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Effect of microbubbles on ozone decomposition of Rhodamine-B

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The effect of microbubbles on ozone decomposition of Rhodamine-B was experimentally studied. Microbubbles increased remarkably volumetric mass transfer coefficient k_La and ozone decomposition rate of Rhodamine-B.

1. Introduction

Environment is very important for human beings. To keep clean environment, pollutants in waste gas and liquid must be completely treated. Ozone is a strong oxidant and widely used to decompose pollutants. Therefore, it is very important to improve the efficiency of decomposition of organic pollutants by ozone. Recently, microbubbles attract much attention because of large surface area and small rising velocity. Much larger utilization efficiency of ozone is expected from use of microbubbles of ozone. There have been many studies about microbubbles (Ohnari (1997, 2000, 2002), Ohnari et al. (1999), Pan et al.(2006a,b),Miyahara et al.(2007)). However, the effect of microbubbles on ozone decomposition of Rhodamine-B is not clear.

In this work, the effect of microbubbles on ozone decomposition of Rhodamine-B was experimentally studied.

2. Experimental

Fig.1 shows a schematic diagram of experimental apparatus. A rectangular bubble column (f) was made of transparent acrylic resin. Its height and cross-section were 1 m and 0.30 m x 0.30 m, respectively. Three kinds of gas distributors were used. They are a 0.03 m I.D. glass ball filter by Kinoshita Rika (= GB), micro bubbler by Ohnari (=

MBO) and micro bubbler by Sigen Kaihatsu (= MBS) (see Fig.2). Air and oxygen were used as gases. Tap water and ultra pure water by Nomura Micro Science at room temperature were used as liquids. Ozone was generated by two ozone generators (TSL10-L200 by Tyuen Electric and ED-OG-R3Lt by Eco Design, Japan). The concentration of Rhodamine-B was analyzed by a spectrophotometer (UV-mini by Shimadzu). The concentration of Ozone in gas and liquid was measured by ozone meters made by TOA DKK in Japan. In order to study effects of ultrasonic waves on ozone decomposition of Rhodamine-B, a ultrasonic generator (W-115 by Honda Electric, Japan) was set under the bottom of the bubble column. The frequency and output of the ultrasonic generator were 100 kHz and 300 watt, respectively. Gas holdup E_G was measured by static pressure difference method. A pump was used to circulate the liquid in the bubble column. Volumetric mass transfer coefficient k_La was measured by oxygen absorption into the water, using the following equation:

$$k_La = ln\{C_s\text{-}C_i) / (Cs\text{-}C_f)\} / t \qquad (1)$$

All runs were conducted at room temperature.

3. Results and discussions

3.1 Average gas holdup E_G

Fig.3 shows the effect of gas distributors on E_G at H_L = 0.7 m. E_G increased with superficial gas velocity U_G. E_G becomes large in the following order: GB < MBO < MBS. E_G for MBS+US was nearly equal to that for MBS. US means the ultrasonic generator. MBS + US means the simultaneous use of both MBS and US. The reason why *EG* has decreased in order of MBS, MBO, GB may be because bubbles have become small in that order. In case of MBS, micro bubbles generated and the whole liquid in the bubble column became white. In case of MBS + US, micro bubbles near the bottom region disappeared and the liquid became transparent.

3.2 Effect of microbubbles on volumetric mass transfer coefficient k_La

Fig.4 shows the effect of microbubbles on volumetric mass transfer coefficient k_La at H_L = 0.3 m. k_La increased with superficial gas velocity U_G. k_La increased in order of GB, MBO, MBS and was correlated by the following equations:

$$k_La = 0.018\ U_G^{0.51} \quad \text{for MBS} \qquad (2)$$

$$k_La = 0.010\ U_G^{0.54} \quad \text{for MBO} \qquad (3)$$

$$k_L a = 0.008\ U_G^{\ 0.65} \qquad \text{for GB} \tag{4}$$

$k_L a$ for MBS was about 1.8 times larger than that for MBO, because MBS produced much smaller bubbles than MBO. Fig.4 also shows values of $k_L a$ by Pan et al.(2006) and the correlation of Hikita et al. (1981). Pan et al. (2006) studied the effect of micro bubblers on $k_L a$ in the bubble column. Values of $k_L a$ by Pan et al. (2006) became slightly larger than those of MBS. Hikita et al. (1981) presented the following correlation for $k_L a$ in a bubble column:

$$k_L a U_G g^{-1} = 14.9\ (U_G \mu_L \sigma^{-1})^{1.75}\ (g \mu_L^{\ 4} \rho_L^{-1} \sigma^{-3})^{-0.248}\ (\mu_G \mu_L^{-1})\ (\mu_L \rho_L^{-1} D_L^{-1})^{-0.604} \tag{5}$$

$k_L a$ for GB is slightly lower than that by Hikita at al.(1981), because the cross-section of the bubble column is so large and the gas distributor is so small that gas dispersion is not good. $k_L a$ for MBO is larger than that by Hikita at al.(1981). $k_L a$ for MBS is much larger than that for Hikita et al. (1981), because of micro bubbles.

3.3 Decomposition rate of Rhodamine-B in air system

Fig.5 shows an example of decomposition rate of Rhodamine-B by ozone. The decomposition rate of Rhodamine-B followed a pseudo first order reaction.

Fig.6 shows the effect of input rate Q_C of ozone on decomposition rate constant K of Rhodamine-B in air system. The rate constant K did not depend on the kinds of gas distributors. The reason why K did not depend on kinds of gas distributors is not yet clear. K increased with increasing input rate of ozone and was expressed by the following equation:

$$K = 0.0041\ (Q_C)^{0.86} \tag{6}$$

Where units of K and Q_C are [sec^{-1}] and [$\mathrm{g \cdot m^{-3}}$], respectively.

3.4 Decomposition rate of Rhodamine-B in oxygen system

Fig.7 shows the effect of concentration C of ozone in inlet gas on K in oxygen system at H_L = 0.70 m and U_G = 0.037 cm/s. K increased with the concentration of ozone in inlet gas. K for MBS system was nearly equal to that for MBO + PUMP system. K for MBS + US system was nearly equal to that for MBS system. The reason why K for MBS+US system was nearly equal to that for MBS system may be because the liquid volume was too large that liquid mixing was not good. K for MBO+ PUMP and GB was expressed by Eqs.(7) and (8),respectively:

$K = 0.010\ C$ for MBO + PUMP system (7)

$K = 0.0052\ C$ for GB system (8)

Fig.8 shows the effect of concentration of ozone in inlet gas on K for $H_L = 0.25$ m and $U_G = 0.037$ cm/s. K increased with the concentration of ozone C in inlet gas and became large in the following order:

GB < MBO + PUMP < MBS < MBS+US+LP

K was expressed by the following equations:

$K = 0.058\ C$ for MBS + US + LP (9)

$K = 0.04\ C$ for MBO + PUMP (10)

$K = 0.031\ C$ for MBS (11)

$K = 0.01\ C$ for GB (12)

where LP means liquid circulation pump. The reason why K for MBS+US+LP system becomes the largest may be because liquid was well mixed in the shallow bubble column.

4. Conclusions

The effect of microbubbles on ozone decomposition of Rhodamine-B was experimentally studied.

1) E_G depended on kinds of gas distributors. E_G became large in the following order:

GB < MBO < MBS ≑ MBS+US

2) k_La depended remarkably on kinds of gas distributors. k_La became large in the following order:

GB < MBO < MBS

3) The rate constant K of ozone decomposition of Rhodamine-B for air system did not depend on kinds of gas distributors and was expressed by Eq.(6).

4) K for $H_L = 0.70$ m and 0.25 m for oxygen system increased with increasing concentration of ozone in inlet gas. K for MBO+PUMP at $H_L = 0.70$ m was nearly equal to those for MBS and MBS + US, and was expressed by Eq.(7). K for GB became nearly half of that for MBO+ PUMP and was expressed by Eq.(8). K at $H_L = 0.25$m depended kinds of gas distributors and became large in the following order:

GB < MBO + PUMP < MBS < MBS+US+LP

K at $H_L = 0.25$ m was expressed by Eqs.(9)-(12).

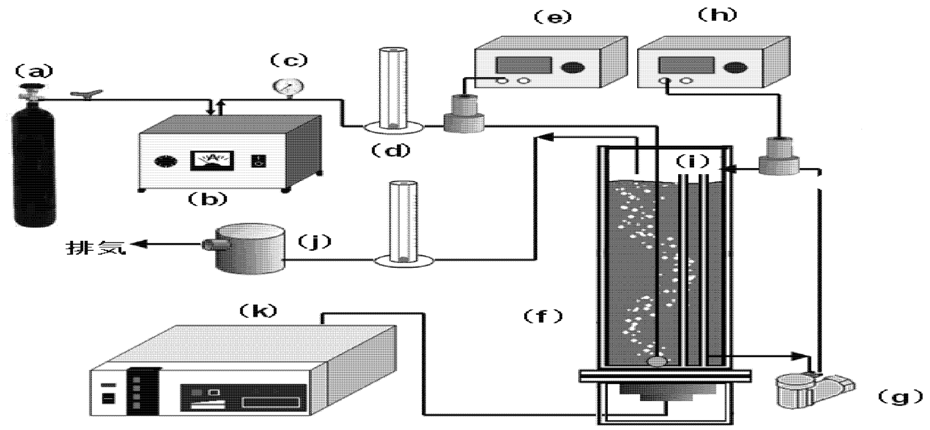
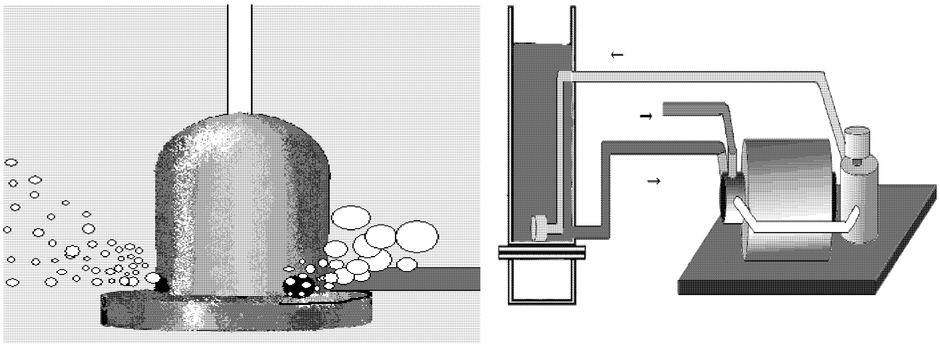


Fig.1 A schematic diagram of experimental apparatus.

a=oxygen gas cylinder, b=ozone generator, c=pressure gauge, d= gas flow meter, e=ozone concentration meter, f=bubble column, g=liquid pump, h= ozone concentration meter, i=manometer, j=ozone decomposer, k=ultrasonic generator



(a) Micro bubbler by Ohnari (b) MB by Shigen Kaihatsu Co.

Fig.2 Micro bubblers of Ohnari and Shigen Kaihatsu Co.

(a) M1-L by Ohnari where water enters from the left side and gas is sucked from the top.

(b) Gas is sucked into the second upper tube and liquid is sucked into the lowest tube. Gas and liquid are injected from the top tube.

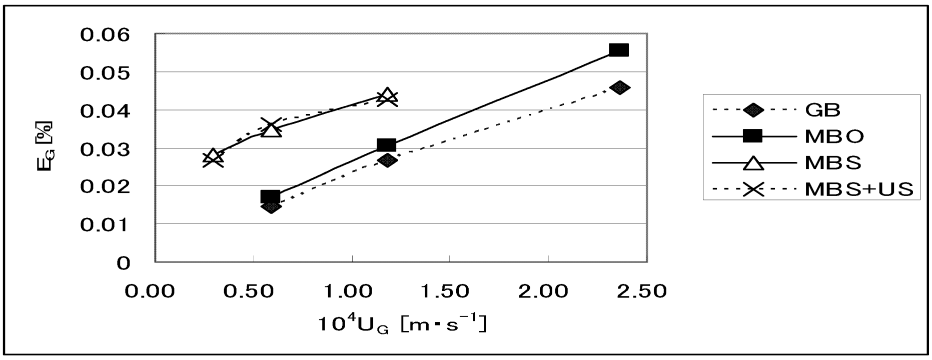


Fig.3 Effect of type of gas distributors on E_G at $H_L = 0.7$ m.

GB=glass ball filter, MBO=micro bubbler by Ohnari, MBS= micro bubbler by Shigen Kaihatsu, MBS +US =simultaneous use of MBS and US, US = ultrasonic generator

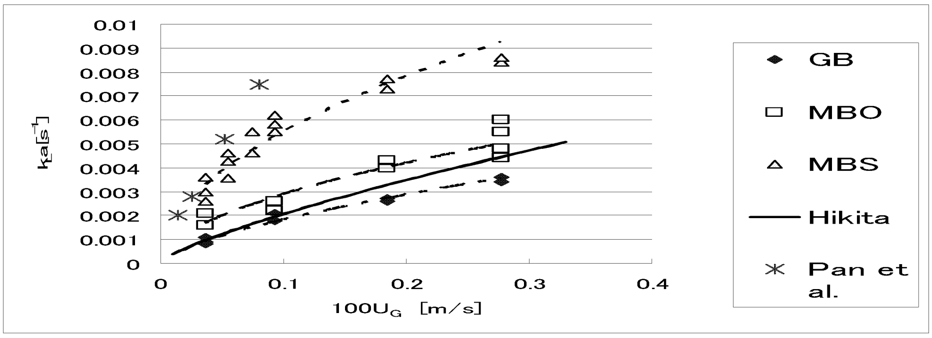


Fig.4 Effect of type of gas distributors on k_La *at* $H_L = 0.30$ *m*.

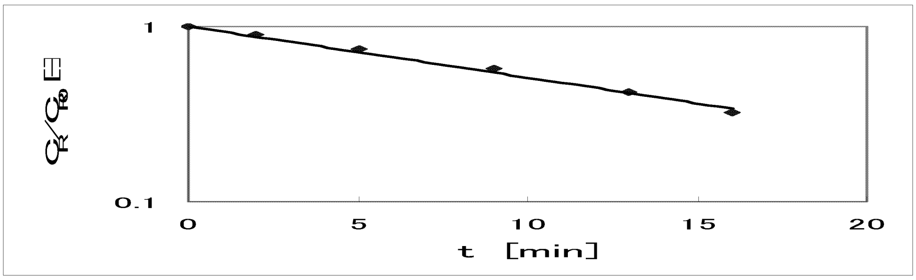


Fig.5 An example of ozone decomposition of Rhodamine-B for GB in O_2 system at $U_G = 0.037$ cm/s, H_L= 0.7m and ozone concentration at inlet gas =10 g・m^{-3}.

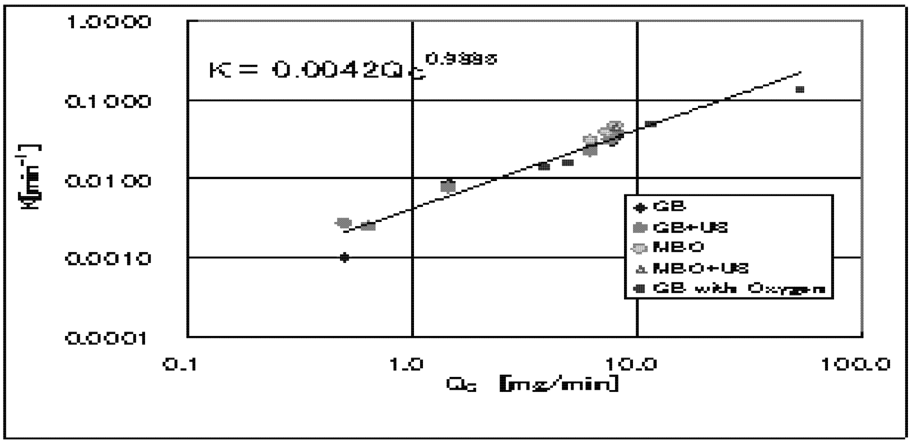


Fig.6 Effect of input rate *Qc* on *K* in case of air system.

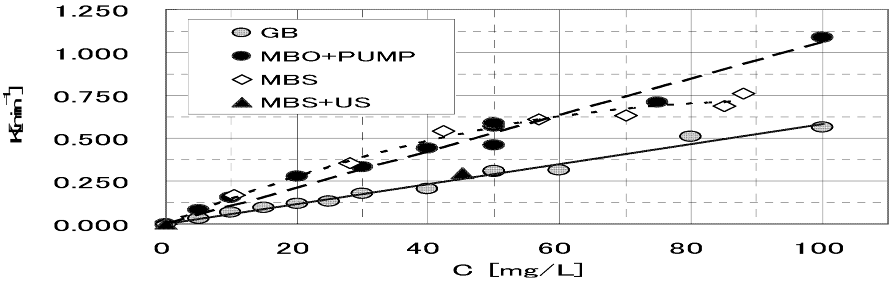


Fig.7 Effect of ozone concentration *C* in inlet gas (oxygen) on *K* for H_L = 0.70m.

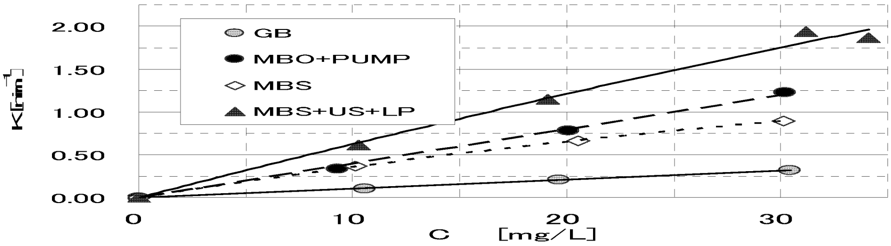


Fig.8 Effect of ozone concentration *C* in inlet gas (oxygen) on *K* for H_L = 0.25 m.

Nomenclature

a = specific surface area [m^2 ・ m^{-3}]

C = ozone concentration in inlet gas [g ・ m^{-3}]

C_R = concentration of rhodamine-B [mol ・ m^{-3}]

$C_{R0} = C_R$ at $t = 0$ [mol ・ m^{-3}]

D_L = diffusion coefficient of oxygen [m^2 ・ s^{-1}]

E_G = average gas holdup [-]

g = gravitational acceleration [m ・ s$^{-2]}$

H_L = clear liquid height [m]

K = rate constant of ozone decomposition of Rhodamine-B [s^{-1}]

k_L = liquid side mass transfer coefficient [m ・ s^{-1}]

k_La = volumetric mass transfer coefficient [s^{-1}]

Qc = input rate of ozone [g ・ min^{-1}]

t = time [s]

U_G = superficial gas velocity [m ・ s^{-1}]

μ_G = viscosity of gas [Pa ・ s]

μ_L = viscosity of liquid [Pa ・ s]

σ = surface tension of liquid [N ・ m^{-1}]

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