Supporting Information

For

Experimental study on the selective removal of SO_2 from a ship exhaust gas stream using a membrane contactor

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Investigating the membrane pore blockage issue: solubility of NaOH and Na_2SO_3 in water

The aqueous solutions of NaOH and Na_2SO_3 reacts with SO_2 to form salts having high solubility in water, so that there is no problem of precipitation in the membrane pore. Table S1 provides a solubility table for the absorbents and their reaction products used in the SO_2 removal experiments.

The amounts of "Na" in the absorbent can be calculated using Equations 1 and 2.

$$\frac{0.2mol}{1L}\text{NaOH} \times \frac{1molNa_2SO_3}{2molNaOH} \times \frac{126g}{1mol}Na_2SO_3 = 12.6\frac{g}{L}Na_2SO_3 \qquad (1)$$

$$\frac{0.2mol}{1L}Na_2SO_3 \times \frac{2molNaHSO_3}{1molNa_2SO_3} \times \frac{104g}{1mol}NaHSO_3 = 41.6\frac{g}{L}NaHSO_3 \qquad (2)$$

The solubility of Na_2SO_3 inn the water at 20 ^{o}C is 270g/L. However, the amount of the Na_2SO_3 formed is just 12.6 g/L that is almost 21 times lower than the solubility value. The solubility of $NaHSO_3$ in the water at 20 ^{o}C is 420g/L. However, the amount of the $NaHSO_3$ formed is just 41.6 g/L that is almost 28 times lower than the solubility value. This means that the formed Na_2SO_3 and $NaHSO_3$ will easily dissolve into the water and there will not be any solid salt in the membrane to deposit of clog the pores.

Absorbents & Products	Solubility		
	0°C	20°C	100°C
NaOH (Sodium hydroxide)	418 g/L	1110 g/L	3370 g/L
Na_2SO_3 (Sodium Sulfite)	140 g/L	270 g/L	260 g/L
$NaHSO_3$ (Sodium bisulfite)	-	420 g/L	-

Table S1. Absorbents and product solubility table for membrane contactor.

Gas flow rates and liquid flow rates used to achieve L/G ratios of 1-5.

Table S2. Feed gas and absorbent flow rates used to achieve different L/G ratios

L/G ratio	Gas flow rate (L/min)	Liquid flow rate (mL/min)
1	16.6	16.6
2	16.6	33.2
3	16.6	49.8
4	16.6	66.4
5	16.6	83

Effect of L/G ratio on pH change of liquid absorbent

The pH of the absorbents were measured using a pH meter (Seven Compact S220, Mettler Toledo). For data reliability, the pH values were measured five times and the average values have been reported. The SO_2 is an acidic gas and when absorbed by the alkali absorbent, the pH value of the liquid absorbent should decrease. The pH values were measured when the absorbent achieved full saturation of SO_2 (SO_2 concentration in the outlet gas flow was constant). Assuming an ideal gas condition, with feed gas containing 1000 ppm of SO_2 and the L/G ratio is 1, the SO_2 flow rate reacting with the liquid absorbent is 0.016 L/min. Thus, 0.0065 moles of SO_2 react with the liquid absorbent per minute. Then, one mole of SO_2 molecule is ionized to SO_4^{2-} and two protons (H^+) are released, which are neutralized with two moles of base ion. The measured change in absorbent pH at different L/G ratios is presented in Fig. S1. It can be seen from the figure that the pH of DW was almost unchanged after SO_2 absorption, whereas the pH values for the aqueous NaOH and Na_2SO_3 solutions slightly increased from 6.7 and 6.3 to 7.4 and 6.8, respectively. The reason for the increment in the pH value is that, with increase in the L/G ratio, the amount of the fresh liquid absorbent increased which, as a result, increased the pH of the absorbent.

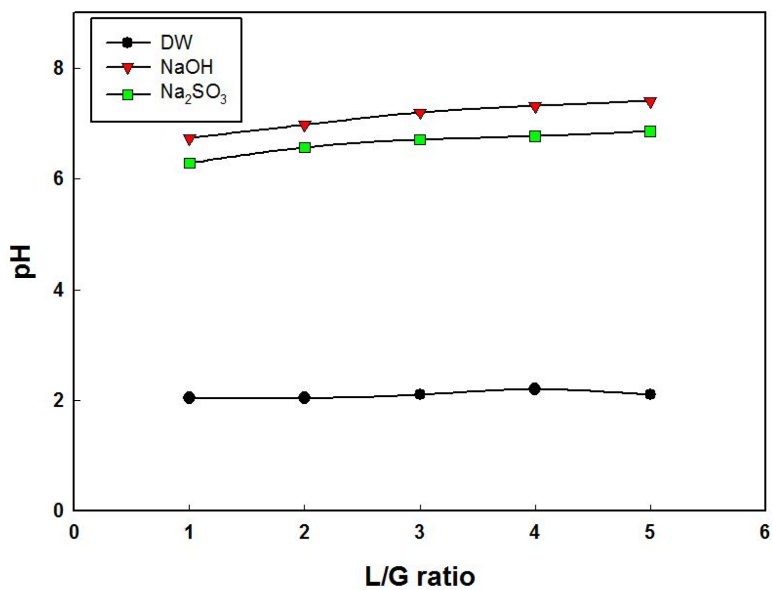

Fig. S1. pH change of liquid absorbent at different L/G ratios.

Long-term stability test

The durability of a membrane is crucial for its commercial application. The durability of the membrane module used in this study was tested for 96 h and the SO_2 gas removal efficiency was recorded. The results are presented below in Fig. S2. It can be seen that the SO_2 removal was steady during the long-term stability test. A steady gas removal efficiency indicates that the membrane prevented wetting and no deterioration occurred.

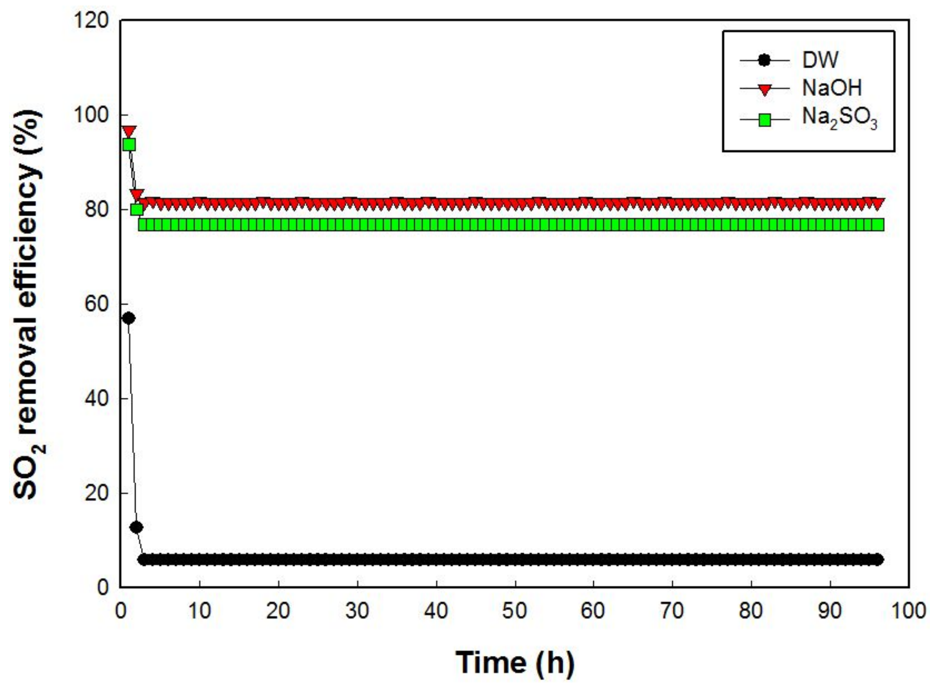

Fig. S2. Long-term stability test; SO_2 removal efficiency achieved by all three absorbents during the 96 h stability test.