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Nitrogen removal by free ammonia stripping from high pH ponds

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Nitrogen is one of the pollutants that is dealt with in particular in any wastewater management program, because of the complex effects that various nitrogenous compounds may have on receiving waters, and the difficulties associated with their removal and/or conversion from a less to a more desirable form. In wastewater reuse schemes, the need for nitrogen removal may become the key factor in determining the type and sequence of treatment processes to be adopted.

Conventional primary-secondary biological treatment has only a limited capacity for removing nitrogen. Several advanced treatment processes have the specific capacity to remove nitrogen from wastewater effluents. These are:[1] desorption of molecular ammonia at the liquid-air interface in an alkaline medium, referred to as "ammonia stripping"; microbial conversion of ammonia to nitrates, followed by microbial conversion of nitrates to nitrogen gas, referred to as "biological nitrification-denitrification"; exchange of ammonia for calcium or sodium ions by use of natural zeolites such as clinoptilolite, referred to as "selective ion exchange" (by this method the recovery of ammonia is also possible); oxidation of ammonia to nitrogenous gases by chlorine, referred to as "breakpoint chlorination."

Additional advanced wastewater treatment (AWT) processes, where nitrogen removal occurs to a certain extent although the specific purpose is to remove other constituents, are: chemical flocculation-sedimentation, flotation and filtration, (which can remove particulate organic nitrogen); electrodialysis and reverse osmosis (which can remove ammonia, as well as nitrates); and land treatment (which can remove nitrogen by a variety of biological and chemical processes and can convert most of the residual nitrogen to nitrates).

The purpose of this paper is to present and discuss the results of the investigation on free ammonia stripping from high pH ponds carried out in the DAN Region AWT pilot plant (Israel) from 1975 to 1977. Results from the operation of the full-scale Dan Region Project (Stage 1) in the period 1977–1979 are included to support the pilot plant data.

AMMONIA STRIPPING SYSTEMS

Removal of nitrogen by stripping of ammonia from the water into the air has been developed as a process that can be used in conjunction with the high-lime treatment process. The lime spent for raising the pH to high values is indirectly utilized to convert most of the ammonia in the effluent from the ionic form (NH_4^+) to the molecular form (NH_3), a dissolved gas that under appropriate conditions can be desorbed from the water and transferred to the air.

When lime treatment is not envisaged as part of the treatment scheme to be adopted, ammonia stripping cannot presumably compete, from an economic point of view, with other nitrogen removal methods. When high-lime treatment is incorporated in the treatment scheme, the ammonia stripping process can compete successfully with any other process of nitrogen removal.

Natural recarbonation from the atmosphere occurs in parallel with ammonia stripping.

Three basic ammonia stripping systems have been developed, investigated and applied, mainly in the U. S., South Africa and Israel. These are air stripping towers, forced stripping (mechanically aerated) ponds, and free stripping (non-aerated) ponds. They are briefly described below.

Air stripping towers. The first pilot and full-scale ammonia stripping towers were operated and investigated at the South Tahoe Water Reclamation Plant. The process is based on the blowing of large quantities of air into the tower, and on the formation of small water droplets to increase the contact area between air and water. Although the ammonia removal efficienies were, in general, satisfactory, two major limitations of the process were identified:[2] calcium carbonate scale formation on the wood surface of the tower packing, and operational difficulties to prevent freezing, as well as reduced efficiency, at ambient air temperatures below 0°C (32°F). The latter problem should not exist in climates where freezing temperatures do not occur, whereas the former can apparently be diminished if an adequate packing design is adopted, enabling easy removal of the accumulated calcium carbonate ($CaCO_3$) scale. Experience at Lake Tahoe and at Orange County Water District showed that counter-current towers and plastic packings are less susceptible to scale accumulation than cross-flow towers and rough-surface wood packing.[2,3] The tower design adopted for Orange County included removable panels and easy access for their removal and cleaning *in situ*.[4]

The research and development work carried out in connection with ammonia stripping towers (mainly at Lake Tahoe), as well as the detailed and accurate reports published on the merits and limitations of the process performance,[5] have provided a sound basis for the understanding of the ammonia stripping process and have undoubtedly stimulated the development of other ammonia stripping systems, such as those using ponds.

Forced stripping ponds. This process is based on detention of the high-pH effluent in ponds equipped with devices or systems that agitate or break the gas film formed at the water-air interface, increase the water-air surface contact, and/or accelerate the upward movement of the gas molecules. Systems investigated and used include blowing of air above the water surface, use of surface aerators, surface sprinkling, and air bubbling. At South Tahoe, as well as in South Africa, high-pH ponds with short detention time (8 to 12 hours) and provided with surface agitation have been used as a first-stage process for partial ammonia stripping and equalization, to be followed by ammonia stripping towers and breakpoint chlorination.[5,6]

Free stripping ponds. Ammonia is freely released from high-pH water if held for relatively long periods in shallow ponds, even without the use of mechanical devices. Under suitable conditions, mainly high temperature and wind velocity, the process can be efficiently used in conjunction with high-lime treatment. It is undoubtedly the simplest and most economic method of ammonia stripping, provided low-cost land is readily available.

This process was first studied in Israel at laboratory scale by Folkman and Wachs in 1971 to 1972.[7] Following successful laboratory results, the process was adopted for the first stage of the large Dan Region (Tel Aviv Metropolitan Area) Sewage Reclamation Project.

THEORETICAL BACKGROUND

In municipal wastewater, nitrogen is usually found as soluble ammonia and as particulate and dissolved organic nitrogen; nitrates and nitrites are usually negligible. In secondary effluents from biological treatment plants (such as oxidation ponds) that do not provide for nitrification, nitrogen is found in the same forms as in raw wastewater. Ammonia produced by hydrolysis of urea and by biological degradation of organic compounds, such as amino acids, usually accounts for most of the soluble nitrogen.[1]

Ammonia is found in equilibrium between the molecular, gaseous form (NH_3) and the ionic form (NH_4^+) according to the reaction given below

$$NH_3 + H_2O \rightleftarrows NH_4^+ + OH^- \qquad (1)$$

The reaction is highly dependent on pH and temperature. Alkaline pH favors the presence of the molecular form, whereas neutral and acidic pH favor the presence of the ionic form. Higher temperatures enhance (at the same pH) the presence of the molecular form. Because the conversion of ammonia to the molecular, gaseous form is the prerequisite of a successful ammonia stripping process, a high pH is required. The distribution between molecular ammonia (NH_3) and ammonium ion (NH_4^+) as a function of pH and temperature is well known.[1,2,5] At 20°C, all the ammonia is found in ionic form at pH 7, whereas at pH 11.5 all the ammonia is found in gaseous form; at pH 10.5 most of the ammonia (about 95%) is found in the gaseous form.

The release of gaseous ammonia from water to the atmosphere is a function of the relative difference in partial pressures of the ammonia gas in each of the two media. The transfer of ammonia from the liquid to the atmosphere occurs when the partial pressure of the dissolved gas in the water is greater than that of the gas in the atmosphere near the air-liquid interface, until an equilibrium of partial pressures is reached in accordance with Henry's law.[10] The ammonia rate mass transfer from water to air is considered to be proportional to the concentration of ammonia nitrogen in solution; it was experimentally proved to be a first-order reaction of the type[11]

$$\frac{dm}{dt} = -kC \qquad (2)$$

where

m = mass of ammonia transferred

t = time

C = ammonia concentration

k = ammonia loss rate constant, depending on pH, temperature, air velocity, and surface turbulence.

Work carried out by Stratton[8,9] on ammonia losses from streams and from slightly alkaline water impoundments has pointed to the possibility of liberating ammonia from alkaline water under natural mixing and turbulence conditions. It was observed that the am-

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monia loss is more pronounced in shallow streams and ponds where algae growth raise the pH to the alkaline range. A similar phenomenon partly explains the losses of ammonia from oxidation ponds, where pH is kept in the range 8 to 9 because of algal activity.

Folkman and Wachs[7] developed, on the basis of laboratory experiments, formulas for ammonia release from effluent treated with lime to pH 11 and determined the coefficients of ammonia release rates under continuous-flow and plug-flow conditions. One important finding of their work was the uniform ammonia concentration throughout the whole depth of the container (30 to 90 cm), even when wind velocity was negligible. This suggested that the rate of ammonia diffusion in a shallow body of water is greater than that of the ammonia release from the water surface. Based on the formulas developed, Folkman and Wachs estimated that under the winter conditions prevailing in the coastal area of Israel, where the Dan Region Project is located, the ammonia concentration could be decreased by 90%, after 15-day detention of the lime-treated effluent in shallow ponds.[7]

PILOT PLANT DESCRIPTION

Prior to the operation of the full-scale project, a large pilot plant (100 000 gal/day or 15 m^3/h) was operated in the vicinity of the full-scale plant; that is, under identical climatic conditions.[10,11]

The pilot plant (Figure 1) was fed with secondary effluent from the Dan Region large oxidation ponds and consisted of a lime treatment unit, with sludge blanket, reactor-clarifier and facilities for storage, preparation and feed of calcium hydroxide ($Ca(OH)_2$) slurry and magnesium chloride ($MgCl_2$) solution added as main chemical and flocculant aid, respectively; a series of shallow ponds (0.9 m deep) provided for long-time detention of the chemically treated high-pH effluent.

The reactor-clarifier consisted of a steel tank, 3.66 m diameter by 3.26 m high. In the center, located concentrically, were an internal bell-shaped cone and an external cylinder (reaction well). A turbine mixer (10–40 rev/min, 0.5 hp) was located on the top of the reaction well, inside the internal cone; a sludge rake (0.25–0.75 rev/min, 1 hp) was located at the level of the tank bottom.

The ponds were located in a basin that had been excavated in the immediate vicinity of the lime treatment plant; they covered a total area of approximately 2 750 m^2 and had a total volume of about 2 200 m^3. The shape of this basin was rectangular at the inlet and trapezoidal at the outlet. Its walls sloped (1:3) and were protected by a layer of concrete 10 cm thick; its bottom was coated with a layer of compacted clay 40 cm thick, in order to reduce water losses by infiltration. The basin was divided into 10 ponds separated from each other by asbestos partition walls. Overflow pipes were provided between the ponds to ensure gravitation flow from pond to pond, while maintaining a constant water depth of 0.9 m. A series of gates provided at the bottom of the partition walls facilitated filling or emptying of all the ponds at the same time.

The ponds had been constructed for pilot studies on free ammonia stripping (without aeration), as well as on forced ammonia stripping (by means of surface aerators). They were operated along two parallel flow lines—one line of seven ponds (Nos. 1 to 7) for free ammonia stripping, and another line of three ponds (Nos. 8 to 10) for forced ammonia stripping. In this paper only the study on free ammonia stripping, conducted in Ponds 1 to 7, is reported.

The operating volume of Ponds 1 to 7 was about 1 500 m^3 and the area at maximum water level (0.9 m) was about 1 600 m^2. The area and volume of each pond, as well as the detention time at various flow rates used during the pilot plant operation, are shown in Table 1.

PILOT PLANT OPERATION

The investigation on free ammonia stripping was carried out during two major periods of operation of the pilot plant: May to October, 1975 (summer–autumn season) and December 1975 to March 1976 (winter–spring season). Because the amount of data collected during one winter season was limited, additional data were collected during the subsequent winter (December 1976 to January 1977). In all periods the pilot plant was operated at a flow rate of 15 m^3/h (about 100 000 gal/day). The reactor-clarifier was operated at optimal conditions for clarification purposes (as established by previous studies and experiments); that is, pH in the range 11 to 11.8, and addition of $MgCl_2$ in such amounts that the total magnesium concentration in the secondary effluent would be 40 to 50 mg/l.

The flow to the ponds was regulated by means of several orifices available in the inlet chamber, in order to obtain the desired detention times in the series of 7 ponds. The maximum detention time in the free ammonia stripping ponds varied between 7 and 14 days.

Daily samples were collected from the secondary effluent fed to the pilot plant from the oxidation ponds (SE), the high-lime effluent (HLE), which is the influent to the ammonia stripping ponds, and from the outlet pipe of each pond (Figure 1). The effluent from the last ammonia stripping pond (No. 7), referred to as tertiary effluent (TE), was conveyed in the Dan Region Project to groundwater recharge prior to reuse. All the samples were analyzed in accordance with the standard methods for examination of water and wastewater.

From a climatic point of view, the study periods can be characterized as follows: in summer, daily average water temperatures in the ponds generally varied be-

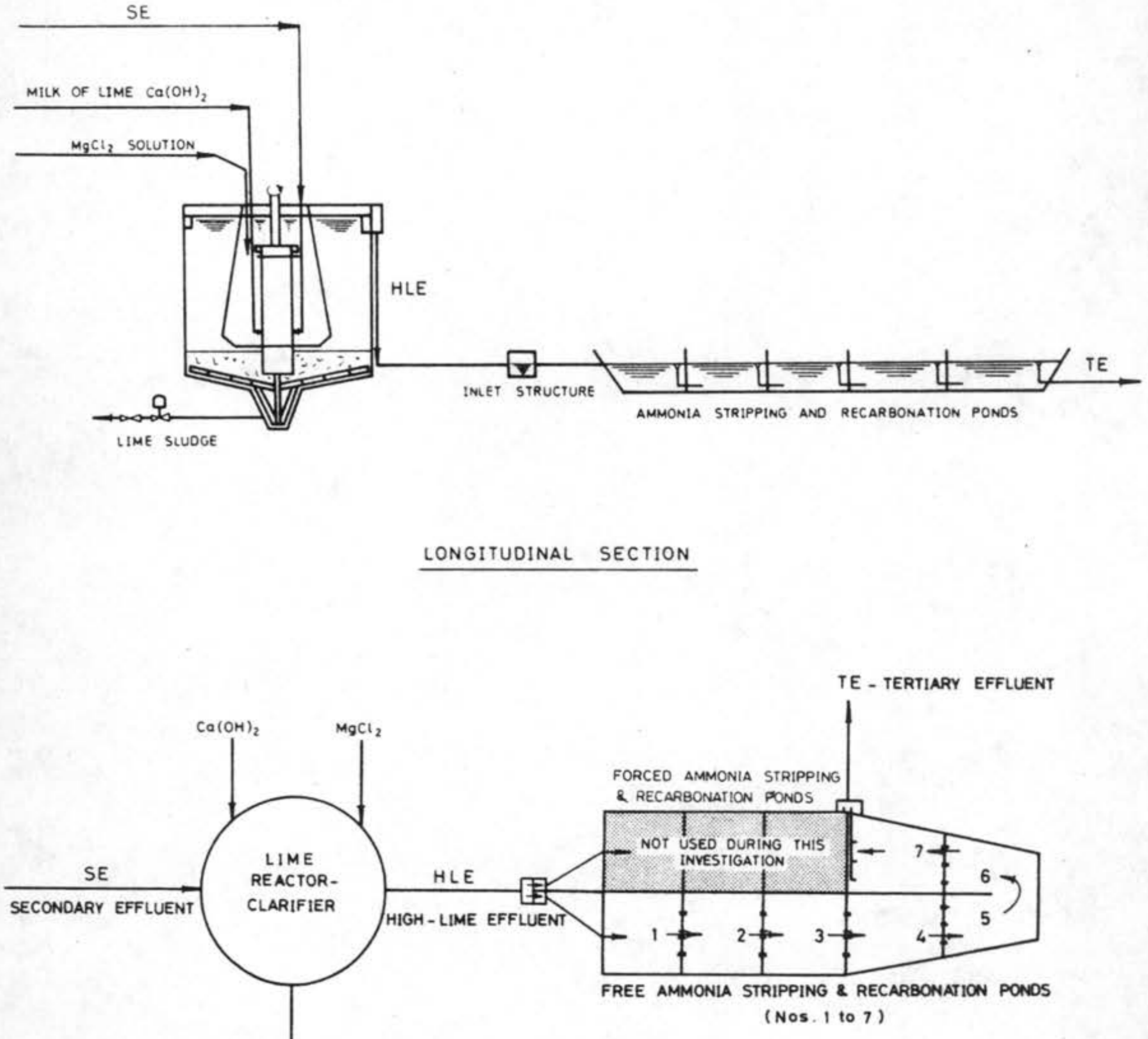

Figure 1—Dan Region AWT pilot plant.

tween 25 and 30°C, whereas in winter they varied between 10 and 20°C. In the transition periods (autumn and spring), temperatures generally varied between 20 and 25°C. The minimum daily average water temperature recorded in winter was 8°C. The winter temperature in the project area rarely drops below 5°C; freezing temperatures, which are known to affect adversely some wastewater treatment processes, and particularly

Table 1—Physical and hydraulic data of the ponds.

Pond no.	Area m²	Volume m³	Detention time (days) at various flow rates used 8.2 m³/h	7.0 m³/h	6.75 m³/h	5.4 m³/h	4.6 m³/h	4.27 m³/h
1	222	200	1.02	1.19	1.23	1.54	1.81	1.95
2	244	220	1.12	1.31	1.36	1.70	1.99	2.15
3	244	220	1.12	1.31	1.36	1.70	1.99	2.15
4	239	215	1.09	1.28	1.33	1.66	1.95	2.10
5	219	197	1.00	1.17	1.22	1.52	1.78	1.92
6	219	197	1.00	1.17	1.22	1.52	1.78	1.92
7	239	215	1.09	1.28	1.33	1.66	1.95	2.10
Total	1 626	1 464	~7.5	~9	~9	~11	~13	~14

the ammonia stripping process, never occur in the project area. Nevertheless, even differences of 10 to 20°C between summer and winter temperatures are significant and have a clear impact on the ammonia stripping process results.

REVIEW OF RESULTS

Figure 2 shows the results obtained during the pilot plant study, grouped into 10 periods, and roughly characterized by the same climatic conditions; that is, temperature, relative humidity, wind velocity. Five of these periods correspond to the summer season (temperatures 25 to 30°C), three to the winter season (temperatures 10 to 20°C), and two to the transition seasons, autumn and spring (temperatures 20 to 25°C).

Figure 3 shows median ammonia concentration and pH at the outlet of each pond, calculated for each period from the available daily results. Mediam ammonia concentration and pH reached in the last polishing pond (No. 7) are shown in Table 2 for each operation period, together with temperature and hydraulic theoretical detention time in the ponds that are the major parameters affecting the ammonia stripping efficiency.

The ammonia concentration in the effluent was reduced by free stripping from values generally in the range 15 to 30 mg/l to values generally in the range [illegible] 12 mg/l after 1 to 2 weeks' detention in the ponds, at temperatures ranging between 10 and 30°C.

In summer, at temperatures varying between 25 and 30°C, the median ammonia concentration was reduced by free stripping from 15 to 25 mg/l to 1 to 5 mg/l after 9 to 14 days' detention in the ponds. In winter, the median ammonia concentration was reduced by free stripping from about 30 mg/l to about 12 mg/l after 8 to 9 days' detention in the ponds, at temperatures varying between 10 and 15°C; and to about 7 mg/l after 13 to 14 days' detention in the ponds, at temperatures varying between 15 and 20°C.

In the transition periods (autumn and spring), at temperatures varying between 20 and 25°C, the ammonia concentration was reduced by free stripping from 20 to 30 mg/l to 2 to 5 mg/l after 11 to 14 days' detention in the ponds.

Ammonia concentrations in the influent to the stripping ponds are usually higher in winter than in summer because of the higher concentrations in the raw wastewater and the lower efficiency of the oxidation ponds in removing nitrogen in winter.

Concentrations of nitrites and nitrates were usually negligible (less than 0.5 mg/l) in the ponds' effluent, because no nitrification occurs in the ammonia stripping ponds. Concentration of dissolved organic nitrogen (about 2 to 4 mg/l) remained unchanged in the ammonia stripping ponds.

DISCUSSION OF PILOT PLANT RESULTS

An analysis of the pilot plant results was carried out, taking into account the data collected during four sum-

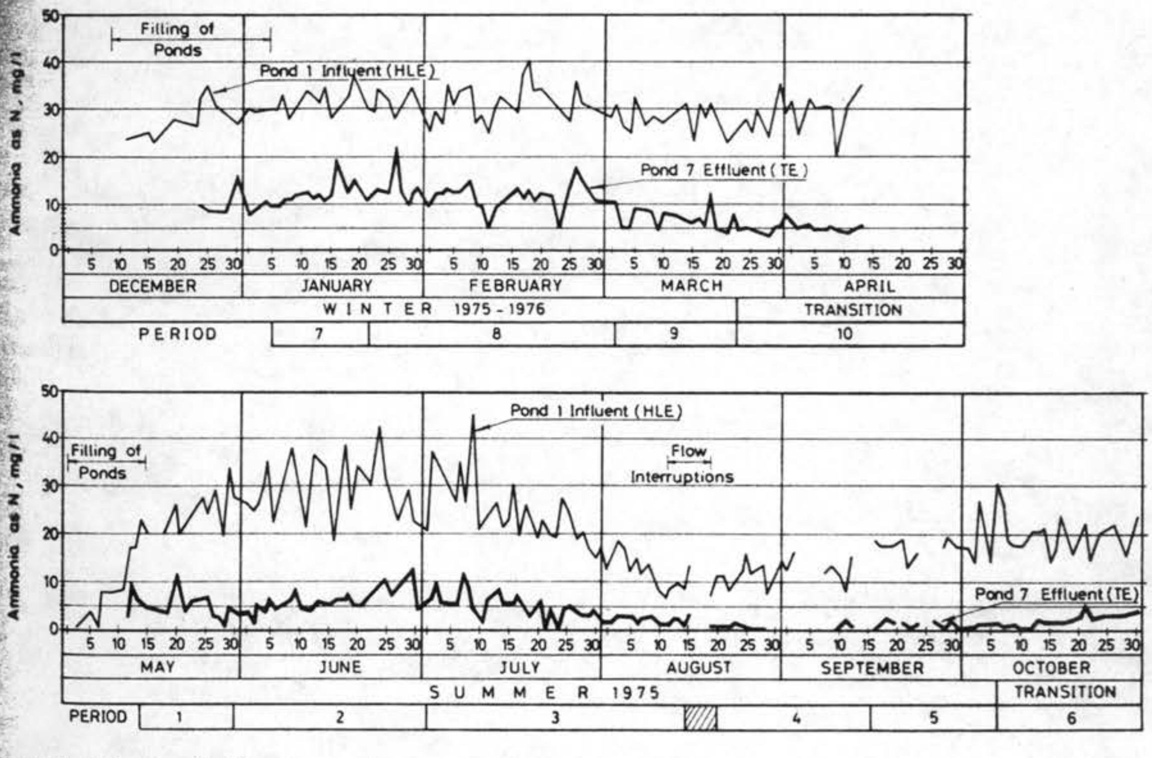

Figure 2—Daily influent and effluent ammonia concentrations.

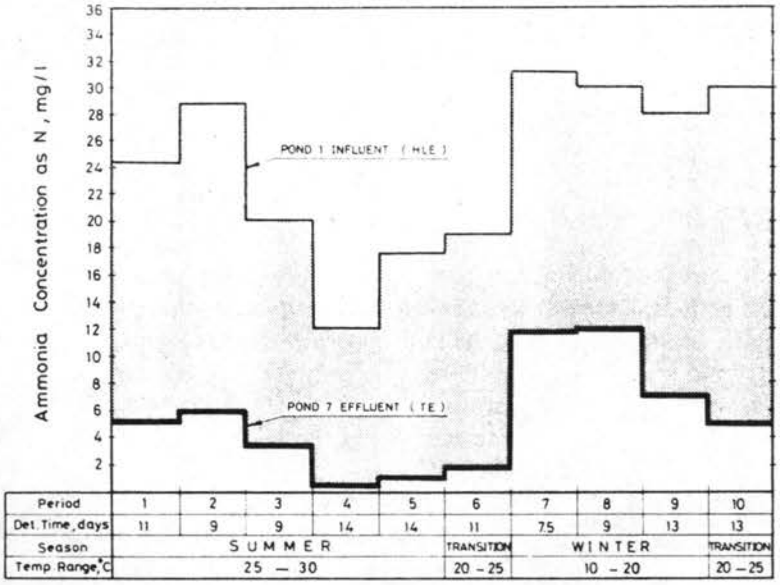

Figure 3—Periodical median ammonia concentration in ponds' influent and effluent.

mer periods (Periods 2 through 5) and two winter periods (Periods 7, 8), which were characterized by typical climatic conditions for the two extreme seasons of the year (25 to 30°C in summer and 10 to 15°C in winter) and by maximum detention times of 9 to 14 days in summer and 7.5 to 9 days in winter. The results obtained for each intermediate pond were taken into account in this analysis.

The efficiency of the ammonia removal process in the stripping ponds was lower in winter than in summer because of the lower temperatures and the lower pH values reached in the last pond effluent. It seems that the concomitant recarbonation process that occurs in the ammonia stripping ponds hinders the completion of the ammonia stripping process in winter.

Ammonia concentration versus detention time in the ponds. In Figure 4, ammonia concentrations are plotted versus detention time in the ponds on a semilogarithmic

Table 2—Summary of pilot plant results for free ammonia stripping ponds.

						Median values in Ponds 1-7			
						Ammonia concentration mg/l		pH	
Season	Period No.	Dates	Length (days)	Temperature range (°C)	Hydraulic detention time (days)	Influent	Effluent	Influent	Effluent
Summer	1	May 14-May 29, 1975	16	25-30	11	24.4	5.1	11.3	10.4
	2	May 30-June 30, 1975	31	25-30	9	28.8	6.0	11.6	10.7
	3	July 1-Aug. 15, 1975	46	25-30	9	20.0	3.5	11.4	10.7
	4	Aug. 20-Sept. 15, 1975	27	25-30	14	12.0	0.4	11.3	10.0
	5	Sept. 16-Oct. 6, 1975	21	25-30	14	17.5	1.0	11.7	10.3
Transition (Autumn)	6	Oct. 7-Oct. 30, 1975	24	20-25	11	19.0	1.8	11.6	10.8
Winter	7	Jan. 5-Jan. 21, 1976 Dec. 16, 1976-Jan. 10, 1977	17 26 } 43	10-15	7.5	31.2	11.9	11.5	10.1
	8	Jan. 22-March 2, 1976	12	10-15	9	30.0	12.0	11.5	10.0
	9	March 3-March 22, 1976	20	15-20	13	28.0	7.0	11.5	10.0
Transition (Spring)	10	March 23-April 13, 1976	22	20-25	13	30.0	4.9	11.7	10.2

Note—Detention times shown are for the entire series of seven ponds; pH values and ammonia concentrations correspond to the influent to the first pond (No. 1) and the effluent from the last pond (No. 7).

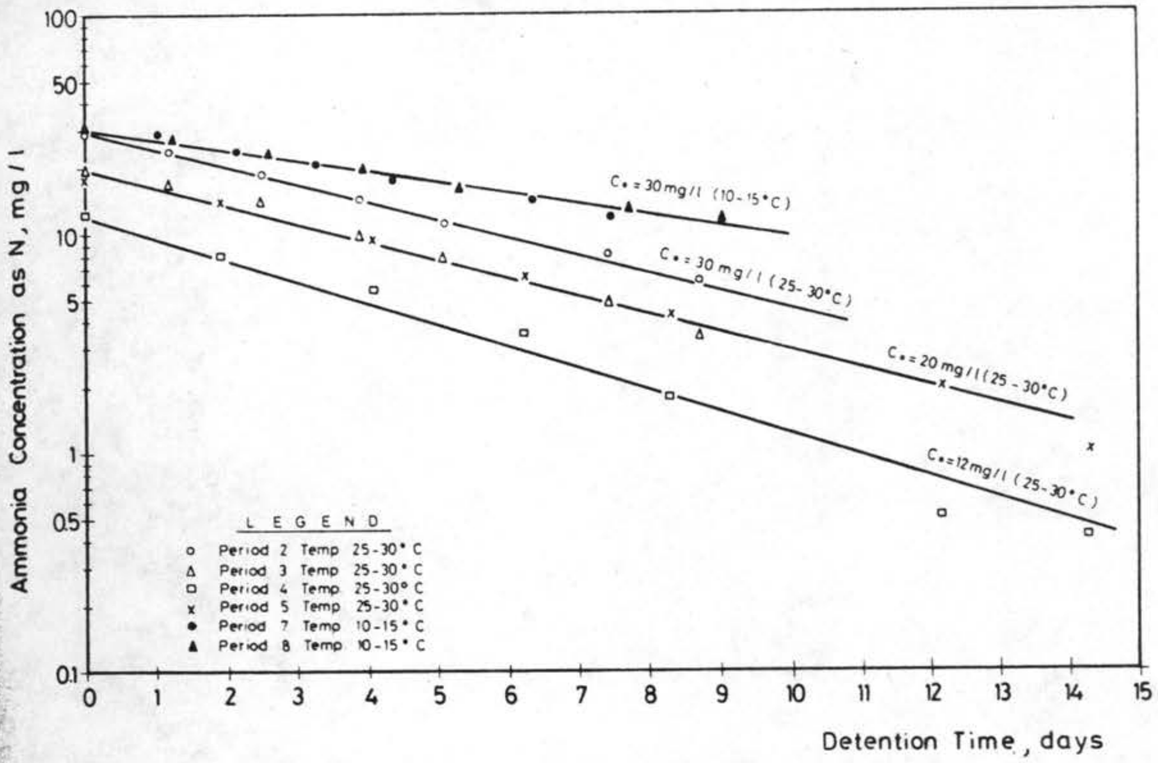

Figure 4—Ammonia concentration at various detention times and initial concentrations.

tude, for the various summer and winter operation periods. The linear plot obtained for all periods confirms that the ammonia stripping is a first-order reaction. The data collection for summer temperatures (25 to 30°C) permitted the drawing of three lines of equal slope corresponding to intial ammonia concentrations of 12, 20, and 30 mg/l. The data collected for winter temperatures (10 to 15°C) permitted the drawing of one line (of smaller slope than in summer) corresponding to an initial concentration of 30 mg/l. Because the slope of the line indicating the reaction rate should be constant at a given temperature range (as proved by the summer data), parallel lines can be approximately drawn for other initial concentrations in winter as well as in summer. Figure 4 can thus be completed (by interpolation and extrapolation) to give ammonia concentration versus detention time for various initial ammonia concentrations.

Process kinetics. Because the ammonia stripping process is a first-order reaction, its kinetics can be represented by the formula of first-order reactions for plug-flow systems

$$\ln \frac{C}{Co} = -Kt \qquad (3)$$

or

$$\frac{C}{Co} = e^{-Kt} \qquad (4)$$

where

Co = initial concentration

C = concentration at time t

K = reaction rate constant

From the data obtained for summer and winter temperatures, the reaction rate constants were calculated as follows:

$K = 0.18\text{–}0.25\ \text{day}^{-1}$ for summer (25 to 30°C)

$K = 0.12\ \text{day}^{-1}$ for winter (10 to 15°C)

Effect of pH on ammonium ion (NH_4^+) and ammonia molecule (NH_3) concentration. By detention of high-pH effluent in open ponds, two "competitive" processes occur: the stripping of the free ammonia molecule (NH_3) that requires high pH values, and the recarbonation of the effluent by absorption of carbon dioxide (CO_2) from the atmosphere, that gradually lowers the pH by converting hydroxides to carbonates. If the ammonia stripping rate is high, very good removal of ammonia is achieved before the pH is reduced to values that can hinder the stripping process. This is the case in summer, when the higher temperatures facilitate high ammonia stripping rates (Figure 5).

If the recarbonation rate is high, only partial removal of ammonia can be achieved, because the pH drops to

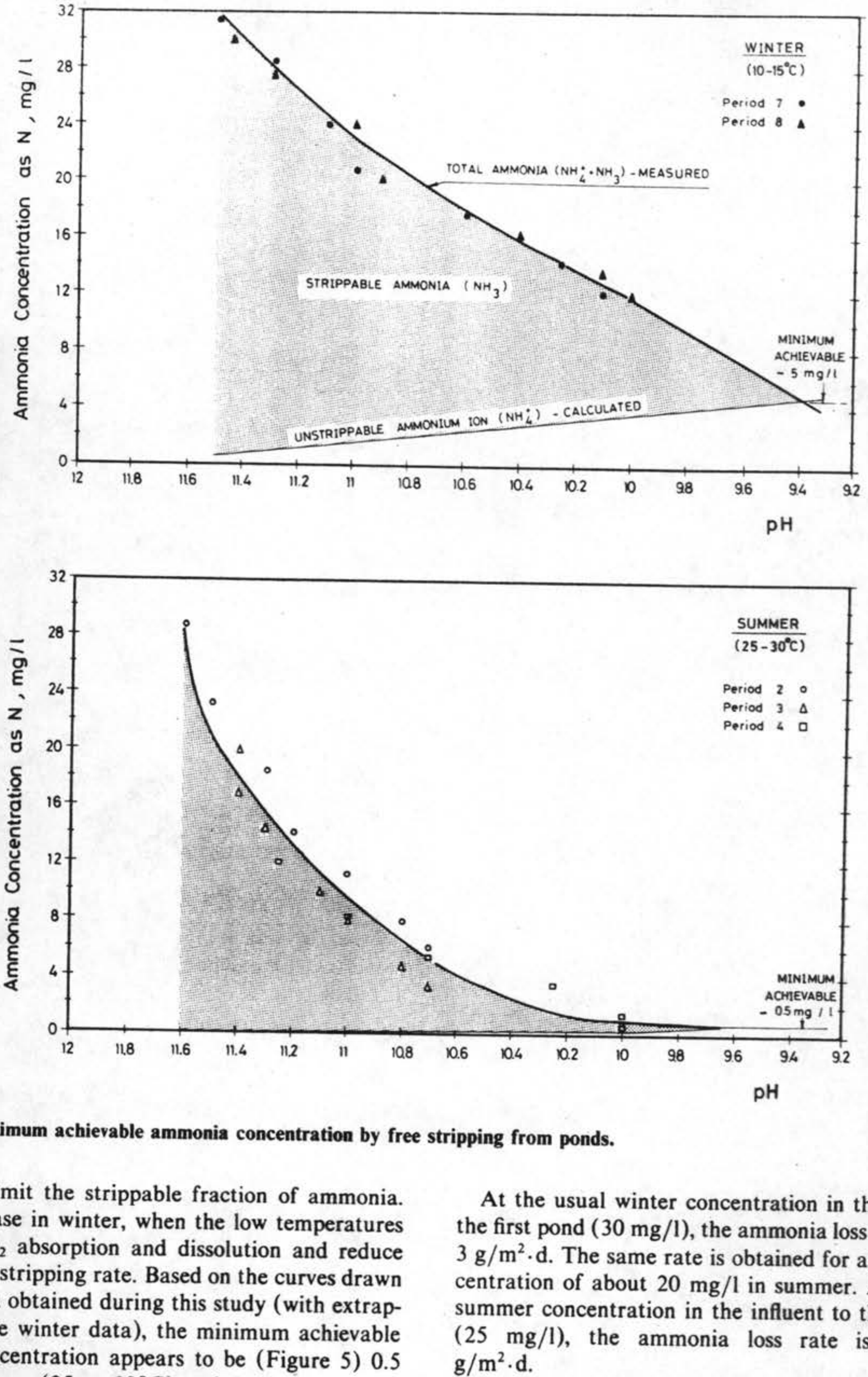

Figure 5—Minimum achievable ammonia concentration by free stripping from ponds.

values that limit the strippable fraction of ammonia. This is the case in winter, when the low temperatures facilitate CO_2 absorption and dissolution and reduce the ammonia stripping rate. Based on the curves drawn from the data obtained during this study (with extrapolation for the winter data), the minimum achievable ammonia concentration appears to be (Figure 5) 0.5 mg/l in summer (25 to 30°C) and 5 mg/l in winter (10 to 15°C).

Ammonia loss rate. The rate of ammonia loss per unit area of pond was calculated for some of the periods studied and plotted as a function of the initial ammonia concentration (Figure 6).

At the usual winter concentration in the influent to the first pond (30 mg/l), the ammonia loss rate is about 3 g/m^2·d. The same rate is obtained for an initial concentration of about 20 mg/l in summer. At the usual summer concentration in the influent to the first pond (25 mg/l), the ammonia loss rate is about 3.7 g/m^2·d.

Ammonia removal efficiency. The percentage removal efficiency of ammonia by free stripping in ponds was calculated and plotted versus dentention time for various temperature ranges (Figure 7). At summer temperatures (25 to 30°C), the removal efficiency is about 70% after 7 days and 95% after 14 days. At winter

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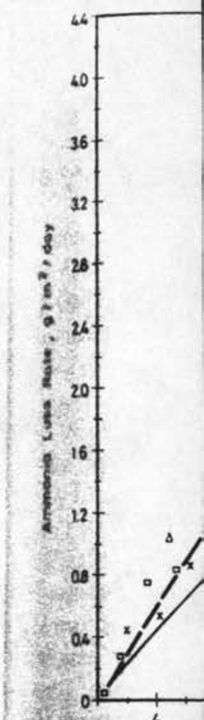

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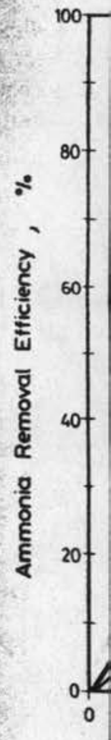

Figure 7-

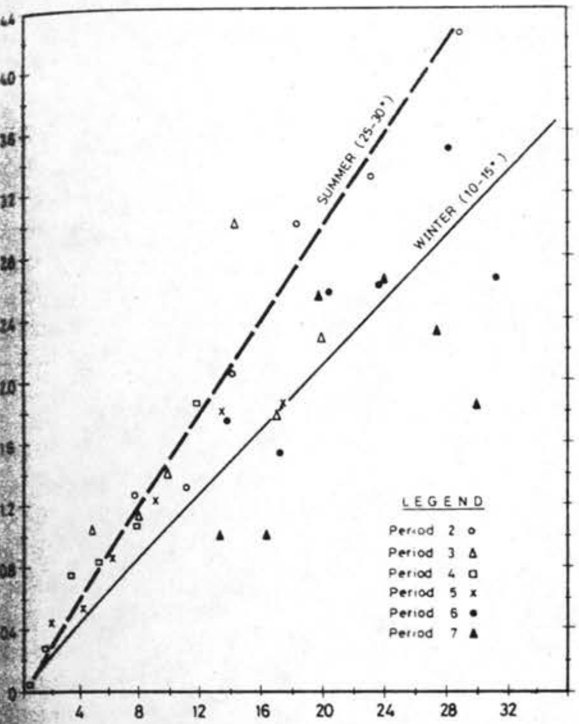

Figure 6—Correlation between ammonia loss rate and initial concentration.

temperatures (10 to 20°C), the removal efficiency is 55 to 60% after 7 days and 70 to 75% after 14 days.

From the available data that covered the temperature range from 12.5°C (average for winter periods with temperatures 10 to 15°C) to 27.5°C (average for summer periods with temperatures 25 to 30°C), the percentage removal efficiency by free stripping in ponds was also plotted versus average temperatures to obtain isolines of various detention times (Figure 8). The slope of the lines indicates that the effect of temperature is more pronounced at larger detention times. After 14 days, for example, the ammonia stripping efficiency is about 70% at 15°C and about 90% at 25°C.

FULL-SCALE OPERATION RESULTS

From January 1977, full-scale free ammonia stripping ponds (polishing ponds) were operated in the Dan Region Reclamation Project, after high-lime treatment and prior to groundwater recharge. The ponds covered an area of about 75 ha and had a water depth of 1 m.

The detention time in these ponds fluctuated widely, owing to variations and interruptions in the inflow and outflow from the ponds; that is, operation of the lime reactor-clarifier and pumping station to the recharge basins, as well as in the seepage losses to ground water from the ponds. However, it has been estimated that the detention time in the polishing ponds varied between 15 and 30 days; that is, the detention time was more than the maximum in the pilot ponds (14 days).

The median value of the results obtained in the full-scale plant in the period of 1977 to 1979 for the two extreme seasons of the year (summer and winter) are

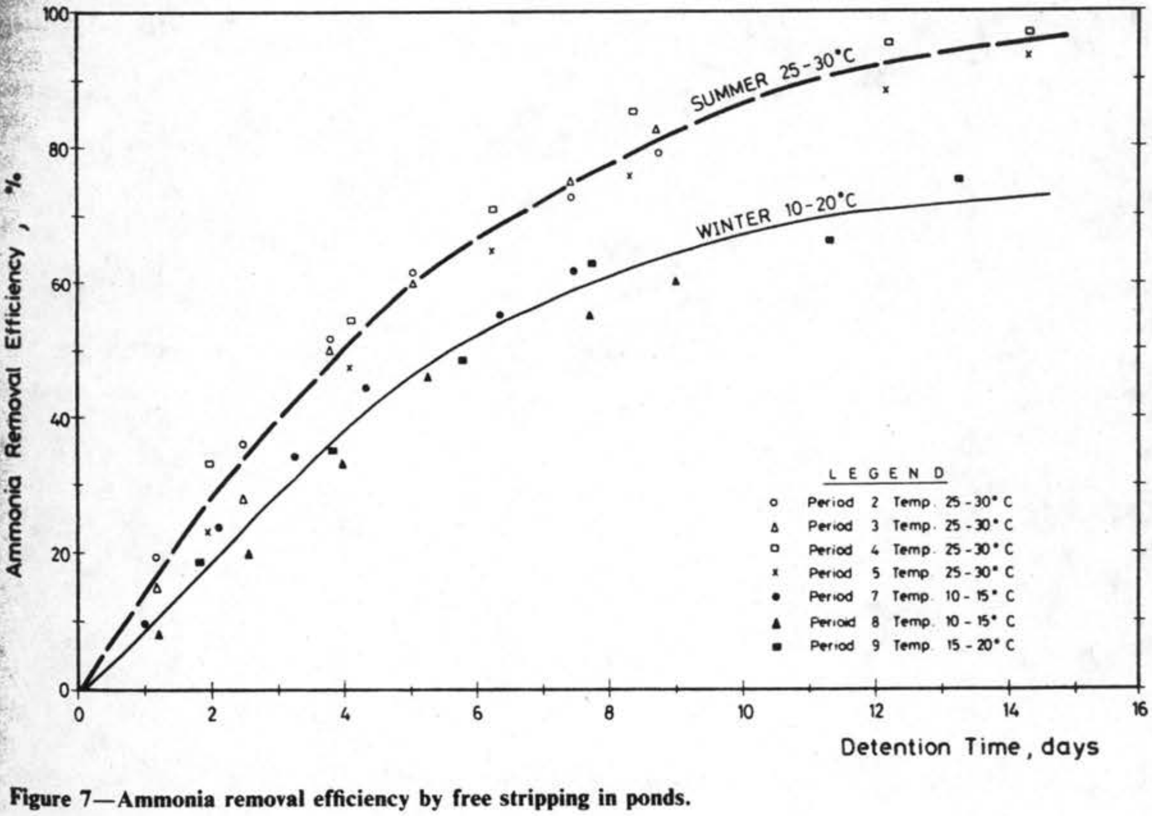

Figure 7—Ammonia removal efficiency by free stripping in ponds.

given in Table 3, together with the median removal efficiencies.

The results obtained in the full-scale plant are in complete agreement with those obtained in the pilot plant study, considering that the detention time was longer in the full-scale plant. The effect of the longer detention time is evident particulary in winter.

The ammonia concentrations reached in the full-scale plant effluent (about 1 mg/l in summer and 6 mg/l in winter) are close to the minimum achievable concentrations in free stripping ponds (0.5 mg/l in summer and 5 mg/l in winter), predicted on the basis of the pilot plant study.

AIR POLLUTION ASPECTS

One of the major concerns related to ammonia stripping processes is the danger of ammonia transfer from water to air, and subsequent odor nuisance, adverse health effects, and surface water pollution.

Studies carried out in connection with ammonia stripping towers have shown that the maximum ammonia concentration in the air discharged from a tower to the atmosphere[12] is 20 mg/m^3. This is more than the concentration of ammonia in clean dry air near sea level (10 mg/m^3),[12] but less than the odor threshold of ammonia (35 g/m^3) and considerably less than concentrations that have been reported to cause eye, nose, and throat irritations (300 to 500 mg/m^3).[1,5]

The danger of water pollution might exist only with respect to surface water sources found in the vicinity of the treatment plant, as a result of ammonia washout from the atmosphere by precipitation. In the case of towers, it has been estimated that this potential danger exists only within a radius of about 5 km.[5] In the case of ammonia stripping ponds, diffusion in the atmosphere from the large surface area of the ponds should be much better than in the case of towers, and if surface water sources exist in the vicinity of the project area, no adverse environmental effects should be associated with ammonia stripping from high-pH ponds. Moreover, the return of some ammonia to land should be beneficial to neighboring agricultural areas.

The continuous operation of the large-scale ammonia stripping ponds in the Dan Region Project, which is located near the Mediterranean Sea, during the period of 1976 to 1979 has caused no environmental nuisance.

SCALING PROBLEMS

The ammonia stripping process involves high pH values, generally attained by excess lime addition. At pH values above 11, there is usually excess $Ca(OH)_2$ that can react easily with CO_2 from the air, causing $CaCO_3$ precipitation. Scaling problems should be therefore considered inherent to the ammonia stripping process. However, although scaling in stripping towers can be a most serious problem for the tower packing,[5] the $CaCO_3$ precipitates gradually settle in the free stripping ponds, with advantages of additional effluent purification, and sealing of the pond bottom against seepage losses.

CONCLUSIONS

Free stripping of ammonia from high-pH ponds following lime treatment is a simple, low-cost wastewater treatment process requiring no energy. The efficiency of the process is dependent mainly on water temperature and detention time in the ponds. In summer (25 to 30°C), the ammonia removal efficiency was about 70% after 7 days and 95% after 14 days. In winter (10 to

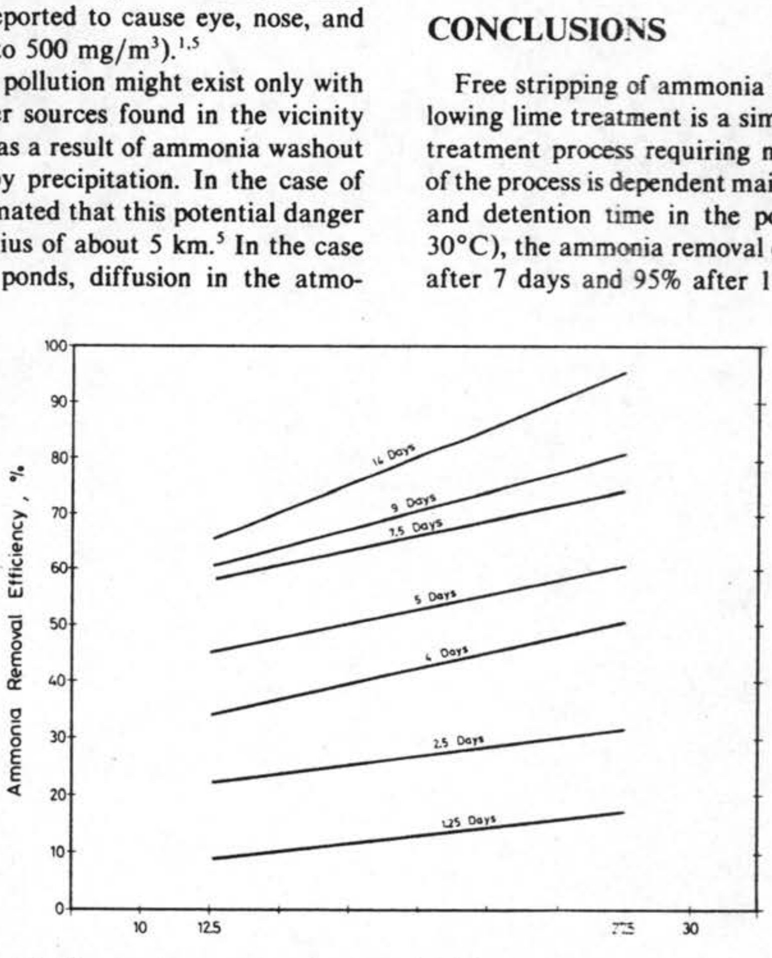

Figure 8—The effect of temperature on ammonia removal efficiency.

Table 3—Ammonia stripping results in full-scale plant.

Season	Year	Temperature	Ammonia concentration as N, mg/l Influent[a]	 Effluent[b]	Removal efficiency %
Summer	1977	25–30°C	24.6	0.9	96.3
	1978		26.5	1.2	95.5
	1979		23.4	0.9	96.2
Winter	1977	10–15°C	30.9	5.3	82.8
	1978		29.6	6.5	78.0
	1979		30.0	6.2	79.9

[a] Median concentrations in influent to first polishing pond (high lime effluent), based on one analysis per week.

[b] Median concentrations in effluent from last polishing pond (tertiary effluent), based on 2 to 3 analyses per week.

Note: pH range was 11 to 12 in the influent and 9 to 10.5 in the effluent.

°C) the efficiency was 55 to 60% after 7 days and to 75% after 14 days. A process of natural recarbonation by absorption of CO_2 from the atmosphere occurs in parallel with the ammonia stripping process. At high temperatures, when the ammonia stripping rate is high, the recarbonation does not hinder the ammonia stripping, and ammonia concentrations as low as 0.5 mg/l can be attained. At lower temperatures, when the ammonia stripping rate is lower, the recarbonation does hinder the ammonia stripping, and the minimum ammonia concentration achievable by free stripping from ponds (even at long detention times) can be only mg/l.

The pilot plant data were confirmed during the full-scale operation of the Dan Region Reclamation Project. At detention times varying between 15 to 30 days, the ammonia concentration was reduced from about 25 mg/l to 1 mg/l in summer (25 to 30°C) and from about mg/l to 5 to 6 mg/l in winter (10 to 15°C).

No air pollution problems occurred as a result of the ammonia stripping in open ponds. Scaling problems in open ponds were minimal; most of the $CaCO_3$ precipitates settled in the first ponds and provided a beneficial protection against seepage losses. Nitrification did not occur in the ponds to any considerable extent; nitrites and nitrates were usually below 0.5 mg/l as N.

In addition to their major function related to ammonia stripping, the ammonia stripping (polishing) ponds, as a unit process following high-lime treatment, provided for partial effluent recarbonation and made an important contribution to the overall improvement of the effluent quality.

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