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Ammonia Removal by Air Stripping Tower*)

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ABSTRACT

Ammonia is a very soluble gas in water. The stage of NH_3 and NH_4^+ is affected by pH and temperature. This study reports an ammonia removal by an air stripping tower which is filled up with packing bed (Intalox Saddles). This tower is an apparatus that removes only isolated NH_3 by air stripping. In vitro removal, the study has revealed that the ammonia removal ratios are 97. 3, 95. 3, 95. 0 and 91. 5% when the flow rates of each test solution are 100, 200 and 300 ml/min. at the condition of pH 11. 0. It also revealed that the ammonia removal rates were more than 90% without regard to the test solution's initial concentration at pH 11. 0 at the flow rate of 100 ml/min. At pH 9. 0, it revealed only 18% removal rate. Each result agrees with the theoretical values of ammonia in water. Thease studies suggest that our ammonia removal system is effective in artificial kidney with dialysate regeneration.

INTRODUCTION

Various dialysate regeneration systems for artifical kidney have so far been developed and reported. Most of them use the uremic metabolite removal technique by means of adsorbents. There is a high rate of urea existing therein, which is a substance highly soluble in water and difficult to be adsorbed. Therefore, a special system had to be considered for application of charcoal to its adsorption. A typical method used for removing urea at present is that in which urea is decomposed by enzymatic hydrolysis into ammonia which is adsorbed by ion-exchange resin1,2).

In case of such a system using an adsorbent, a decrease in clearance is observed with the lapse of time and a large amount of adsorbent is required due to the adsorbed quantity on the quantity of adsorbent. In addition, the adsorbed quantity will be decreased by the effects of other coexisting solutes. Thus, sufficient efficiency has not yet been reached.

Noting that NH_4^+ in water solution turns into NH_3 depending on pH and temperature and into free NH_3 almost 100% at pH 11 at a room temperature, the authors have designed a system for removing ammonia by making it to contact with a high flow rate of air for a physical stimulation.

METHOD AND RESULT

1. Ammonia Removal System

Principle: The concentration of ammonia in water is expressed by the following Eqs. (1) and (2). From Eqs. (4) and (5) giving the dissociation constants of ammonia and water, Eq. (3) can be obtained to make clear the dependency of the concentration of ammonia on pH and temperature.

$$NH_3(\%) = \frac{[NH_3]}{[NH_3]+[NH_4^+]} \times 100 \qquad (1)$$

$$= \frac{100}{1+[NH_4^+]/[NH_3]} \qquad (2)$$

$$= \frac{100}{1+K_b[H^+]/K_w} \qquad (3)$$

$$[NH_4^+][OH^-]/[NH_3] = K_b \qquad (4)$$

$$[H^+][OH^-] = K_w \qquad (5)$$

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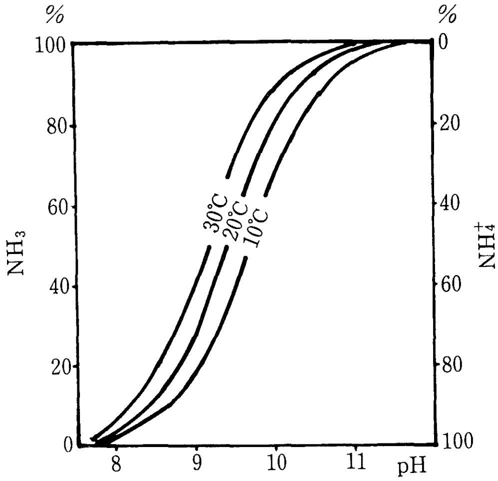
K_b : Dissociation constant of NH_4OH
K_w : Dissociation constant of Water

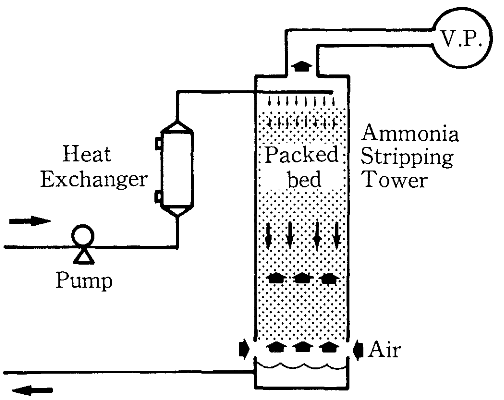
Fig. 1 shows the variation in proportion of NH_4^+ and NH_3 depending on pH and temperature. From this, NH_4^+ solution made to pH 11 or higher will become in the state of almost 100% NH_3. However, NH_3 is a substance hardly soluble in water and will not be dispersed unless any physical stimulation is given. From among a number of such a physical stimulation methods, the authors selected the gas-liquid contacting operation method that can be easily performed continuously. There are also 2 types of the gas-liquid contacting operation method—the gas-dispersed type and the liquid-dispersed type. The dispersed phase generally shows more uniform flow than that in the continuous phase, and therefore, gives a reasonable mass transfer coefficient. In case of NH_3 with a great gas-film resistance, the use of the liquid-dispersed type is considered more advantageous. Thus, a liquid-dispersed gas-liquid contacting-type ammonia removal system was designed and studied.

Apparatus: An ammonia stripping tower of 11 cm in diameter and 78 cm in length was manufactured and filled with Intalox saddle. Projections were provided at every 13 cm on its inside wall to prevent channelling reducing its effeciency. Air was taken into from the tower bottom and discharged from the tower top. The liquid was sprayed from tower top and passed through the packing in the opposite direction to that of the air flow as contacting with the air (Fig. 2).



(J. M. Cohen, 1971)

Fig. 1. Relationship diagram of pH and ratio of NH_3 and NH_4^+



Tower diameter : 11cm
Tower length : 78cm
Packed bed : ½ inch Intalox Saddle
Air flow rate : 2.7m^3/min

Fig. 2. Scheme of ammonia removal system

The flow rate of air was calculated as a function of the following equation from the correlation diagram of Eckert:

$$\frac{G^2(a/\varepsilon^3)(\mu_L/\mu_W)}{g\rho_G\rho_L} = f\left(\frac{L}{G}\left(\frac{\rho_G}{\rho_L}\right)^{\frac{1}{2}}\right)$$

G : Mass velocity of air (kg/m^2·hr)
L : Mass velocity of intake liquid (kg/m^2·hr)
ρ_G : Density of air (kg/m^3)
ρ_L : Density of intake liquid (kg/m^2)
μ_L : Viscosity of intake liquid (c. p.)
μ_W : Viscosity of water (c. p.)
a : Specific surface of paking (m^2/m^3)
ε : Void fraction of paking
g : Acceleration of gravity (m/hr^2)

In this study, the flow rate of air (2.7 m^3/min) that reaches the loading velocity at 100 ml/min of the flow rate of the intake liquid was used.

The intake liquid used was a NH_4Cl-added dialysate that raised pH of 1N, NaOH. Its temperature was changed between 40-65°C using a heat exchanger (JMS HE-01, Japan Medical Supply Co. Ltd).

Results: The intake dialysate was set at pH's 11.0 and 9.0. When the total nitrogen concentration of intake ammonia was changed between 1000-15000 μg/dl, a removal rate of more than 98.9% at pH 11.0 under the condition of 100 ml/min flow rate and 60-65°C intake temperature. On the contrary, almost no removal, 16.3-17.9% was observed at pH 9.0 (Table 1). Next, using a liquid of initial concentration 1500 μg/dl and making fine changes in pH between 7.0-13.0, the removal rates higher than 100% were obtained at pH over 11.0 against 0% at pH 7.0 (Fig. 3). This figure is in good agreement with Fig. 1 showing the relation between pH and NH_3 and NH_4^+ and demonstrates that the authors' method has nearly completely removed NH_3 contained in the intake liquid. When the flow rate of the intake liquid was changed to 100, 200 and 300 ml/min, removal rates of higher than 90% were able to be obtained regardless of the degree of the initial concentration (Table 2).

Table 1. The effect of pH on the ammonia removal rates

Initial pH	Initial conc. (μg/dl)	Out conc. (μg/dl)	Out pH	Removal rate (%)
11	1000	11	9.5	98.9
	7500	30	9.5	99.6
	15000	165	9.5	98.9
9.0	1000	837	7.5	16.3
	7500	6270	7.2	16.4
	15000	12315	7.6	17.9

Flow rate: 100 ml/min
Initial temp.: 60~65°C

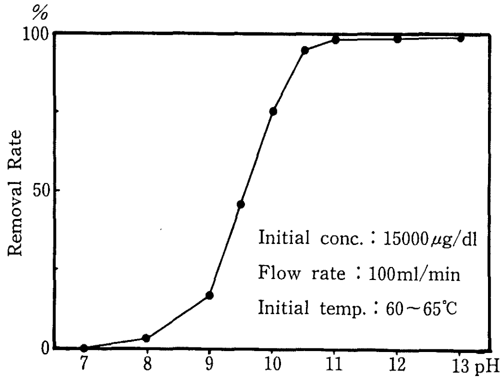


Fig. 3. The effect of pH on the ammonia removal rate

Table 2. The effect of flow rate on the ammonia removal rates

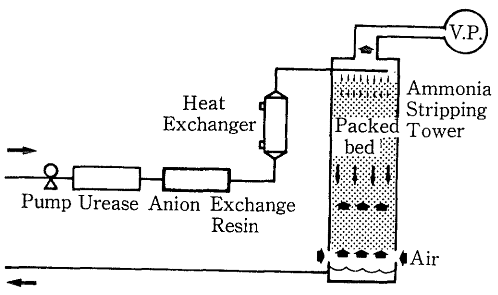
Initial conc. (μg/dl)	Removal rates (%)		
	Flow rate 100 ml/min	200 ml/min	300 ml/min
1000	98.9	97.0	93.8
7500	99.6	95.6	90.2
15000	98.9	95.5	92.1
30000	91.9	91.7	89.8
M±SD	97.3±3.6	95.0±2.3	91.5±1.8

Initial pH: 11.0
Initial temp: 60~65°C

2. Urea Removal System

Apparatus: The authors designed a urea removal system (Fig. 4) incorporating the ammonia stripping tower that had demonstrated its high efficiency. This system is to change urea to ammonia by urease, exchange Cl^- with OH^- by anion exchange resin to raise pH to higher than 11, and change NH_4^+ to NH_3, which is removed through the ammonia stripping tower.

Method and Results: Using 2000 cc of anion exchange resin (IRA-410, Rohm and Haas Co., Ltd.), a dialysate with 15 mg/dl of urea-



Scheme of urea removal system

Fig. 4. Scheme of urea removal system

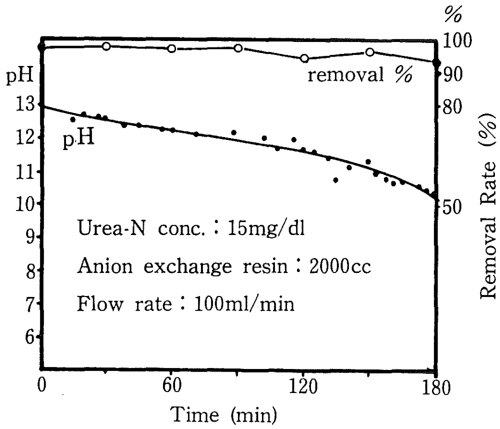


Fig. 5. Relationship of removal rate and pH by urea removal system

N concentration was run through the tower at a flow rate of 100 ml/min for 3 hr.

As a result, after passing the anion exchange resin column, pH higher than 11 and the urea removal rate higher than 95% were always maintained up to 150 min (Fig. 5).

DISCUSSION

The method of removing ammonia in the form of free NH_3 is often used in chemical and waste water treatment industries. This idea was initially applied to the artifical kidney with dialysate regeneration system by Ota[3] and Piskin[4-6]. In particular, Piskin has reported a goot result obtained by using the packed bed column with rashing rings[6] or gass oxygenator[5] as an ammonia removal system.

The greatest feature of this ammonia removal system is the use of a physical removal method, which maintains almost semipermanent removing performance and a constant removal rate even at any higher concentration of ammonia, and in addition, is not subject to the effects of any coexisting substances. The important factors affecting the removal efficiency are pH, liquid temperature and the air/liquid flow rate ratio (A/W ratio). The effect of pH being especially great, the removal rate cannot reach over 99% unless pH is higher than 11 in room temperature. The higher liquid temperature will result in the smaller solubility of NH_3 facilitating its despertion into the air. As shown in Fig. 1, the higher the liquid temperature, the more effective removal can be performed at lower pH's. The higher A/W ratio shows better results. The highest A/W ratio can be obtained at the loading velocity of the gas flow at the loading point (at which the pressure loss in the tower will be increased as the flow rate in the tower is increased) that will be determined according to the shape of the removal tower (diameter and packing).

Using a removal tower thus determined, constant ammonia removal rates higher than 90% could be obtained. The most difficult problems in practical application of this system to an actual dialysate regeneration is how to regulate the degree of pH. When performing a hydrysis of urea by urease, pH will rise to over 9, which is not high enough. The authors used anion exchange resin to raise pH to over 11 and removed NH_3 resulting in the urea removal rate of over 90% for 3 hr. The pH of the liquid discharged from the removal tower was lowered only to 9. 5, which required compensation by continuous injection of HCl.

REFERENCES

1. **Ash, S. R., Barile, R. G., Thornhill, J. A., Sherman, J. D. and Wang, N-H. L.** 1980. In vivo evaluation of calcium-loaded zeolites and urease for urea removal in hemodialysis. Trans. Am. Soc. Artif. Intern. Organs **26** : 111-115.
2. **Kjellstrand, C., Borges, H., Pru, C., Gardner, D. and Fink, D.** 1981. On the clinical use of microencapsulated zirconium phosphate-urease for the treatment of chronic uremia. Trans. Am. Soc. Artif. Intern. Organs **27** : 24-29.
3. **Ota, K., Era, K., Suwa, S., Kaneko, I., Aida, K. and Agishi, T.** 1979. A new method of urea removal using urease and expanded polytetrafluorethylene membrane. Artif. Organs **3** : 350-353.
4. **Piskin, E. and Chang, T. M. S.** 1980. Effects of pH and urea concentration on urea removal from dialysate by enzymatic conversion and gas adsorption using a capillary hemodialyzer. Int. J. Artif. Organs **3** : 36-40.
5. **Piskin, E. and Chang, T. M. S.** 1981. Effects of temperature on the removal of urea as ammonia by enzymatic conversion and gas absorption using an oxygenator. Int. J. Artif. Organs **4** : 45-48.
6. **Piskin, E., Evren, V., Özdural, A. R. and Chang, T. M. S.** 1981. Design of a packed-bed gas desorption column for the removal of urea as ammonia. Artif. Organs **5(Suppl.)** : 624-627.