การกำจัดไอระเหยของ Butyl Oxitol จากโรงงานเคลือบผิวโลหะด้วย Wet Scrubber

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บทคัดย่อ

ไอระเหยของสาร ethyl glycol monobutyl ether หรือ butyl oxitol (BO) เป็นสารอินทรีย์ที่ระเหยง่าย ละลายน้ำได้ และมีความเป็นพิษ การกำจัดสารดังกล่าวด้วยเครื่อง wet scrubber เป็นวิธีการที่น่าสนใจเพราะเป็นวิธีการที่มีค่าใช้จ่ายต่ำและเกิดการสูญเสียความดันน้อย งานวิจัยนี้ได้ทำการศึกษาถึงปัจจัยต่างๆ ที่มีผลต่อประสิทธิภาพในการดูดซับและสภาวะที่เหมาะสมในการดำเนินการ การทดลองด้วยเครื่อง wet scrubber ที่โรงงานเพื่อศึกษาผลของอัตราการไหลและความเข้มข้นของ BO จากการทดลองพบว่า การดูดซับในช่วงแรกของทุกอัตราการไหลมีประสิทธิภาพถึงร้อยละ 100 จากนั้นประสิทธิภาพในการดูดซับจะลดลงเป็นร้อยละ 60, ร้อยละ 60 และร้อยละ 30 สำหรับอัตราการไหล 24.7, 19.7 และ 14.6 ลบ.ม./ชม. ตามลำดับ ในส่วนของการทดลองด้วยเครื่อง wet scrubber ขนาดเล็กในห้องปฏิบัติการ จากการทดลองพบว่าประสิทธิภาพในการดูดซับจะเพิ่มขึ้นเมื่ออัตราการไหลของไอระเหยและ Loading ratio เพิ่มขึ้น แต่ประสิทธิภาพกลับลดลงเมื่ออุณหภูมิเพิ่มขึ้น นอกจากนี้ประสิทธิภาพในการดูดซับจะลดลงเมื่อความเข้มข้นของ BO ในน้ำมีค่า 12,000 พีพีเอ็ม ส่วนค่าอัตราการดูดซับในเฟสก๊าซและเฟสของเหลวมีค่าเท่ากับ 1.89×10^{-5} กก./ลบ.ม.วินาที และ 1.92×10^{-5} กก./ลบ.ม.วินาที ตามลำดับ จากผลของการจำลองพบว่า มีค่า loading ratio 2.5 ล./ลบ.ม. และควรเปลี่ยนน้ำหลังจากใช้งานแล้วสามวัน

คำสำคัญ : การดูดซับ / การเคลือบผิวโลหะ / การกำจัดสารอินทรีย์ที่ระเหยง่าย / Wet scrubber / Butyl oxitol

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Removal of Butyl Oxitol from Metal Coating Factory by Wet Scrubber

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Abstract

The ethyl glycol monobutyl ether (butyl oxitol, BO), a volatile organic compound, is a toxic and water soluble substance. The removal of this pollutant by using a wet scrubber is an interesting technique due to its low operation cost and pressure drop. The aims of this study were to investigate the absorption efficiency of the wet scrubber and to determine the optimum operating conditions, which cause minimum effect to production line. The effect of solution flow rate and dissolved BO concentration on absorption efficiency was conducted in a pilot plant wet scrubber at the site. It was found that the absorption efficiency of all water flow rates achieved 100% at the beginning of operation. Then, they gradually decreased and reached the minimum at 60%, 60% and 30% for water flow rate of 24.7, 19.7, and 14.6 m^3/h, respectively. A wet scrubber system with water recycle at laboratory scale was conducted to study the effect of BO vapor flow rate at various water temperatures and loading ratios on the solubility of BO. It was indicated that the absorption capacity of BO increased with increasing vapor flow rate and loading ratio but decreasing with increasing of water temperature. Moreover, the absorption efficiency significantly declined when dissolved BO concentration reached 12,000 ppm. BO absorption rate in gas and liquid phase were 1.89×10^{-5} kg/m^3 (column volume).s and 1.92×10^{-5} kg/m^3 (water volume).s respectively. The simulation result showed that the wet scrubber was subject to loading ratio of 2.5 l/m^3. The water should be changed on the third day of operation.

Keywords : Absorption / Metal coating / VOC removal / Wet scrubber / Butyl oxitol

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1. Introduction

The volatile organic compounds (VOCs) emissions are mostly discharged from many chemical processes such as metal coating plant, color and painting, and petrochemical industry. As a response to increasingly stringent regulations for VOCs emissions, many researchers develop technologies that are both efficient and cost effective. The treatment of such emissions using conventional technologies such as incineration [1] or absorption [2] is particularly expensive and energy exhausting. In this context, the liquid absorption in a wet scrubber gains the interest due to its low operation cost and pressure drop. The wet scrubber was also examined for carbon dioxide, ammonia, and hydrogen sulfide removal with high efficiency.

The metal coating sheets process of Sahatharawat Co. Ltd. was investigated. The process is shown in Fig. 1. Ethylene glycol monobutyl ether (BO) that is glycol ether compounds and easily dissolves in water is used as organic solvent. During drying in an oven at 200 °C, the solvent evaporates to vapor emitting to environment resulting in air pollution problem. In order to remove the VOC, a liquid wet scrubber using water as an absorption medium was introduced.

In this study, the effect of system parameter on the operation of the pilot plant wet scrubber was investigated. These parameters were water flow rate and dissolved BO concentration. Since some operating parameters of the pilot plant unit such as BO flow rate and temperature and loading ratio could not be adjusted during production, a laboratory scale wet scrubber was used instead. Finally, the efficiency of the wet scrubber was predicted by mathematical model.

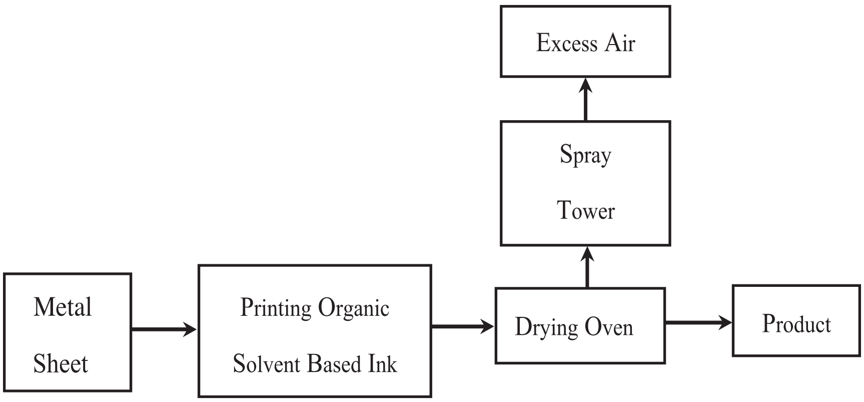


Fig. 1 Process diagram of metal coating sheet

2. Materials and Methods

Ethylene glycol monobutyl ether (butyl oxitol, BO) was commercial grade and obtained from M-line Co. Ltd. Gas detector cylinder and isopropyl alcohol detector tube (IM00113LJI, 50-80 ppm) was purchased from Wako chemical. All other chemicals were analytical grade purchased from Sigma.

Absorption with a pilot plant wet scrubber

Figure 2 describes the diagram for absorption of a pilot plant wet scrubber. A cylindrical body of wet scrubber was made of carbon steel, 3.7 m internal diameter and 6 m height. An outlet pipe (1 m diameter and 10.65 m height) was mounted at center. Inside the unit, 37 coarse flow spray nozzles were installed. The demister was set up inside the outlet pipe to prevent spilling of water droplet.

Firstly, vapor of BO was fed into the top of tower by a blower at flow rate of 167 m^3/min. The incoming BO-laden air (BO concentration of 111.50-269.88 ppm) flows downward in a spiral path. The centrifugal force developed in the vortex tends to move the air upward and back into the outlet, then, leaves through environment. Consequently, 15 m^3 of tap water was sprayed at various flow rates into the tower through 37 nozzles. The water flow rates of 14.6, 19.6, and 24.7 m^3/h were obtained by adjusting the valve at the by pass pipe (no. 6) by which pressure drop was changed to 1, 1.5 and 2 kg/cm^2, respectively. The sprayed water moves downward and returns back to a water storage tank. The wet scrubber was operated 12 hours per day. The sampling period was 6 hours per day. The outlet air, BO-laden water, pH and temperature were sampled every half-hour at beginning of operation (3-4 days) and every hour for the last period of operation. The BO-laden air and outlet air were taken at sampling ports (no. 1 and 2). BO concentration in air was then measured by a gas detector cylinder connected with isopropyl alcohol detector tube. For BO-laden water was taken from liquid sampling port (no. 5). Then, the concentration was determined by Gas Chromatography (GC), HP5890, FID Capillary Column. All measurement was done on the sampling day.

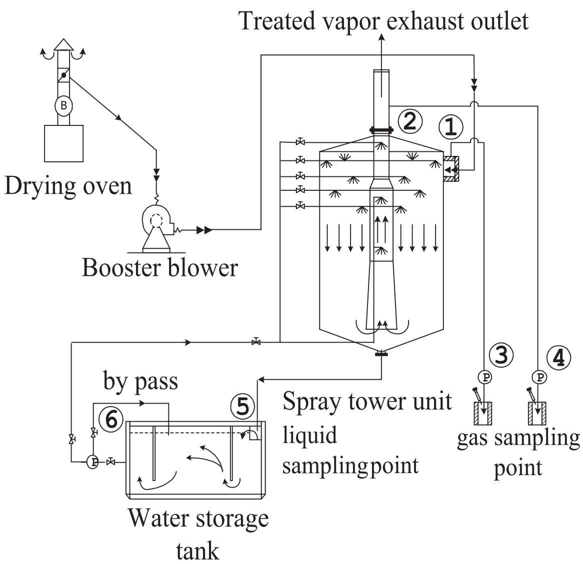


Fig. 2 Diagram of pilot plant wet scrubber

BO absorption in a laboratory wet scrubber

The absorption at laboratory scale was carried out using a test rig shown schematically in Fig. 3. The effect of BO flow rate was examined at 14.3, 17.9, and 20 m^3/h, while water flow rate and temperature was kept constant at 943.8 m^3/min and 30 °C, respectively. For the effect of temperature study, temperature of 30, 40, and 50 °C was investigated, while the operating condition was the same as mentioned in the effect of BO flow rate.

Absorption efficiency

The wet scrubber absorption efficiency was calculated from equation (1).

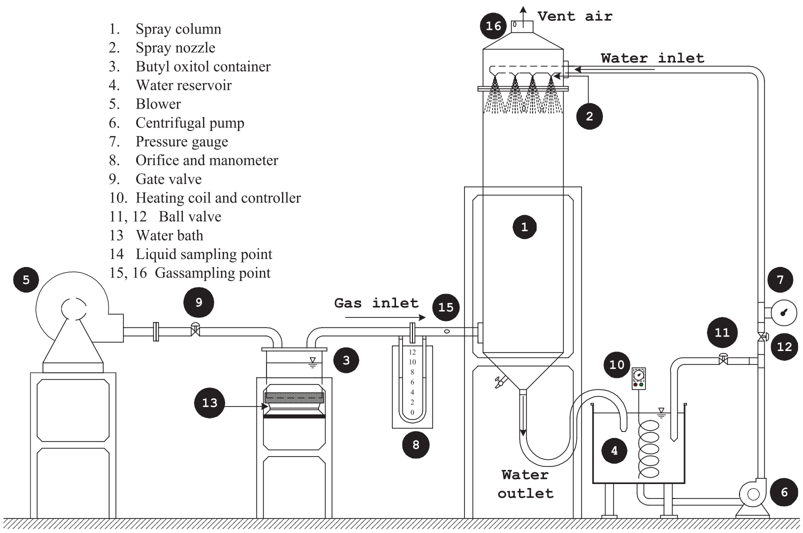


Fig. 3 Laboratory scale wet scrubber

$$Adsorption\ \ efficiency = \left[1 - \frac{BO\,oulet\,concentration}{BO\,inlet\,concentration}\right] \times 100 \qquad \textbf{(1)}$$

3. Results and Discussion

1. Study of the pilot scale wet scrubber:

Effect of water flow rate

The performance of the wet scrubber at various flow rates is shown in Fig. 4. At the beginning period, the absorption efficiency achieved 100% with all flow rates because of using fresh water. Therefore, BO was not detected in outlet air. However, the higher dissolved BO in water resulted in reducing the absorption efficiency. After 10 hours, BO was detected in outlet air. At the end of operation, the efficiency decreased to 60% at the flow rate of 24.7 m^3/h and 19.7 m^3/h while it reduced to 30% at the flow rate of 14.6 m^3/h.

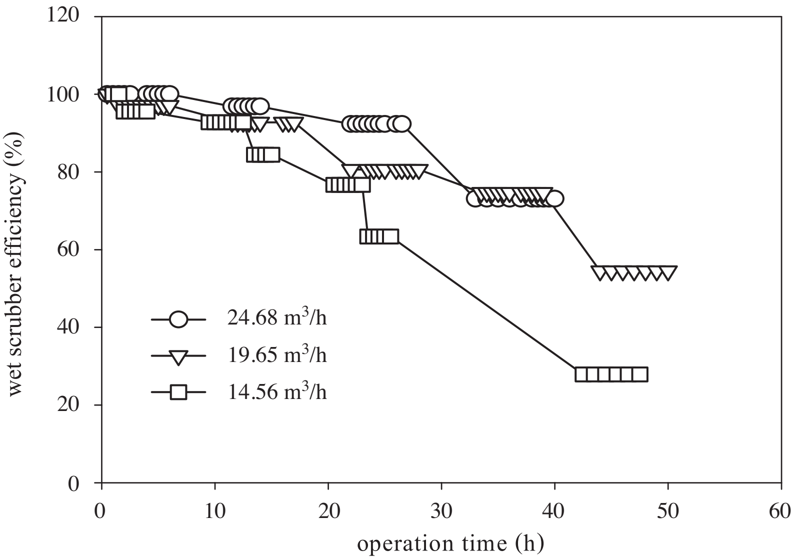


Fig. 4 Performance of the pilot scale wet scrubber at various flow rates.

The absorption of VOC with water is mass transfer of solute from gas phase crossing interface to liquid phase. BO is a high soluble solute in water and has no reaction with other species. Therefore, the absorption efficiency should depend on mass transfer across the interface. In this system, the resistance of transfer should be at gas phase side, which means gas phase controlling. From mass balance, the overall volumetric mass transfer coefficient on gas phase ($K_g a$) can be determined by using equation (2) [3].

$$K_g a = \frac{G(y_{A1} - y_{A2})}{zP(\Delta y_A)_{ln}} \quad \textbf{(2)}$$

Where G is gas molar flux (kmol/m^{2}s), Z is height of wet scrubber (m), P is pressure of system (1 atm), y_{A1} and y_{A2} are mole fraction of BO in inlet and outlet gas, respectively. $(\Delta y_A)_{ln}$ is obtained from equation (3).

$$(\Delta y)_{ln} = \frac{(y_A - y_A^*)_1 - (y_A - y_A^*)_2}{\ln\left[\frac{(y_A - y_A^*)_1}{(y_A - y_A^*)_2}\right]} \quad \textbf{(3)}$$

where y* is mole fraction of BO at steady state.

Figure. 5 shows the effect of water flow rate on overall volumetric mass transfer coefficient. It was found that the overall volumetric mass transfer coefficient increased with increasing of water flow rate. The same trend was also reported by the study in packed column [4]. At molar water flow rate of 125.4 kmol/m^2.s (or water flow rate of 24.7 m^3/h), $K_g a$ values were higher than flow rate of 19.7 and 14.6 m^3/h. The diameter of water stream passing through a spray ball at high flow rate should be narrower than low flow rate resulting in small water droplet that has higher surface area. Moreover, the small droplet takes longer contact time before falling to the bottom of the scrubber. When considering the variation of $K_g a$ over operation time, $K_g a$ decreased with increasing of operation time. The lower driving force of BO concentration should cause the reduction of K_ga values.

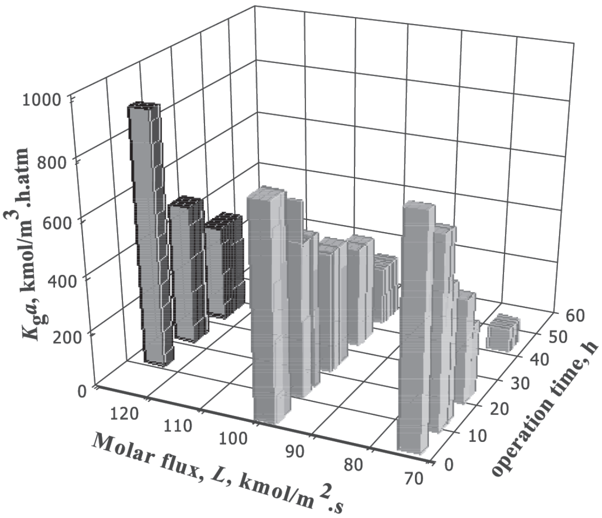


Fig. 5 Effect of water flow rate and operation time on overall mass transfer coefficient of the pilot scale wet scrubber.

Effect of dissolved BO concentration

The solubilization of BO concentration in water versus operation time is shown in Fig. 6. At the beginning period (0-20 h), BO concentration in water increased dramatically with all flow rates. However, the concentration slightly increased after 25 h and reached plateau at 30 h and 45 h for the flow rate of 24.7, 19.7 and 14.6 m^3/h, respectively. Figure 7. shows the removal efficiency relating to dissolved BO concentration. The removal efficiency was in the range of 80-100% when dissolved BO in water was less than 13,000 ppm. At flow rate of 14.6 m^3/h, the efficiency was dramatically decreased when BO concentration was more than 15,000 ppm. In this system, the spray water was reused resulting in accumulation of BO in the water, which should reduce the driving force of BO transferring. Therefore, the higher BO concentration in water dissolved, the lower removal efficiency was obtained. The same trend was also reported in gas desulphurization which an increase in the inlet flue gas SO_2 concentration led to a decrease in SO_2 removal [5].

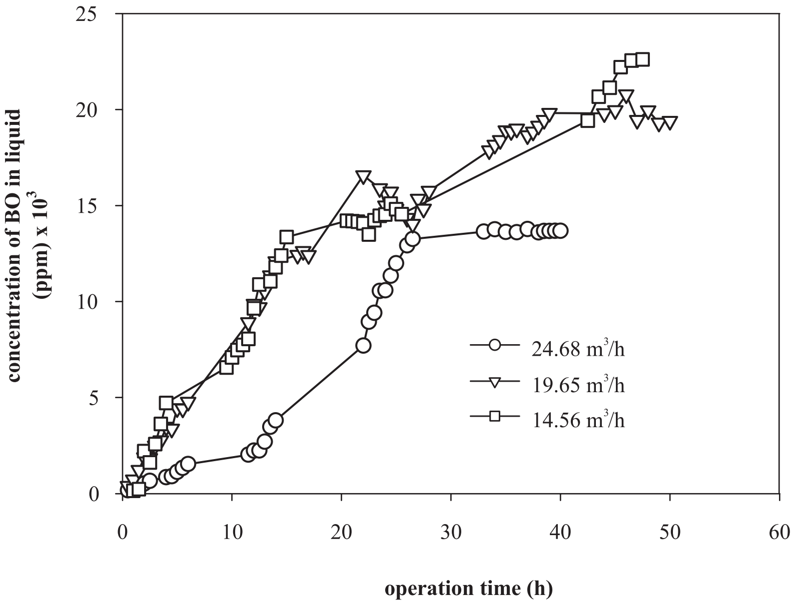


Fig. 6 Dissolved BO in water at various operation times of the pilot scale wet scrubber.

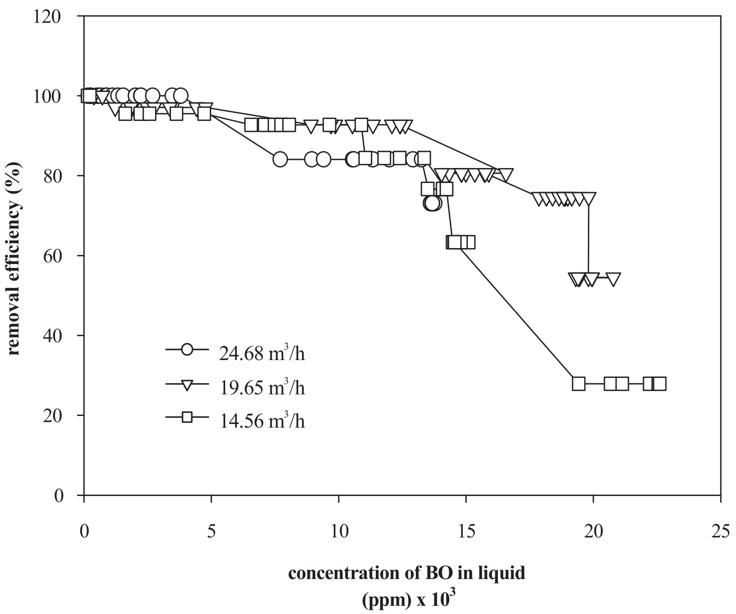
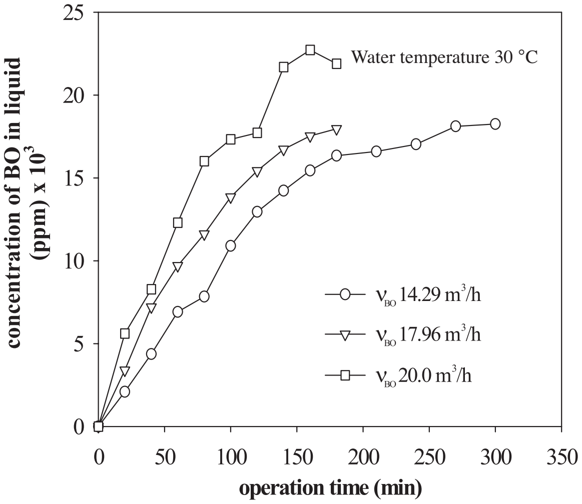


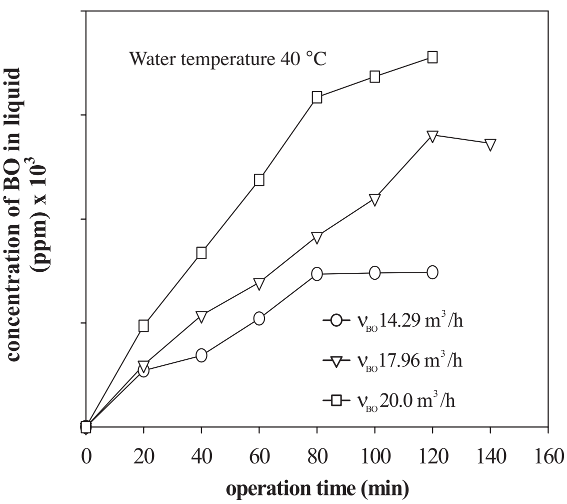
Fig. 7 Effect of BO concentrations on removal efficiency of the laboratory scale wet scrubber.

2. *Study of the laboratory scale wet scrubber: Effect of BO flow rate and temperature*

The effect of BO flow rate on absorption efficiency at various temperatures is shown in Fig. 8 a-c. It was found that at the same temperature (30 °C) the BO concentrations in liquid phase with flow rate of 20 m^3/h was higher than the others flow rate. At high flow rate, more amount of BO was introduced into the wet scrubber resulting in higher dissolved BO concentration. Moreover, increasing of gas flow rate reduces the thickness of gas film and increase the level of turbulence, both of which enhance the transport of solute between the gas and liquid phase [6]. The same trend was also found at the temperature of 40 and 50 °C. For the affect of temperature, at the same flow rate the BO concentration in liquid phase at 30 °C was the highest. As the BO absorption in liquid was exothermic reaction, therefore, the lower the temperature the higher dissolved BO concentration should be obtained.



(a)



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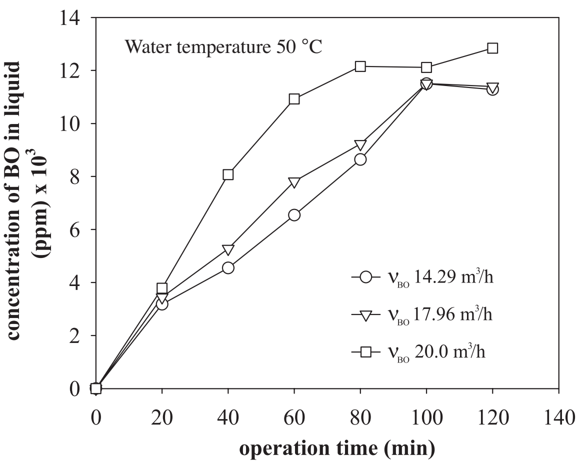

(c)

Fig. 8 Effect of BO flow rate on absorption efficiency of laboratory scale wet scrubber at various temperature (a) 30 °C (b) 40 °C and (c) 50 °C

Effect of water to BO flow rate ratio (loading ratio)

Figures 9 and 10 are shown the effect of water to BO flow rate ratio on BO concentration in water and air, respectively. At the loading ratio of 1, BO concentration in liquid was minimal whereas it was maximal in air. When the operation time increased, the dissolved BO rate in water increased sharply at the beginning period and then reached steady state. Moreover, the absorption efficiency increased with increasing of loading ratio. At high loading ratio, this caused more small water droplet because of increasing water flow rate and injection pressure [6] which resulted in higher interfacial area and mass transfer [7]. Vinci et al. [7] reported that performance of spray tower in oxygen absorption was improved by increasing water flow rate. Although the loading ratio of 3 gave the highest BO concentration in water, the small droplet was blown out with air. This causes the loss of water during operation. The loading ratio was normally designed in the range of 0.4-2.7 l/m^3.

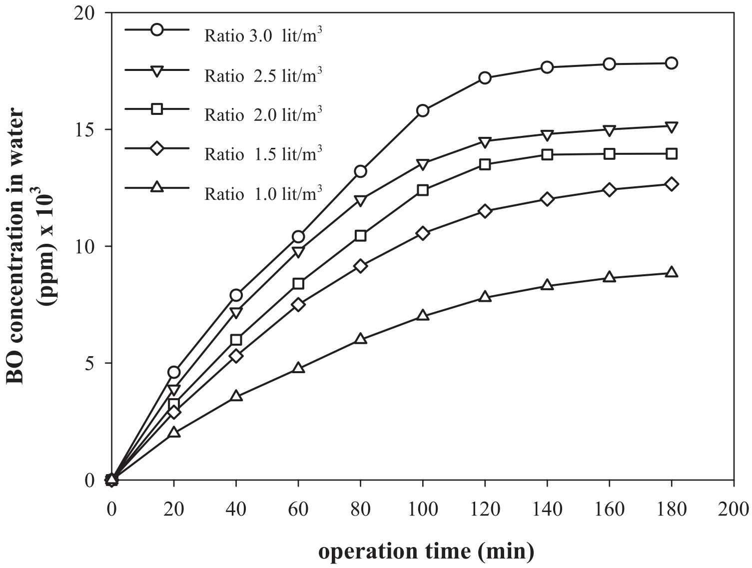

Fig. 9 Effect of loading ratio on BO concentration in water of the laboratory scale wet scrubber

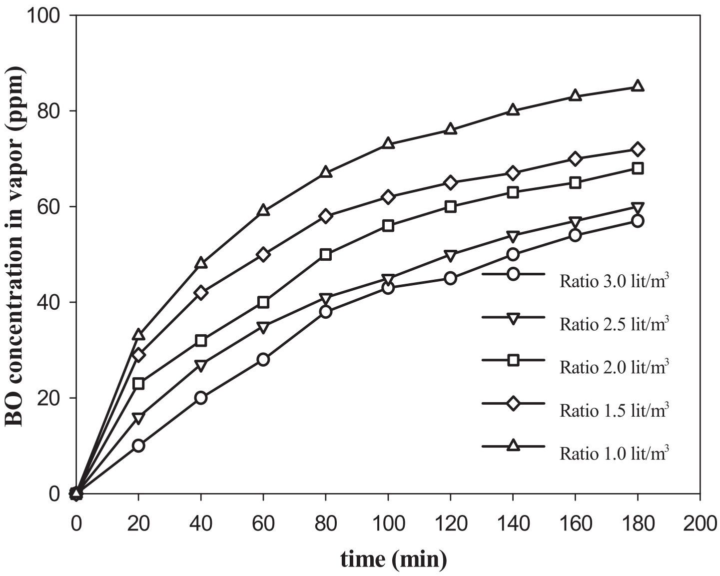

Fig. 10 Effect of loading ratio on BO concentration in air of the laboratory scale wet scrubber

Rate of BO absorption

In this study, the absorption rates of BO in air and water operated in the laboratory scale wet scrubber were determined and compared with the pilot plant scale wet scrubber. The operating conditions were loading ratio in the range of 1.0-2.5 l/m^3, inlet BO concentration of 115 ppm and BO flow rate of 0.005 m^3/s. The absorption rate of BO in air and water can be determined from mass balance at controlled volume as shown in equation (4) and (5).

$$-r_B = \frac{V_s \dfrac{dC_B}{dt} - \left[(\nu_B C_B)_{in} - (\nu_B C_B)_{out}\right]}{V_s} \quad \textbf{(4)}$$

$$r_w = \frac{V_D \dfrac{dC_w}{dt} - \left[(\nu_w C_w)_{in} - (\nu_w C_w)_{out}\right]}{V_W} \quad \textbf{(5)}$$

where r_B is the absorption rate of BO in air per volume of wet scrubber (kg/m^3.s), r_W is the absorption rate of BO in water (kg/m^3.s). Table 1 presents the equilibrium BO concentration and the absorption rate of BO in water and air from the laboratory scale wet scrubber. It was found that at loading ratio of 1.5, which had the equilibrium BO concentration of 12,000 ppm, the rate of absorption in water started to decline. Therefore, the water should be changed at the dissolved BO concentration of 12,000 ppm

Table 1 Absorption rate of BO in the laboratory scale wet scrubber

Loading ratio	BO concentration in water at steady state	R_W x 10^{-5} (kg/m^3.s)	R_B x 10^{-5} (kg/m^3.s)
1.0	8,800	1.20	1.40
1.5	12,000	1.60	1.65
2.0	14,000	2.10	1.80
2.5	15,000	2.50	2.30

Prediction of BO absorption efficiency

The prediction of BO concentration in water and air should be performed in order to estimate the maximum operation time. The equation (4) and (5) were used to determine BO concentration in air and water, respectively. The prediction was based on the following assumptions;

1. BO inlet concentration was 115 ppm or $5.635 x 10^{-4}$ kg/m^3.
2. Total recycled water volume was 15 m^3. Wet scrubber volume was 57.73 m^3.
3. Loading ratio was 2.5 l/m^3. The water and BO flow rate were $4.62 x 10^{-4}$ m^3/s and 2.78 m^3/s, respectively.
4. The maximum BO concentration in water was 12,000 ppm.
5. The absorption rate of BO in water and air were fixed at $1.89 x 10^{-5}$ and $1.92 x 10^{-5}$ kg/m^3.s, which were averaged value at loading ratio of 2.5 from Table 1 and Table 2.

Table 2 Absorption of BO in the pilot plant scale wet scrubber

Loading ratio	R_W x 10^{-5} (kg/m^3.s)	R_B x 10^{-5} (kg/m^3.s)
1.5	1.0	1.6
2.0	1.2	2.1
2.5	1.7	2.4

Fig. 11 shows the predicted BO concentration in water compared with data from a pilot plant wet scrubber. The trends of both data sets were similar during 0-30 h. The BO concentration of a pilot plant wet scrubber reached plateau at 12 kg/m^3 within 30 h while at the same concentration the prediction time was obtained at 37 h. The BO concentration in air from the laboratory and pilot plant wet scrubber was compared with the prediction data, as shown in Fig. 12. It was found that the prediction data was close to the pilot plant data at equilibrium period. However, the error between prediction and pilot plant data at transient period should be caused by the actual rate of adsorption in air was lower than data from prediction.

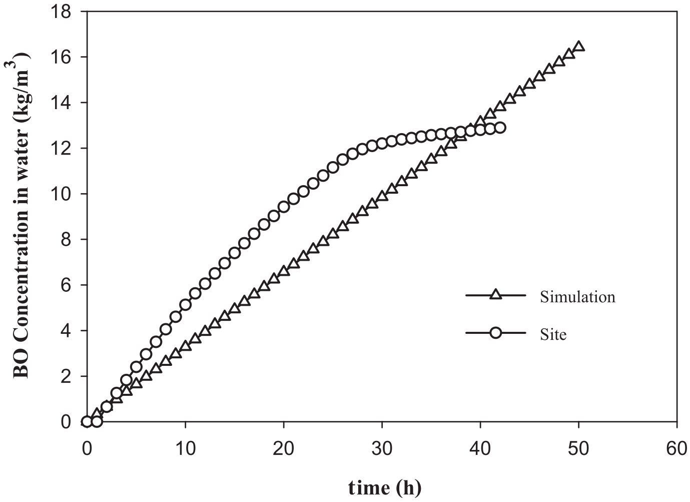

Fig. 11 BO concentration in water from the pilot scale wet scrubber compared with predicted data.

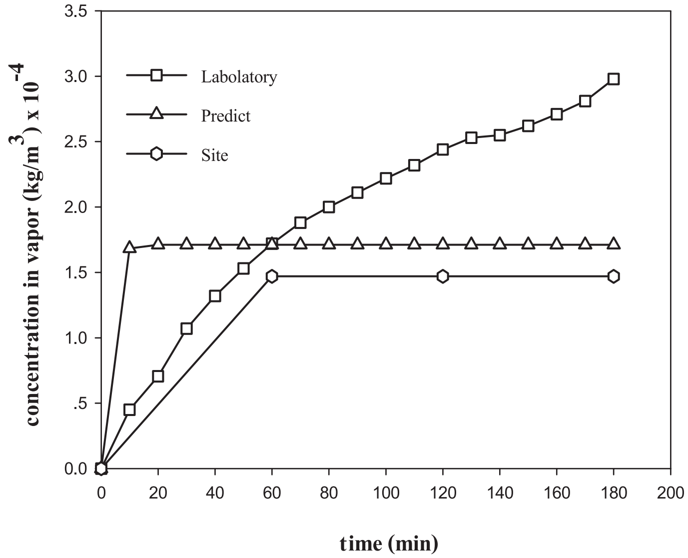

Fig. 12 BO concentration in air from the pilot scale wet scrubber compared with data from the laboratory scale wet scrubber and predicted data.

5. Conclusions

1. Water was a good solvent for BO absorption. The efficiency of wet scrubber was achieved 100% at beginning of operation. Then, it gradually decreased to 30-60%.

2. The absorption of BO increased with increasing of loading ratio.

3. The optimum operation of the pilot plant was an operating time of 3 days with water volume of 15 m^3, inlet water flow rate of 24.68 m^3/h, and loading ratio of 2.5 l/m^3. The absorption rate of BO in water and air at this condition were $1.89x10^{-5}$ and $1.92x10^{-5}$ $kg/m^3.s$.

6. Acknowledgement

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7. References

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