AND NITRIC OXIDE IN AQUEOUS MIXED SOLUTIONS OF SODIUM CHLORITE AND SODIUM HYDROXIDE

EIZO SADA, HIDEHIRO KUMAZAWA, YASUO YAMANAKA, ICHIBEI KUDO AND TAKASHI KONDO
Department of Chemical Engineering, Nagoya University, Nagoya 464

The rates of single and simultaneous absorptions of dilute SO_2 and NO in aqueous mixed solutions of $NaClO_2$ and NaOH were measured at 25°C using a stirred vessel with a plain gas-liquid interface. In the SO_2–$NaClO_2$ system, the absorption rate exceeded the gas-film controlled rate, which implies the possibility of gas-phase oxidation of SO_2 due to the evolved ClO_2. In the SO_2–($NaClO_2$+NaOH) system, the absorption rate agreed with that under gas-film controlled conditions. In the (SO_2+NO)–($NaClO_2$+NaOH) system, the reduction of the NO absorption rate in the presence of SO_2 substantially exceeded that evaluated through the decrease in interfacial concentration of $NaClO_2$ and NaOH due to surface reaction with coexisting SO_2. The rate of absorption of SO_2 exceeded the gas-film controlled rate. The decomposition of $NaClO_2$ proceeds to a greater degree during simultaneous absorption than the single absorption of SO_2.

Introduction

Nitrogen oxides are one of the major pollutants in the atmosphere and, in addition, have been recognized as essential components in the formation of photochemical smog. Stationary combustion facilities are major sources of these oxides. In this case, more than 90 percent of the nitrogen oxides is inactive nitric oxide with a concentration of several hundred ppm. Thus a considerable amount of research has been directed toward developing a system for the removal of nitric oxide by wet and dry methods. With respect to another air pollutant, sulfur dioxide, several wet scrubbing processes have been developed and their technical systems have been established. The flue gases emitted from fossil-fired facilities generally contain both sulfur and nitrogen oxides. Thus it is convenient to treat sulfur dioxide and nitrogen oxides simultaneously, in the same equipment. In a wet scrubbing process appropriate for the removal of nitrogen oxides there is some possibility of removing sulfur dioxide simultaneously. Otherwise, by some modification of existing wet scrubbing processes for the removal of sulfur dioxide, the nitrogen oxides may also be treated.

Received September 10, 1977. Correspondence concerning this article should be addressed to E. Sada, Dept. of Chem. Eng., Kyoto Univ., Kyoto 606. I. Kudo and T. Kondo are at Dept. of Ind. Eng., Aichi Inst. of Techn., Toyoda 470-03. Y. Yamanaka is now with Tonen Co., Ltd., Kawasaki 210.

In our previous work[7], the absorption of nitric oxide by alkaline solutions of sodium chlorite was discussed from the standpoint of chemical absorption to clarify the chemical reaction kinetics. This system is a promising wet scrubbing process for the removal of nitrogen oxides, and further seems to have a possibility of simultaneous treatment of nitrogen oxides and sulfur dioxide. In the present work, single and simultaneous absorptions of dilute nitric oxide and sulfur dioxide were performed in a stirred thank absorber with a plain gas-liquid interface and the kinetics of relevant single and simultaneous absorptions were analyzed on the basis of chemical absorption theory.

1. Experimental

Figure 1 shows a schematic diagram of the experimental apparatus. The apparatus is set up in a constant-temperature room. All experimental runs were made using a stirred vessel with a plain gas-liquid interface. The absorber is continuous for the single CO_2 and SO_2 absorption runs and batchwise for the single NO and simultaneous SO_2 and NO absorption runs. The vessel is sketched in **Fig. 2**. The vessel, made of acrylic resin, is of 10.0 cm i. d. with four symmetrically located vertical baffles in the liquid phase. The width of each baffle is 1.3 cm. The liquid-phase volume is 785 cm^3 and the gas-phase volume 573 cm^3.

gas-phase stirrer is a paddle agitator with four flat blades and is placed 3.5 cm above the gas-liquid interface. The liquid-phase stirrer is also a paddle agitator with eight flat blades and is mounted 5.0 cm below the interface. The temperature of the absorber was maintained at 25°C in the water bath.

Solute gases, SO_2 and NO were diluted by N_2, saturated with water vapor at the temperature of the apparatus and fed into the absorber. The concentrations of SO_2 and NO in the feed stream were varied from 1.1 to 9.6 vol% and 0.5 to 7.5 vol%, respectively. The compositions of SO_2 and NO in the gas streams into and from the absorber were determined by gas chromatography (column: Chromosorb T with 10% dibutylphthalate as a fixed liquid phase at 88°C for SO_2 analysis and molecular sieve 13X at 53°C for NO analysis, carrier gas: N_2). The concentrations of SO_2 and NO above 0.5 percent could be reproducibly determined by this method. The absorption rates of SO_2 and NO were calculated from the difference between inlet and outlet concentrations and the total gas flow rate.

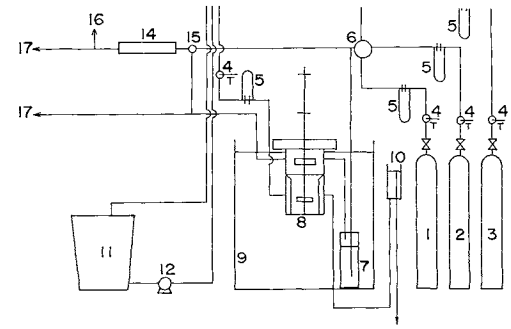
1. 1 Measurements of liquid-side and gas-side mass transfer coefficients

Prior to the chemical absorption experiments, the physical absorption of pure CO_2 into water was performed at 25°C in the same stirred vessel to determine the liquid-side mass transfer coefficients. The volumetric flow rates of liquid and gas were varied from 2.3 to 9.6 cc/sec and from 1.4 to 3.6 *l*/min, respectively. Agitator impeller speed in the liquid phase was varied from 40 to 190 rpm, whereas the gas-phase impeller speed was maintained at 400 rpm. The absorption rate was determined by chemical analyses of the inlet and outlet liquids.

In addition, to determine the gas-side mass transfer coefficients, the absorption of lean SO_2 into an aqueous solution of NaOH was carried out with the same absorber. The concentration of SO_2 in the feed stream was approximately 4 percent. The concentration of NaOH in the absorbent was 1.0 mol/*l*. The absorption process under consideration is believed to be completely gas-film controlled. The impeller speed in the gas phase ranged from 100 to 600 rpm. The volumetric flow rate of gas was varied from 0.97 to 6.31 *l*/min, whereas the liquid-phase impeller speed was maintained at 100 rpm. The volumetric flow rate of liquid was also kept constant at 3 cc/sec.

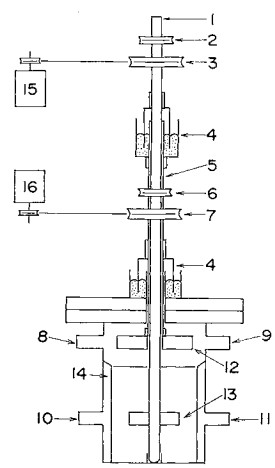
1. 2 Single and simultaneous absorptions of SO_2 and/or NO in aqueous mixed solutions of $NaClO_2$ and NaOH

Experiments were performed on the following absorption systems: (1) absorption of SO_2 in aqueous solutions of $NaClO_2$, (2) absorption of SO_2, (3) absorption of NO and (4) simultaneous absorption of SO_2 and NO in aqueous mixed solutions of $NaClO_2$ and NaOH. The experimental conditions of these systems



1. N_2 gas cylinder
2. NO gas cylinder
3. SO_2 gas cylinder
4. Flow control valve
5. Orifice flow meter
6. Gas mixing chamber
7. Water vapor saturator
8. Stirred vessel
9. Water bath
10. Level controller
11. Feed tank
12. Circulating pump
13. Head tank
14. Drying column
15. Three-way stop cock
16. to gas chromatograph
17. to ventilator

Fig. 1 Schematic diagram of experimental apparatus



1. Shaft of liquid phase stirrer
2. Pulley of tachometer for liquid phase stirrer
3. Pulley for liquid phase stirrer
4. Mercury seal
5. Shaft of gas phase stirrer
6. Pulley of tachometer for gas phase stirrer
7. Pulley for gas phase stirrer
8. Gas inlet
9. Gas outlet
10. Liquid inlet
11. Liquid outlet
12. Gas phase stirrer
13. Liquid phase stirrer
14. Baffle plate
15. Driving motor for liquid phase agitation
16. Driving motor for gas phase agitation

Fig. 2 Detail of stirred tank absorber

	[mm]	[mm]	[mol/l]	[mol/l]	[g/mm]	[cc/sec]	[rpm]	[rpm]
SO_2–$NaClO_2$	0.01–0.05	—	0.0041–0.60	—	3.03	3	400	100
SO_2–$NaClO_2$+NaOH	0.01–0.10	—	0.02–1.64	0.01–0.20	3.03	3	400	100
NO–$NaClO_2$+NaOH	—	0.01–0.08	0.29–1.64	0.015	1.2	—	400	100
SO_2+NO–$NaClO_2$+NaOH	0.015–0.03	0.007–0.006	0.48–1.64	0.015	1.25	—	400	100

Table 2 Diffusivity of nitrous oxide in aqueous mixed solutions of sodium chlorite and sodium hydroxide derived from physical absorption data with the liminar liquid-jet at 1 atm and 25°C

Sodium chlorite concentration [mol/l]	Sodium hydroxide concentration [mol/l]	Diffusivity of nitrous oxide [cm^2/sec]
0.00	0.00	1.66×10^{-5}
0.25	0.10	1.62×10^{-5}
0.50	0.10	1.60×10^{-5}
1.00	0.10	1.57×10^{-5}
1.50	0.10	1.52×10^{-5}
2.00	0.10	1.46×10^{-5}
1.00	0.20	1.58×10^{-5}
1.00	0.50	1.23×10^{-5}
1.00	0.70	9.48×10^{-6}

are given in **Table 1**.

2. Experimental Results and Discussion

2. 1 Liquid-side and gas-side mass transfer coefficients

The liquid-side mass transfer coefficient, k_L°, for absorption of pure CO_2 into water was correlated with the liquid-phase stirring speed n_L by

$$k_L^\circ=6.89\times10^{-5}n_L^{0.768} \quad (1)$$

which is valid in the range of 40–190 rpm. The k_L° value was independent of liquid flow rate within the experimental conditions.

The gas-side mass transfer coefficient of SO_2, k_G, was correlated to the gas-phase stirring speed n_L in the range of 100–600 rpm by

$$k_G=6.09\times10^{-7}n_G^{0.752} \quad (2)$$

There was negligible effect of the gas flow rate on k_G. This indicates that the gas phase is completely mixed.

The values of liquid-side and gas-side mass transfer coefficients for gaseous component I were calculated by the following correlations with experimental values of k_L° and k_G, that is, k°_{L,CO_2-H_2O} and k_{G,SO_2-N_2}, respectively.

$$k_{LI}=k^\circ_{L,CO_2-H_2O}(D_I/D_{CO_2-H_2O})^{2/3} \quad (3)$$

$$k_{GI}=k_{G,SO_2-N_2}(\mathscr{D}_I/\mathscr{D}_{SO_2-N_2})^{2/3} \quad (4)$$

2. 2 Solubility and diffusivity

For the evaluation of the effect of chemical reaction in the liquid phase on the rate of absorption the values of physical solubility and diffusivity of solute gas in the absorbent are required. The interfacial concentrations of NO or SO_2 in aqueous mixed solutions of $NaClO_2$ and NaOH were calculated from the correlation of gas solubility in mixed electrolyte solutions[5]:

$$\log(C_{Ji}/C_{Jiw})=\log(\alpha_J/\alpha_{Jw})=-(K_BI_B+K_EI_E) \quad (J=A_1, A_2) \quad (5)$$

where K_B and K_E are the salting-out parameters for the electrolyte B ($NaClO_2$) and E (NaOH), respectively. The salting-out parameter depends on the ion and gas present and is expressed by

$$K=x_g+x_a+x_c \quad (6)$$

The values of x for various species are available in the literature[4,6,7]: $x_g(SO_2)=-0.3145$, $x_g(NO)=-0.1825$, $x_a(OH^-)=0.3875$, $x_a(ClO_2^-)=0.3497$ and $x_c(Na^+)=-0.0183$. The interfacial concentration of SO_2 in water, C_{A_1iw}, in equilibrium with p_{A_1i} was evaluated by using Fujita's equation[2], whereas the interfacial concentration of NO, C_{A_2iw}, was estimated by assuming Henry's law ($H_{A_2}=1.92\times10^{-6}$ mol/cm^3·atm at 25°C).

The liquid-phase diffusivity of NO was estimated from the following equation proposed by Joosten and Danckwerts[3].

$$(D/D_w)_{NO}=(D/D_w)_{N_2O} \quad (7)$$

Here the value of D_w for NO in water is available in the literature[10] (2.53×10^{-5} cm^2/sec at 25°C). The diffusivity of N_2O in the mixed salt solutions was measured in the laminar liquid-jet apparatus. In **Table 2**, the measured values of N_2O diffusivity are given as a function of the concentrations of $NaClO_2$ and NaOH. On the other hand, the reduction of diffusivity of SO_2 in the aqueous solutions was neglected ($D_{A_1}=1.90\times10^{-5}$ cm^2/sec at 25°C), because the aqueous solutions were much diluted under the experimental conditions where the diffusion and chemical reaction in liquid phase become significant as compared to the diffusion in gas-film. The effective diffusivities of relevant ions were estimated by the method of Vinograd and McBain[9].

2. 3 SO_2–$NaClO_2$ system

The experimental results for the region $C_{B0}/C_{A_1i}<10$ where the effect of gas-film resistance on total mass transfer rate is believed to be less, are shown as a conventional plot of ϕ_{A_1} vs. C_{B0}/C_{A_1i} in **Fig. 3**. In an acidic solution, the absorbent $NaClO_2$ is decomposed by[1]

$$NaClO_2+H_2O=NaOH+HClO_2 \quad (I)$$

$$8HClO_2=6ClO_2+Cl_2+4H_2O \quad (II)$$

$$2NaClO_2+Cl_2=2NaCl+2ClO_2 \quad (III)$$

$$10NaClO_2+4H_2O=8NaOH+8ClO_2+2NaCl \quad (IV)$$

Thus the solute gas SO_2 reacts mainly with the resulting NaOH according to the two-step instantaneous reaction

$$SO_2+OH^-=HSO_3^-$$
$$HSO_3^-+OH^-=SO_3^{2-}+H_2O \quad (V)$$

By considering the stoichiometric relationship between NaOH and $NaClO_2$ in Reaction (IV), that is [NaOH]=(8/10)[$NaClO_2$], the film-theory enhancement factor for the SO_2–$NaClO_2$ system can be approximately given by

$$\phi_{A_1}=1+\left(\frac{D_{OH^-}}{D_{A_1}}\right)\left(\frac{8}{10}\right)\left(\frac{C_{B0}}{2C_{A_1i}}\right) \quad (8)$$

The solid line in Fig. 3 represents the theoretical equation (8) with D_{OH^-}/D_{A_1} equal to 1.76. The experimental points deviate considerably from the theoretical line. The deviation exceeds that which might occur in estimating the diffusivity and solubility. It suggests the existence of reaction of SO_2 with ClO_2:

$$5SO_2+2ClO_2+6H_2O=5H_2SO_4+2HCl \quad (VI)$$

as well as reaction with OH^-. In addition, some ClO_2 desorbs into the gas phase and may oxidize SO_2. At present it is difficult to interpret quantitatively the difference between measured and calculated values encountered in Fig. 3. The higher the concentration of $NaClO_2$ in the liquid phase, the more ClO_2 is produced, and correspondingly, it is expected that the amount of ClO_2 evolved into the gas phase increases. **Figure 4** shows the measurements of SO_2 absorption rates for a wider range of $NaClO_2$ concentration. The chain line in this figure represents the theoretical prediction of absorption rate in a completely gas-film controlled region. The observed absorption rates at $NaClO_2$ concentrations greater than 0.2 molar significantly exceed the absorption rate under completely gas-film controlled conditions. This implies the possibility of occurrence of gas-phase oxidation of SO_2 by the evolved ClO_2 and supports the existence of Reaction (VI) in the liquid phase.

2. 4 SO_2–($NaClO_2$+NaOH) system

The reaction prevailing for the present system proceeds under an alkaline situation and hence the decomposition of $NaClO_2$ according to Reaction (IV) is suppressed. Thus it is considered that the dissolved SO_2 reacts with OH^- to form SO_3^{2-} and SO_3^{2-} is oxidized by ClO_2^- to form SO_4^{2-}:

$$SO_2+2OH^-=SO_3^{2-}+H_2O \quad (V)$$
$$2SO_3^{2-}+ClO_2^-=2SO_4^{2-}+Cl^- \quad (VII)$$

It follows from the above reaction scheme that the rate of SO_2 absorption is independent of $NaClO_2$ concentration if OH^- comes only from the NaOH added.

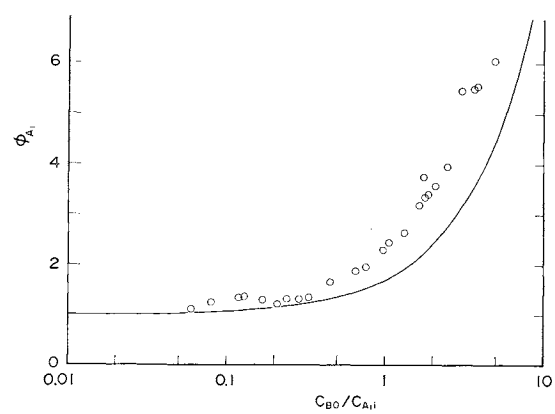


Fig. 3 Plots of ϕ_{A_1} vs. C_{B0}/C_{A_1i} for SO_2 absorption into an aqueous solution of $NaClO_2$

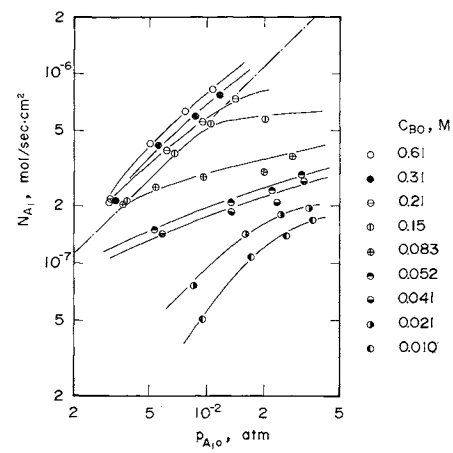


Fig. 4 Effect of $NaClO_2$ concentration on SO_2 absorption rate (SO_2–$NaClO_2$ system)

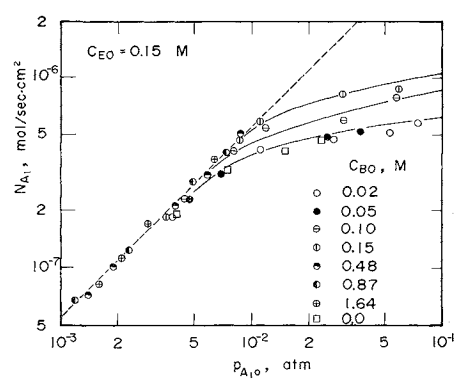


Fig. 5 Effect of SO_2 concentration on absorption rate (SO_2–($NaClO_2$+NaOH) system)

But **Fig. 5** shows that the presence of $NaClO_2$ affects the absorption rate for $C_{B0}<0.15$ molar. In the range of $C_{B0}<0.15$ molar and $0.0012<p_{A_1o}<0.011$ atm, the absorption rate agrees with that under completely gas-film controlled conditions. There is no promotion in absorption rate as observed in the SO_2–$NaClO_2$ system. From this experimental evidence,

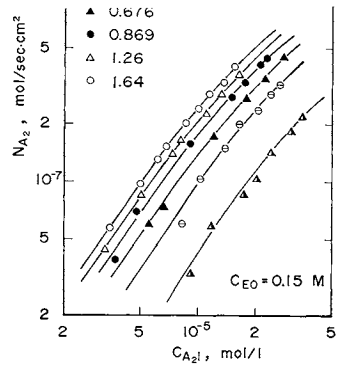


Fig. 6 Relationship between N_{A_2} and C_{A_2i} as a parameter of $NaClO_2$ concentration (NO–($NaClO_2$ +NaOH) system)

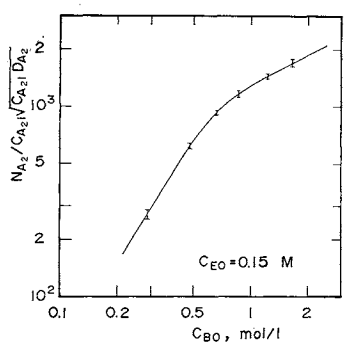


Fig. 7 Effect of $NaClO_2$ concentration on $N_{A_2}/C_{A_2i}\sqrt{C_{A_2i}D_{A_2}}$

some $NaClO_2$ decomposes to form OH^- and ClO_2 even in the presence of NaOH, but the amount of ClO_2 produced is not large enough to desorb into the gas phase and oxidize SO_2.

2. 5 NO–($NaClO_2$+NaOH) system

The reaction between NO and ClO_2^- in an alkaline solution is considered to be[7]

$$2NO+ClO_2^-=2NO_2+Cl^- \quad \text{(VIII)}$$

$$4NO_2+ClO_2^-+4OH^-=4NO_3^-+Cl^-+2H_2O \quad \text{(IX)}$$

The overall reaction reduces to

$$4NO+3ClO_2^-+4OH_3^-=4NO_3^-+3Cl^-+2H_2O. \quad \text{(X)}$$

Here it is assumed that the chemical reaction is regarded as the m-th order for NO and the n-th order for ClO_2^-. Then the order of reaction relative to NO can be derived from the slope $(m+1)/2$ of a logarithmic plot of N_{A_2} vs. C_{A_2i}, when the chemical absorption process lies in a fast-reaction regime and the rate of NO absorption can be given by

$$N_{A_2}=\sqrt{\frac{2}{m+1}kC_{B0}^nC_{A_2i}^{m+1}D_{A_2}} \quad (9)$$

The validity of this assumption was confirmed in the of 1.5 for lower values of C_{A_2i}. According to Eq. (9), a slope of 1.5 means that the order of reaction in NO is equal to 2.

Figure 7 shows the effect of $NaClO_2$ concentration on absorption rate. The ordinate in the same figure is related to

$$N_{A_2}/C_{A_2i}\sqrt{C_{A_2i}D_{A_2}}=\sqrt{(2/3)kC_{B0}^n} \quad (10)$$

which is derived by substituting 2 into m in Eq. (9) and rearranging the resulting equation. For low concentrations of $NaClO_2$, dependence of N_{A_2} on C_{B0} was very high and no simple relationship between the two factors could be derived. Only for C_{B0} greater than ca. 0.8 molar did a linear relationship with the slope of 0.5 appear. The order of reaction in $NaClO_2$ can be determined as unity. Thus, for $C_{B0}>$ 0.8 molar and the partial pressures covering the present experiment ($0.003>p_{A_2o}>0.018$ atm), the rate constant of the third-order reaction is determined to be 2.1×10^{12} $(l/mol)^2/sec$. In the previous paper[7] the effect of NaOH concentration on the rate constant was empirically correlated by

$$k=3.80\times 10^{12}\exp(-3.73\,C_{E0}) \quad (11)$$

in the range of $0.05<C_{E0}<0.5$ molar.

The rate constant estimated from Eq. (11) with [NaOH]=0.15 molar is 2.17×10^{12} $(l/mol)^2/sec$ and coincides well with the experimentally derived value.

2. 6 ($NO+SO_2$)–($NaClO_2$+NaOH) system

1) Effect of the presence of SO_2 on the NO absorption rate The rate-controlling step for the absorption of SO_2 is the diffusion process in the gas film because of high concentration of $NaClO_2$. At a gas-liquid interface, SO_2 reacts with OH^- and ClO_2^- through Reactions (V) and (VII). Therefore, it is expected that the interfacial concentrations of $NaClO_2$ and NaOH in the liquid phase, C_{Bi} and C_{Ei}, become low as compared to the bulk concentrations, C_{B0} and C_{E0}. The reduction of $NaClO_2$ concentration results in a decrease of NO absorption rate, while the reduction of NaOH concentration results in an increase of NO absorption rate.

Figure 8 shows the relations of N_{A2} vs. C_{A_2i} as a parameter of the feed composition of SO_2. The reduction of the NO absorption rate in the presence of SO_2 increases with feed composition of SO_2. On the other hand, the reduction decreases with increase in $NaClO_2$ concentration. Some quantitative interpretation for the reduction in absorption rate is made by a procedure similar to that of Teramoto *et al.*[8]

From above consideration, the absorption of NO into an aqueous mixed solution of $NaClO_2$ and NaOH with concentrations C_{B0} and C_{E0}, respectively, in the

$C_{Ei}(C_{Bi}<C_{B0}$ and $C_{Ei}<C_{E0})$ in the absence of SO_2. The interfacial concentrations of $NaClO_2$ and NaOH during the simultaneous absorption of NO and SO_2 can be estimated from the material balances at the interface:

$$N_{A_1}=k_{GA_1}(p_{A_1o}-0)=2k_{L,ClO_2^-}(C_{B0}-C_{Bi}) \\ =(1/2)k_{L,OH^-}(C_{E0}-C_{Ei}) \quad (12)$$

The coefficients 2 and 1/2 in the right-hand sides of Eq. (12) are derived from reciprocals of stoichiometric factors based on the reaction equations (V) and (VII). k_{L,ClO_2^-} and k_{L,OH^-} are liquid-side mass transfer coefficients of ClO_2^- and OH^- and are estimated to be 2.18×10^{-3} cm/sec and 4.23×10^{-3} cm/sec, respectively ($D_{ClO_2^-}=1.72\times10^{-5}$ cm²/sec and $D_{OH^-}=3.34\times10^{-5}$ cm²/sec). Once estimating C_{Bi} and C_{Ei} from Eq. (12), the absorption rate of NO can be derived by the aid of Fig. 7 and Eq. (11). **Figure 9** compares the absorption rates of NO thus estimated, $N_{A_2,cal}$, with those measured during simultaneous absorption of NO and SO_2, $N_{A_2,obs}$. As a whole, $N_{A_2,cal}$ is considerably larger than $N_{A_2,obs}$. The calculated interfacial concentration of ClO_2^- exceeds approximately 95 percent of its bulk concentration, whereas the OH^- concentration at the interface amounts to 49 percent of its bulk concentration for feed composition of SO_2 equal to 1.5 percent. For $p_{A_1f}=0.03$ atm, the OH^- is completely depleted at the interface. Thus, the decomposition of $NaClO_2$ near the interface is promoted and the chlorite concentration is further decreased. The fact that the concentration of OH^- near the interface becomes low enough to decompose $NaClO_2$ is also supported by the following experimental evidence.

2) Effect of the presence of NO on the SO_2 absorption rate As shown in Fig. 5, the process of SO_2 absorption in the absence of NO is completely gas-film controlled. However, the absorption rate of SO_2 in the presence of NO exceeded the completely gas-film controlled rate of absorption. **Figure 10** shows experimental results for simultaneous absorption. The abscissa is absorption rate of NO and the ordinate is that of SO_2. These experimental results suggest the possibility of occurrence of gas-phase reaction, as stated in a previous section. More of the OH^- is consumed during the simultaneous absorption of SO_2 and NO than during the single absorption of SO_2. Some of the decomposition product ClO_2 diffuses back into the gas phase and oxidizes SO_2.

Conclusion

In the system SO_2–$NaClO_2$, the absorption rate of SO_2 exceeds the gas-film controlled rate, which implies

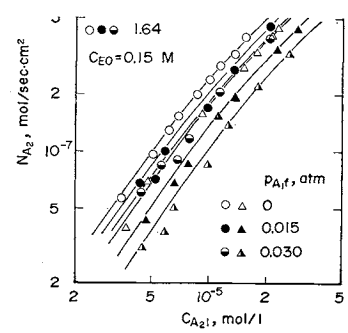
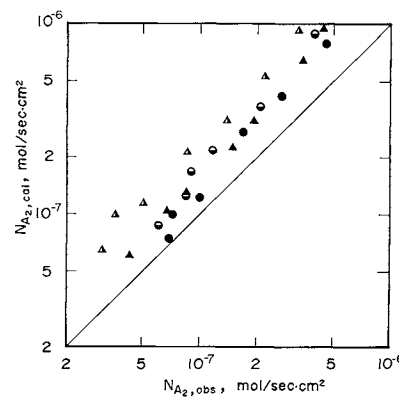


Fig. 8 Effect of SO_2 concentration on NO absorption rate ($NO+SO_2$)-($NaClO_2$ +NaOH) system)



Keys as in Fig 8

Fig. 9 Comparison of experimental results with theoretical predictions for NO absorption rates ($NO+SO_2$)-($NaClO_2$+NaOH) system)

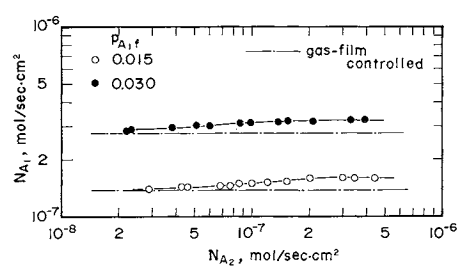


Fig. 10 Effect of NO absorption rate on SO_2 absorption rate

the possibility of the presence of gas-phase oxidation of SO_2 due to the evolved ClO_2.

In the SO_2-($NaClO_2$+NaOH) system, the absorption rate agrees with that under gas-film controlled conditions. In the (SO_2+NO)-($NaClO_2$+NaOH) system, the reduction of the NO absorption rate in the presence of SO_2 considerably increased over that derived through the decrease in interfacial concentrations of $NaClO_2$ and NaOH due to surface reaction with SO_2, and the rate of SO_2 absorption exceeded the gas-film controlled rate. Judging from this

Acknowledgment

The authors wish to express their thanks to Takeda Science Foundation for its financial support.

Nomenclature

C	=	concentration in liquid phase	[mol/l]
D	=	diffusivity in liquid phase	[cm^2/sec]
$\mathscr{D}$	=	diffusivity in gas phase	[cm^2/sec]
H	=	Henry's law constant	[mol/cm^3·atm]
I	=	ionic strength	[g-ion/l]
K	=	salting-out parameter	[l/mol]
k	=	rate constant of (m, n)-th order reaction	[(l/mol)$^{m+n-1}$/sec]
k_G	=	gas-side mass transfer coefficient	[mol/sec·cm^2·atm]
k_L	=	liquid-side mass transfer coefficient	[cm/sec]
m	=	order of reaction relative to absorbing component	
N	=	absorption rate	[mol/sec·cm^2]
n	=	order of reaction relative to liquid-phase reactant	
n_G	=	agitation speed in gas phase	[rpm]
n_L	=	agitation speed in liquid phase	[rpm]
p	=	partial pressure	[atm]
V_G	=	volumetric gas flow rate	[l/min]
V_L	=	volumetric liquid flow rate	[cc/sec]
x_a, x_c, x_g	=	contribution to K of anions, cations and the gas, respectively	[l/g-ion]
α	=	Bunsen absorption coefficient	[cm^3 of gas/cm^3 of solution]
ϕ	=	enhancement factor	
B	=	liquid-phase reactant B ($NaClO_2$)	
E	=	liquid-phase reactant E (NaOH)	
f	=	feed stream	
i	=	gas-liquid interface	
o	=	outlet	
w	=	water	
0	=	initial value	

〈Superscript〉

°	=	without reaction

Literature Cited

1) Amatsu, H.: *J. Japanese Tech. Assoc. of Pulp and Paper Industry*, **10**, 416 (1956).
2) Fujita, S.: *Kagaku Kōgaku*, **27**, 112 (1963).
3) Joosten, G. E. H. and P. V. Danckwerts: *J. Chem. Eng. Data*, **17**, 452 (1972).
4) Onda, K., E. Sada, T. Kobayashi, S. Kito and K. Ito: *J. Chem. Eng. Japan*, **3**, 18 (1970).
5) Onda, K., E. Sada, T. Kobayashi, S. Kito and K. Ito: *ibid.*, **3**, 137 (1970).
6) Sada, E., H. Kumazawa, N. Hayakawa, I. Kudo and T. Kondo: *Chem. Eng. Sci.*, **32**, 1171 (1977).
7) Sada, E., H. Kumazawa, I. Kudo and T. Kondo: *ibid.*, **33**, 315 (1978).
8) Teramoto, M., T. Kitagawa and H. Teranishi: *Kagaku Kogaku Ronbunshu*, **3**, 99 (1977).
9) Vinograd, J. R. and J. W. McBain: *J. Am. Chem. Soc.*, **63**, 2008 (1941).
10) Wise, D. L. and G. Houghton: *Chem. Eng. Sci.*, **23**, 1211 (1968).

(Presented at the 11th Autumn Meeting of The Soc. of Chem. Engrs., Japan, at Tokyo, October 1977.)