Separation of gaseous air pollutants using membrane contactors

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Abstract. This work deals with the separation of CO2 gaseous pollutant from gas mixtures to a water solution using the laboratory contactor. The laboratory set process parameters showed the rate of carbon dioxide transition through the interface in a so promising level the contactor separators can be considered as a very promising pathway to reduce the content of this greenhouse gas from the air.

1. Introduction

Adsorption, membrane, condensation and absorption processes are basic separation processes which have widely been applied to a large industrial scale for separation of gaseous pollutants from the air. Absorption is widely used diffusion separation process where gas/liquid contact occurs. With the use of membrane contactors these phases are in contact through pores of a membrane which provides very high contact surface. In this work we demonstrate separation efficiency of a membrane contactor with an example of absorption of CO_2 into aqueous solution.

2. Absorption rate

Absorption rate can be expressed using equation describing the rate of mass transfer between phases. Using partial mass transfer coefficients of the substance in the liquid and gaseous phase, tha absorption rate is given by the following equation (1):

$$\frac{\dot{n}}{A} = k_{gP} \cdot \left(P_g - P_f\right) = k_{lC} \cdot \left(C_f - C_l\right) \tag{1}$$

Where $\dot{n}$ is the constant flow of molar amount of absorbed substance, A is the surface area of the interface k_{gP} and k_{lC} are the partial coefficient of the mass transfer in the gaseous and liquid phase, respectively. P_g and P_f, are the partial pressure of the absorbed substance in the gaseous phase and at the interface, respectively, C_l and C_f are the molar concentration of absorbed substance in the liquid and at the interface, respectively.

3. Membrane contactors basic principles

Membrane contactors are mostly used as a bundle of hollow fibre membranes (HFMs) with very small fibre diameter. The membrane pores provides contact between the two phases. The fibres are mostly made of hydrophobic materials such polyethylene, polypropylene, Teflon, or polyvinylidenfluoride. The HFM's function is to separate the two phases and to prevent their mixing. The interface is kept in the pore surface of the HFM which is filled with one of the phases. The direct contact of the phases is thus through the pores and the contactor works as device of a continual mass transfer similar to an absorber [1].

The operation of a membrane contactor is based on a presence of capillary forces which drive one of the two phases on the membrane surface. If the gas phase is inside the hollow fibres and submerged into a liquid the liquid will not pass through the membrane until the liquid pressure ΔP_C reaches a certain value given by the Young-Laplace equation (2) [2,3]:

$$\Delta P_C = -\frac{4\lambda \cos\theta}{d} = P_K - P_P \quad (2)$$

Where λ is the liquid surface tension, θ is the contact angle between liquid and the membrane surface, d is the diameter of the membrane pore, P_K is the liquid pressure outside of the membrane and P_P is the gas pressure inside of the membrane.

4. Materials and methods

4.1. Experimental device

The testing equipment consists of two independent circuits i.e. gas and liquid circuit. The scheme of the device is shown in figure 1 and the real view of the device in figure 2. For further detail see work of Ostrezi [4].

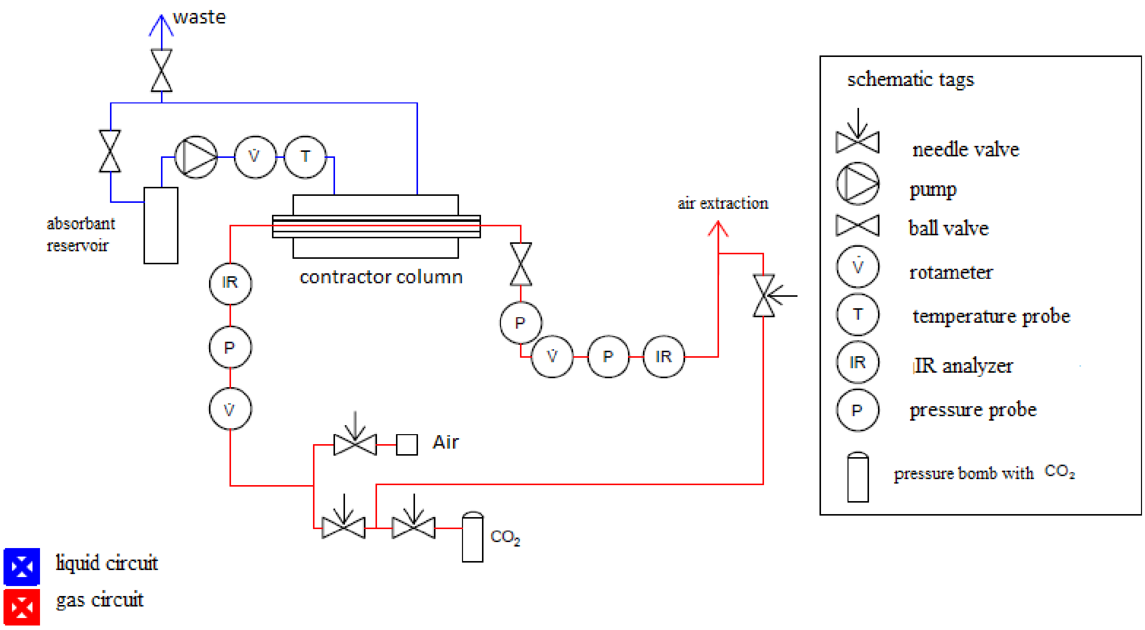

Figure 1. Technologic scheme of the experimental device.

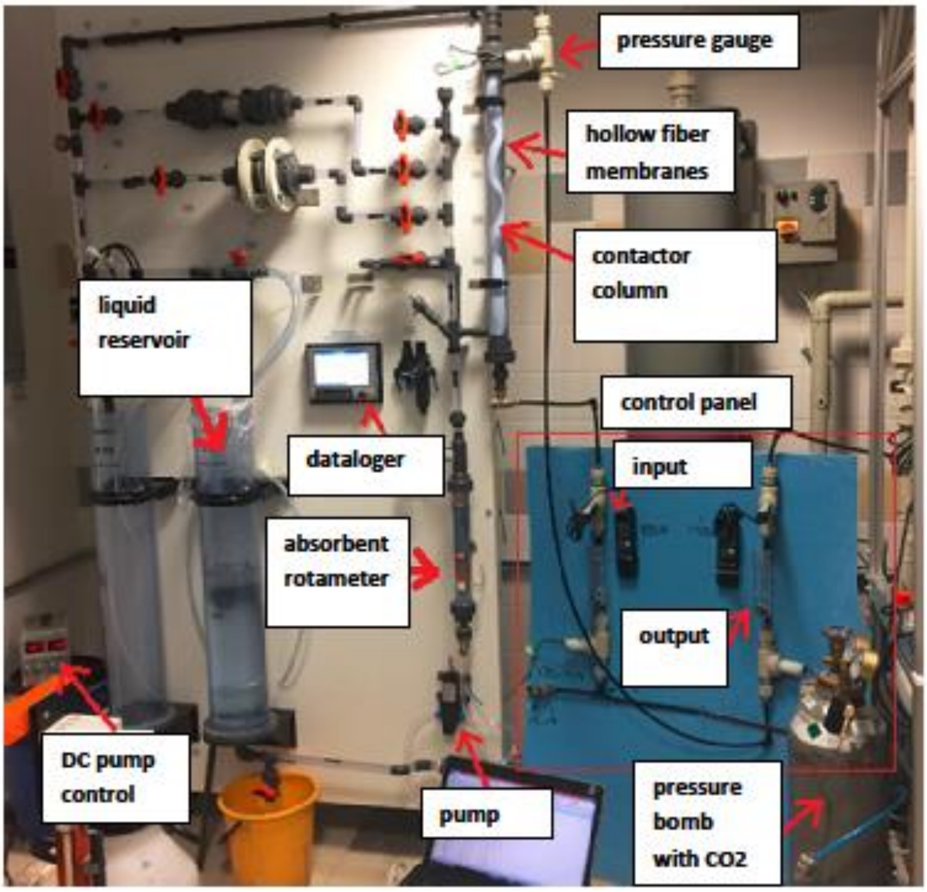

Figure 2. A real view of the experimental device.

4.2. Hollow fibre membrane (HFM) module

The HFM made of polypropylene by Zena Membrane [5] were used. The HFM's parameter are shown in table 1, a real view of the membrane is in figure 3.

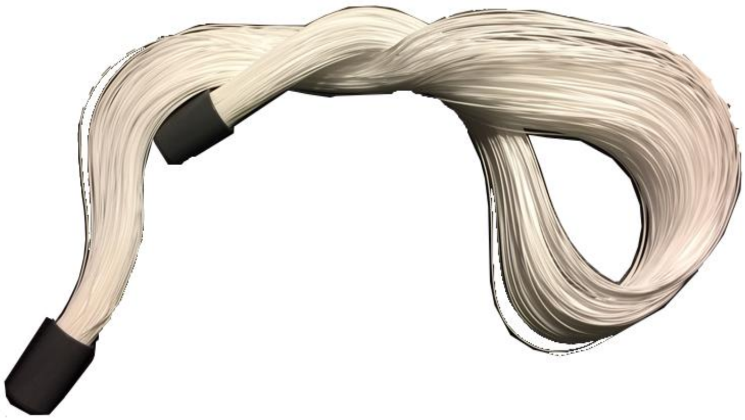

Figure 3. A real view of the HFM

Table 1. Parameters of the hollow fibre membrane used in the experiments.

Fiber diameter [μm]	Surface treatment	Surface area [m^2]	Number of fibers
620	hydrophobic	0.4	300

4.3. Calculation of the efficiency of the absorption process

The process efficiency η was calculated as follows (equation (3)):

$$\eta = \frac{\Delta \dot{n}_{CO2}}{\dot{n}_{CO2\ IN}} \cdot 100\% = \frac{\left(\dot{n}_{CO2\ IN} - \dot{n}_{CO2\ OUT}\right)}{\dot{n}_{CO2\ IN}} \cdot 100\% \quad (3)$$

where $\dot{n}_{CO_2 IN}$ is the amount of CO_2 transferred to liquid phase and $\dot{n}_{CO_2 OUT}$ is the amount of CO_2 in the gas phase.

5. Results and discussion

The rate of the CO_2 transfer per unit of area and the concentration gradient is shown in figure 4.

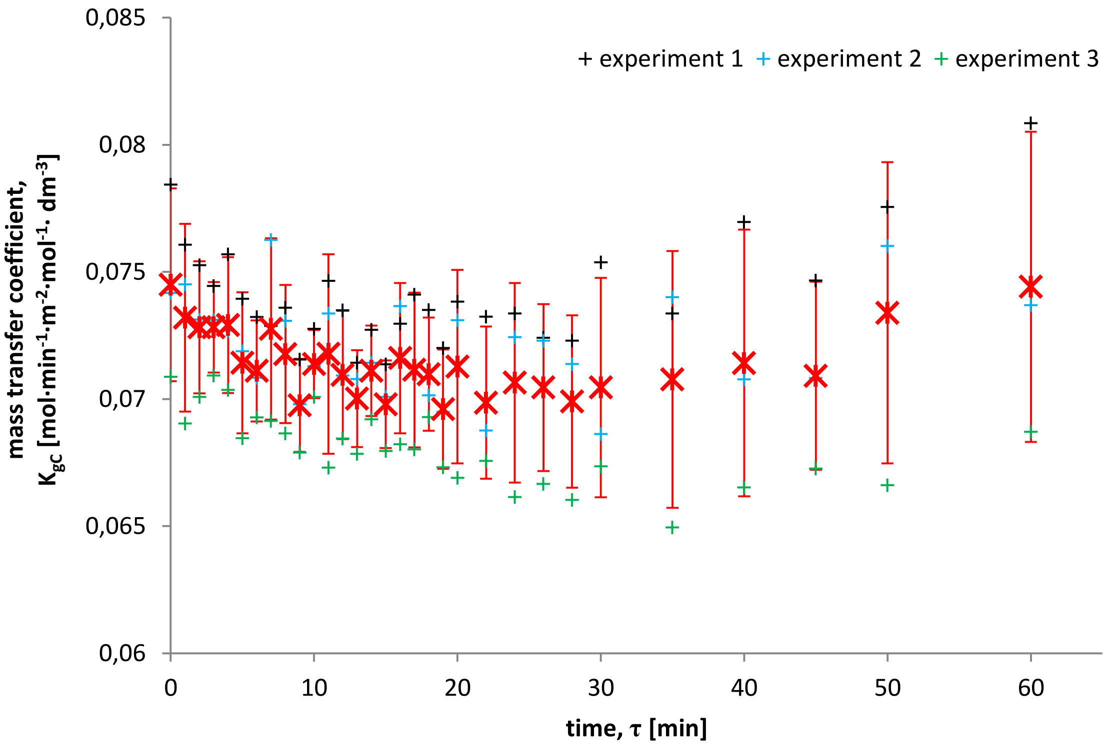

Figure 4. Mass transfer coefficient as a function of time.

6. Conclusion

Using the membrane contactor developed in our laboratory, the CO_2 mass transfer rate from air to aqueous environment was $1.9 \cdot 10^{-4}$ mol/min. Expressed as the mass transfer coefficient at given conditions it was 0.072 ± 0.005 mol·min^{-1}·m^{-2}·mol·dm^{-3}.

Acknowledgments
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