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Note: Gas Absorption in Water with Microchannel Devices

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ABSTRACT

A micro-tube device for gas absorption is demonstrated as an example of the potential for design of separation process with micro-channel devices. CO_2 gas absorption in water with microchannels that were 10^{-4} to 10^{-3} m in hydraulic diameter was studied as a chemical unit operation. Pressure drops in whole experimental system and gas absorption rate were monitored with a conventional experimental system. Gas absorption rate was strongly enhanced with decreasing hydraulic diameter.

Key Words: Microreactor; Microchannel; Gas absorption.

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In this paper, CO_2 gas absorption in water within a microchannel, was studied as a chemical unit operation. Enhanced CO_2 absorption and size effect were obtained.

Microreactor technology has been developed in a variety of unit operations such as mixers, heat exchanger, and chemical reactors.[1−3] The objectives for the microreactor system are to miniaturize a function and to achieve high throughput per unit device in chemical processing. Owing to features such as the enhanced driving force induced by difference in temperature, pressure and concentration in the micro-fluidic system, higher contact area-to-volume ratio, and minimization of unit-processing hardware, microreactor technology has received increasing attention during the last decade.

Most of the separation process has occupied large and tall spaces in the conventional chemical plants and played an important role in determining the production quality. However, only a few studies have been reported on micro-separation devices. Ehrfeld et al.[1,2] demonstrated reactive absorption with various types of gas/liquid microreactor, where enhanced conversion and higher productivity were reported. TeGrotenhuis et al.[3] also studied solvent extraction and gas absorption with microchannel contactor, where the height equivalent to a theoretical plate (HETP) in the microchannel is reported, and suggested that two or three orders of magnitude size reduction is possible by comparison with conventional packing tower operations.

In this work, four different sizes of single-microchannnel, which have hydraulic diameters of 100, 250, 500, and 1000×10^{-6} m and the same lengths of 0.48 m were used as an absorber. The microchannel is connected to the rest of the system with standard fittings and valves. Carbon dioxide and nitrogen from cylinders are individually passed through a flowmeter and mixed. In order to prevent the vaporization of water as an absorbent, the gases are saturated with water. The flow rate of water as absorbent was controlled by HPLC pump. The fluid exiting from the absorber was introduced to the gas/liquid separator followed by wet gas meter. The gas composition was periodically analyzed by GC with TCD. Pressure drops across the microchannels are also measured with a pressure gauge. All experiments were carried out at room temperature and ambient pressure.

The pressure drop increased with the increase in the flow rate of water as absorbent. The pressure drop was larger for the operation at smaller hydraulic diameter of the channel. Microchannels with 100 and 1000×10^{-6} m permit visual observation of the flow pattern. Although a discriminated interface between gas and liquid was observed in the first lane in the single microchannel, where gas and liquid were in contact in the straight channel with an angle, the gas bubbles or slug are found after the first curve of the channel. This may be caused by the absorption of the gas phase, resulting in the unstable interface between gas and liquid.

Figure 1 shows the effect of the channel size and the flow rate on the gas absorption ratio, where a gas mixture of 75% N_2 and 25% CO_2 is used at a total gas flow rate of 2.5×10^{-5} mol/s. Gas absorption ratio, G/G_0, is defined by the total gas flow rate at outlet to that at inlet. When the 500 or 1000×10^{-6} m of microchannels were used as an absorber, no absorption was observed. On the other hand, for those with 100 or 250×10^{-6} m, the gas was dramatically absorbed into the water with the increase in the water flow rate. Consequently, it indicated that a higher flow rate of absorbent and a smaller size of channel favored the absorption of gases. The mass transfer induced by the micro-order channel improved the gas absorption.

Figure 2 shows the effects of the gas flow rate on the absorption ratio as a function of the L_0/G_0 ratio for 100×10^{-6} m channel, where L_0 is a flow rate of water at the inlet. The gas was absorbed with the increase in the water flow rate and also with the increase in the gas flow rate. Therefore, the enhanced mass transfer effectively improved the gas absorption.

Although the CO_2 is selectively absorbed in the water compared with N_2 from the estimation by Henry's law, the gas absorption selectivity was not evaluated in these experiments. In spite of less absorption of N_2 in the water by Henry's law, N_2 is also dramatically absorbed into the water as shown in Figs. 1 and 2, where 75% of N_2 is used as the gas feed. In order

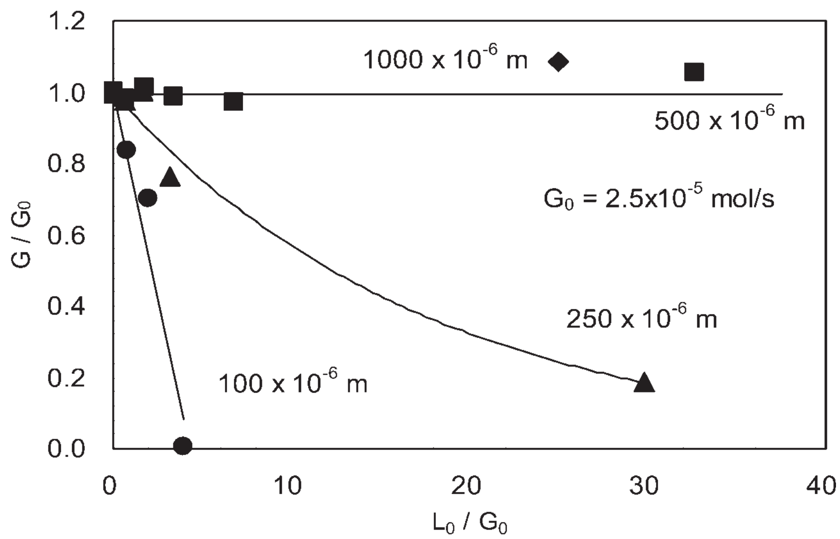

Figure 1. Effect of the channel size and water flow rate on absorption ratio. (Total gas flow rate = 2.5×10^{-5} mol/s, N_2/CO_2 = 75%/25%).

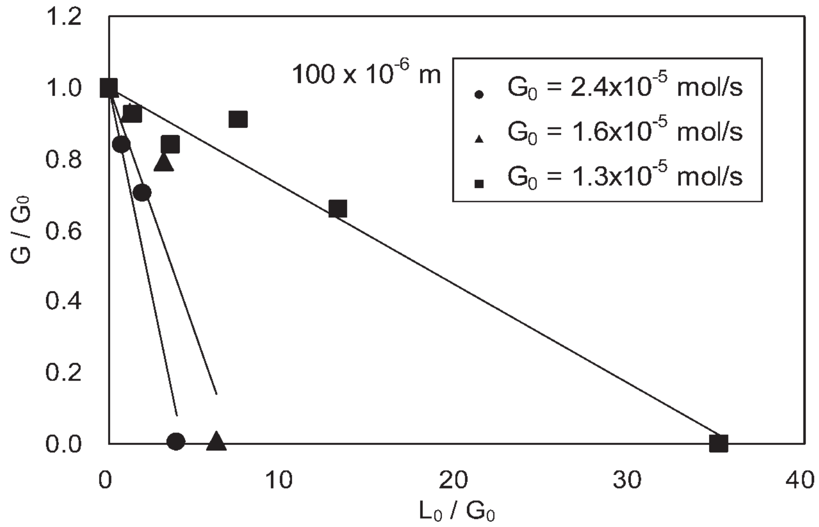

Figure 2. Effect of the flow rate of water and gas on absorption ratio. (Feed gas composition $N_2/CO_2 = 75\%/25\%$).

to compare between concentrations calculated by Henry's law and measured by experiments, pure CO_2 was used as the gas feed. The measured concentrations of CO_2 in water were 14 to 600 times higher than the calculated concentration at measured pressure drops. Enhanced gas absorption may be not only induced by a pressure drop, but another factor may also affect the microchannels. More detailed discussion to analyze this phenomenon and the mass transfer are under progress.

In conclusion, gas absorption in water with microchannel was studied as a fundamental research of a chemical unit operation. The pressure drop increased with the increase in the flow rate of gas and absorbent and was larger for the operation at smaller hydraulic diameter of the channel. For the smaller hydraulic diameter channels less than 250×10^{-6} m, the gas was dramatically absorbed into the water with the increase in the flow rate of the gas and absorbent. It indicated that an enhanced mass transfer rate and a smaller size of channel favored the absorption of gases.

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