of flue gas divides by 2.25 m^2 (the cross-sectional area of spray tower) is the empty container velocity (v_e). The wastewater was

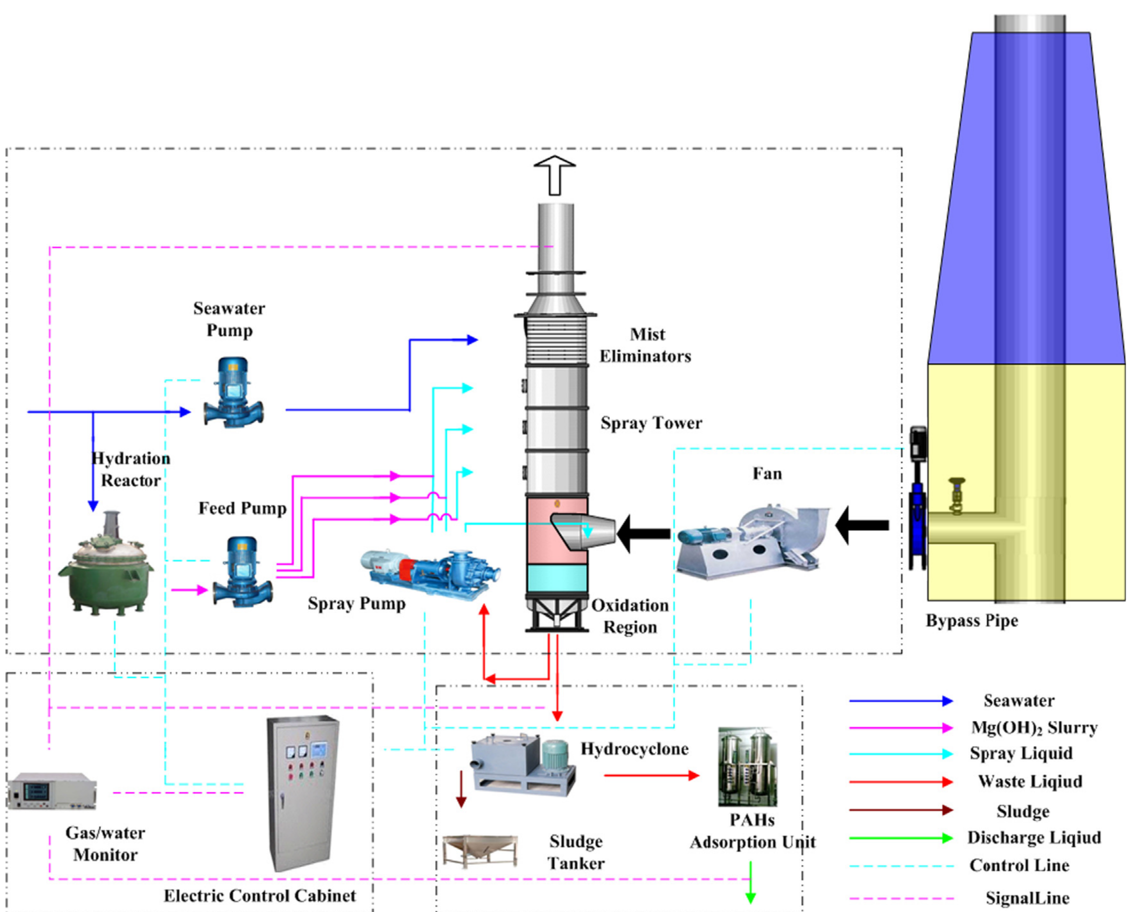

Fig. 1. Flow chart of M&S scrubber system.