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MODELLING AN AIR STRIPPING PROCESS FOR AMMONIA REMOVAL

Pollution abatement by air stripping is nowadays a high-level technology in water treatment processes. The paper describes some batch-scale laboratory as well as pilot-plant field experiments allowing air stripping which is a selected method for the recovery of regenerative brines. The method proposed enables the recycling of brines to selective ion exchange columns. The ammonia removal efficiency was tested in several model systems (batch reactors, laboratory aeration tower and air stripping pilot tower) of various values of operation parameters such as air flow rate, temperature, pH and initial ammonia concentration. The aim of this study was to develop certain empirical design for recovery of exhausted regenerative brines using air or steam stripping method.

1. INTRODUCTION

Stripping operations are becoming more important because of the greater demands for water treatment (e.g., ammonia removal from wastewaters of concentrations ranging from mg to g per dm^3 or VOC removal from underground or surface waters). Physical-chemical stripping is a mass transfer process which has been used in chemical engineering for many years.

Simplifying, the process consists of the following steps: rising pH of water to the values ranging from 10.8 to 11.5, formation of water droplets in a tower and providing air–water contact and droplet agitation by circulation of large air quantities through the tower [1].

But before applying the ammonia stripping, we have evaluate three major potential environmental impacts, i.e., air pollution, washout of ammonia from the atmosphere and noise. Then the potential process characterized by extreme simplicity and low cost can be put in motion. The only factor which must be controlled during the operation is the pH value of the influent water flowing into stripping tower. This process is limited by two factors: temperature variations and potential scale (calcium carbonate) accumulation on the tower packing. Therefore the stripping process will not be generally effective at low temperatures [2].

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This paper describes some batch scale laboratory as well as the results of air stripping carried out in a pilot plant. This method was selected because it allowed the recovery of regenerative solution (natrium chloride solutions saturated with ammonia) which thus could be recycled in ion exchange system.

2. MATERIALS AND METHODS

For a batch laboratory operation the modified strippers constructed of cylindrical vessels of various volumes (up to 50 dm^3) were used. At the bottom of each vessel an air diffuser fed through a central air pressure system via a rotameter was installed. Temperature variation of liquid media was provided by a thermostat.

Laboratory aeration tower ($250 \times 250 \times 1700$ mm) for ammonia removal in simulated exhausted regenerative solution was a plexiglass rectangular tube with a vertical layer in the shape of half-cylinder. The half-cylinder contained a packing material having a large specific surface. Above the packing there was a nozzle of a water spray distributor fed with the solution from the bottom which was pumped in a closed cycle. A fan sucking up ammonia from the tower was located at the top of this laboratory model.

In the field pilot plant, cylindrical steel column (of 0.6 m diameter, operation high 3.2 m and operation volume 0.9 m^3) filled with PVC tubes (32×50 mm) was used as the air stripping unit. In the unit, air and water were flowing countercurrently through the packing media. In order to shorten the stripping interval, an air–steam mixture was blown into the column in an upflow mood.

Concentrations of ammonia in aquatic solution were determined by the Nessler method. At the laboratory, pH was adjusted by means of NaOH brine, while in the field experiments – by means of lime.

3. RESULTS AND DISCUSSION

At the pH range from 10.5 to 11.5, when all ammonium in aquatic solutions is converted into gaseous ammonia, air stripping of ammonia may be employed. Although the mathematical models are not normally used for the design of stripping tower and the procedure of empirical design is preferred, some basic equations of the process can be applied.

According to Henry's law the concentration of a substance in a gaseous phase above a solution at the equilibrium state is proportional to the concentration of the substance in the solution. This law is valid only for the solubility of an ideal gas at low dissolved concentrations (see the well-known equation [2], [3]):

$$c = Hp$$

where:

c – concentration of the substance in solution,

p – concentration of the substance in gaseous phase,

H – Henry's constant (function of temperature and pressure).

Ammonia removal in the mentioned process can be represented kinetically by the first-order equation [3], [4]:

$$\frac{dc}{dt} = -kc,$$

$$c = c_0 \exp\left(-QH\frac{t}{V}\right)$$

where:

t – time,

k – the first-order rate constant of desorption,

c_0 – initial concentration of the substance in solution,

V – volume of the liquid,

Q – air flow rate.

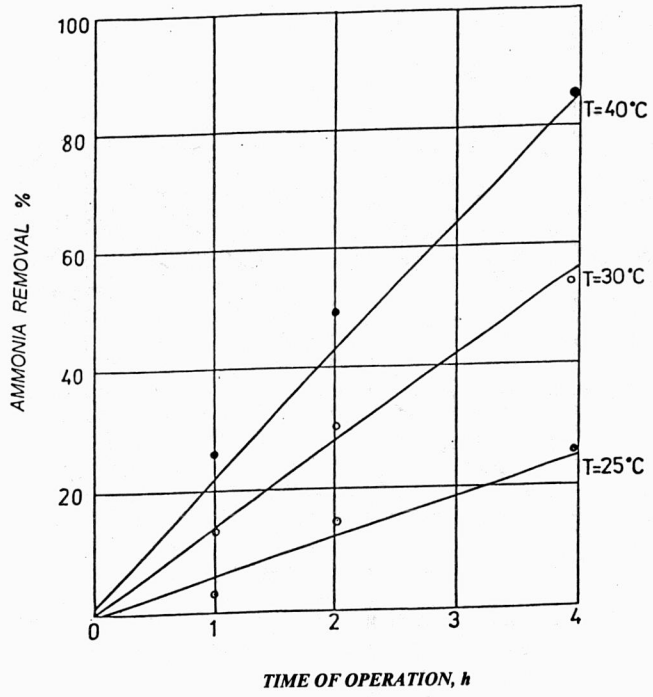

Fig. 1. Ammonia desorption versus time at variuos temperatures (aeration intensity 2 m^3 per 1 dm^3 and hour) in batch system

Based on the dependence of ammonia mass transfer on temperature, ionic strength, pH as well as the variations in air or steam flow rates, POWERS et al. [3] made a mathematical approach to the change in ammonia concentration during one stripping interval. They expressed it as the following mass balance [3]:

$$c_{i+1} = c_i - [(c_i HF_i - c_{i-1} H_{i-1} F_{i-1}) V_A + c_i H_i F_i Q \Delta t + c_i V_E (Q + Q_p) \Delta t]/v$$

loss to headspace — loss with air stream — loss by entrainment

where:

F – dissolved ammonia fraction,
V_A – headspace volume,
Q_p – steam flow rate,
Δt – time interval.

In laboratory, the ammonia stripping process was monitored by various operating data, e.g., pH, T, initial ammonia concentration, air flow rate, to verify earlier mathematical predictions.

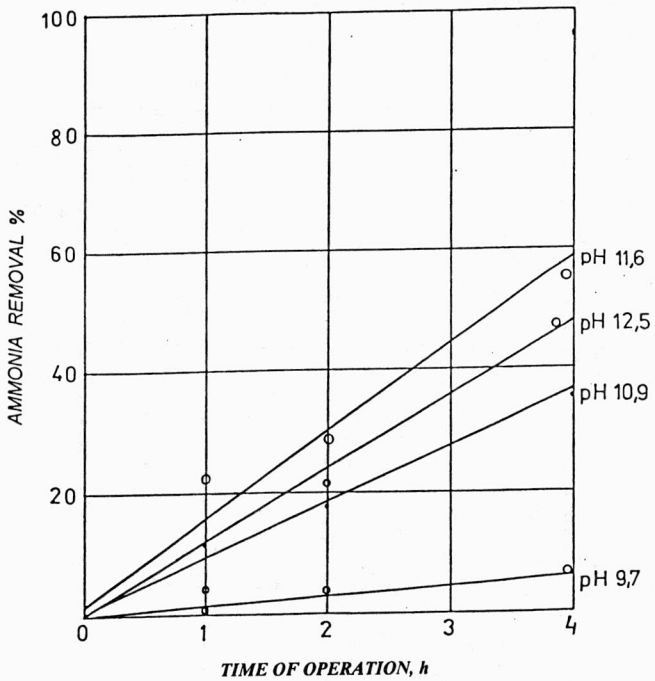

Fig. 2. Ammonia desorption versus time at various pH values (aeration intensity 2 m^3 per 1 dm^3 and hour) in batch system

Figures 1 and 2 demonstrate the dependence of ammonia desorption from liquid phase upon temperature and pH. The plots in fig. 2 confirm the statement that the air stripping process proceeds at pH ranging from 10.8 to 11.5. The process is represented by a straight line whose slope at pH = 12.5 is lower than that at pH = 11.6.

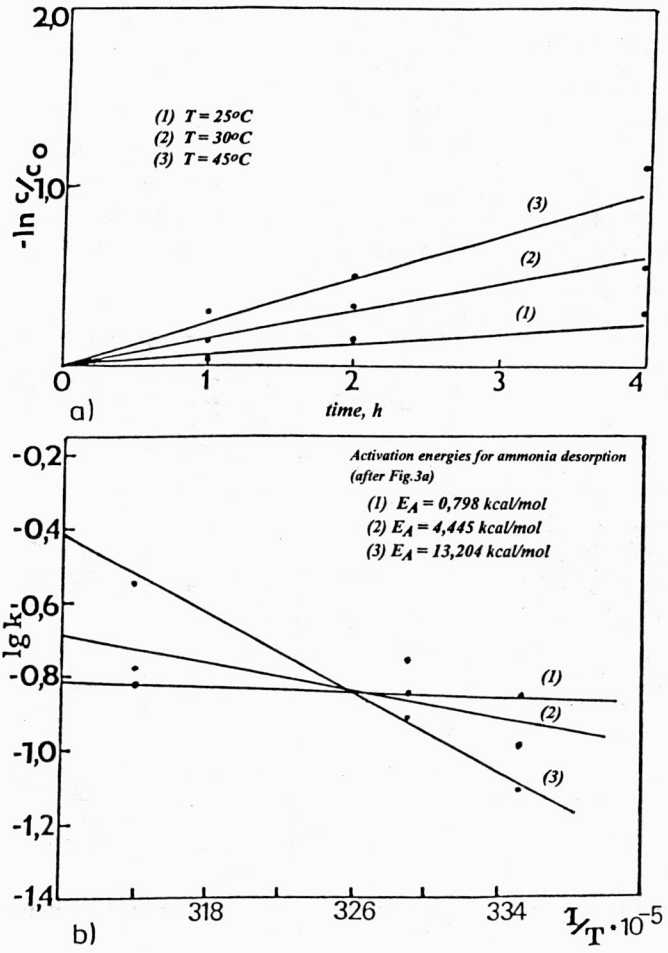

Fig. 3. a) Kinetics of ammonia desorption at various temperatures as ($-\ln c/c_0$ versus time) dependence b) ($\lg k$ versus $1/T$) dependence for ammonia desorption at various pH (1) 9.7, (2) 10.9, (3) 11.6 kinetic constants in 1/h

Plot in figure 3a presents the ammonia removal as the first-order process. The constants of the first-order rate derived from the slope of the dependence ($\ln c/c_0$ versus t) plotted as logarithm of these constants versus reciprocal absolute temperature (in K) enabled us to calculate the Arrhenius activation energies for laboratory ammonia desorption (figure 3b).

Use of exhausted regenerative solution, simulated by the addition of 20 g $NaCl/dm^3$ and 120 mg NH_4Cl/dm^3 into tap water with pH adjustment by NaOH, showed that we have to blow about 30 dm^3 of air into the batch system in order to remove 1 mg of NH_3 from the brine at 36°C.

Some different experiments were performed using laboratory aeration tower described in the previous chapter. Over hundred recyclings from the bottom of an

accumulation basin to the top of this tower had to be repeated to remove about 95% of ammonia. Apparently a high number of cycles is due to low initial ammonia concentration in the simulated brines (10 mg/dm^3). Curves *1–4* in figure 4 illustrate ammonia removal by brine specific flow rate reaching 2.7 dm^3/s/m^2, curves *5–8* represent the removal by 10 times lower. Curve *4* demonstrates low efficiency of ammonia removal because the fan was out of the work; in the case of the curves *5–8* this low efficiency could be explained by the fact that only a half of the tower construction was used.

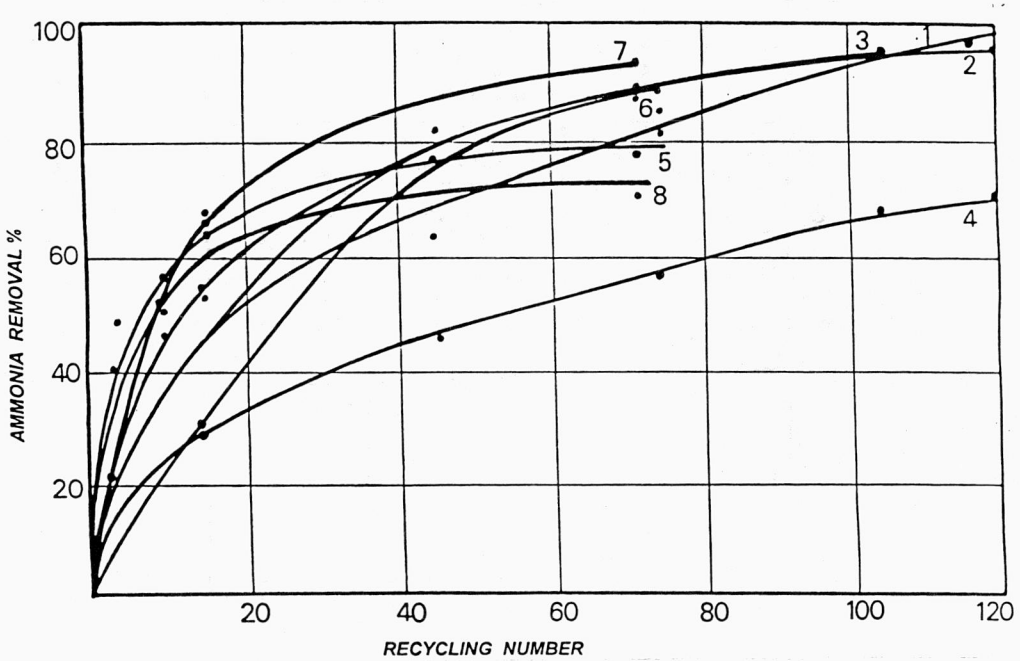

Fig. 4. Ammonia desorption versus recycling number in laboratory aeration tower (curves *1–4* – brine specific flow rate of 2.7 dm^3/s/m^2, curves *5–8* – flow rate of 0.27 dm^3/s/m^2 at a half of tower height)

In field experiments, an air stripping tower was a steel column of 3 m height filled with PVC tube-shaped waste as a part of closed pilot wastewater treatment system using natural ion exchanger. A blower of the capacity of 0.5 m^3/s was located at the base of the tower in a forced-draft system. Flow rate of treated wastewater in the pilot plant unit reached 900 dm^3/h. That is why we investigated the efficiency of ammonia removal at some other flow rates (up to 4-times higher) of brine solutions stripped in the tower.

On the basis of small differences in the efficiencies of ammonia removal at the flow rates tested we choose the lowest one obtained during a unified operation of the whole facility (0.9 dm^3/s/m^2). Air consumption necessary for ammonia stripping

from the regenerative brines at the ambient temperature (20°C) was about 20 m^3/dm^3. Figure 5 illustrates some other factors (recycling of the stripped brine volume in closed mood or recycling of stripped and nonstripped brine volumes by separation, installation of screen at the tower headspace preventing lateral ammonia expansion) influencing the efficiency of ammonia removal. Parallel trials are presented in figure 5. High temperature (about 45°C) provided by simultaneous air and steam stripping into the system shortens rapidly an operating cycle (to 2.5 hours).

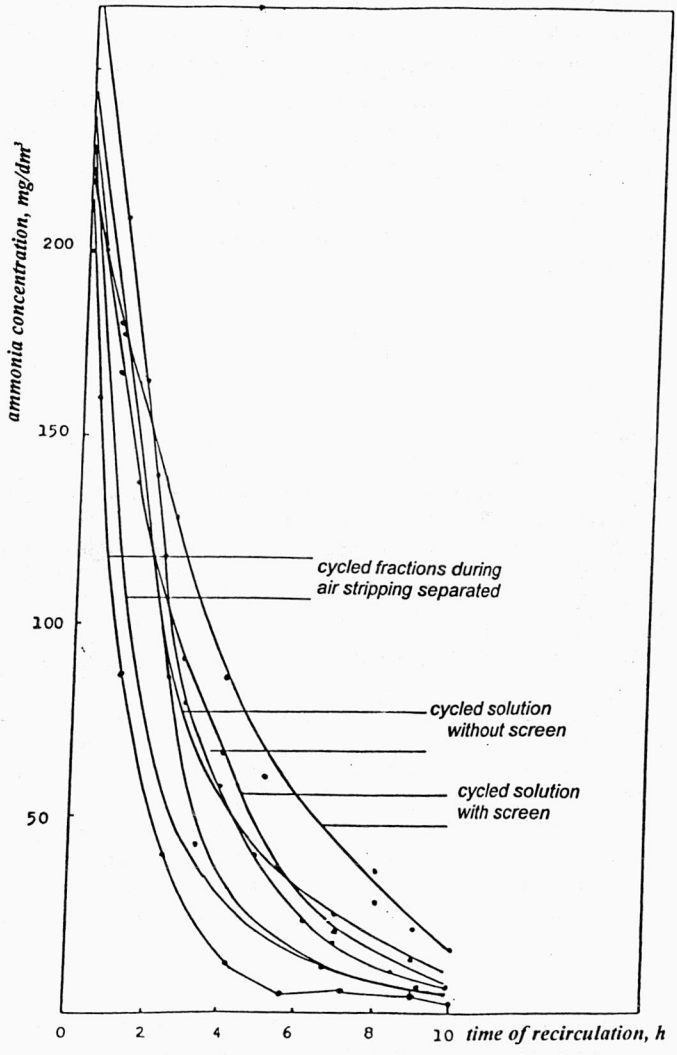

Fig. 5. Ammonia concentration versus time of brine recirculation in pilot air stripping tower

Tests were performed without scraping the stripped ammonia into liquid but for industrial facility there was supposed to use the scraped ammonia in fertilizer production.

4. CONCLUSIONS

Based on the results of this study the following conclusions are drawn:

1. The experiments carried out confirm that in air stripping such factors as temperature, pH, air flow rate, stripper construction and initial ammonia concentrations influence the process efficiency. Among the most important operation variables, whose increase causes the rapid shortening of stripping process, is temperature.

2. The process described is effective for ammonia removal from liquids with high initial concentrations of ammonia (about hundreds of mg/dm^3) when the operating costs on the base of intense concentration gradient are lower.

3. For a successful removal of ammonia by air stripping, a sufficient interphase contact between the tower packing and an adequate water–air loading is necessary.

LITERATURE

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MODELOWANIE PROCESU ODPĘDZANIA AMONIAKU

Zmniejszanie zanieczyszczeń przez odpędzanie lotnych składników jest dziś efektywną technologią w procesach oczyszczania wód. W artykule przedstawiono wyniki badań laboratoryjnych i pilotowych odpędzania amoniaku jako wybranej metody, która umożliwia odzysk roztworów regeneracyjnych (solanek) pochodzących z kolumn jonowymiennych. Efektywność usuwania amoniaku sprawdzono w kilku układach modelowych (reaktory, laboratoryjna wieża napowietrzająca i pilotowa wieża przedmuchiwana powietrzem) przy zmiennych parametrach pracy takich jak: natężenie przepływu powietrza, temperatura, odczyn i początkowe stężenie amoniaku. Celem badań było opracowanie pewnych danych empirycznych istotnych podczas odzysku zużytych solanek regeneracyjnych za pomocą metody przedmuchiwania powietrzem lub parą wodną.

МОДЕЛИРОВАНИЕ ПРОЦЕССА ОТГОНКИ АММИАКА

Понижение загрязнений посредством отгонки летучих компонентов является в настоящее время эффективной технологией в процессах очистки вод. В настоящей статье представлены результаты лабораторных и пилотажных исследований отгонки аммиака как избранного метода,

который дает возможность восстановления регенерационных растворов (соляных растворов), происходящих из ионообменных колонок. Эффективность удаления аммиака была проверена в нескольких модельных системах (реакторы, лабораторная аэрирующая башня и ловящая башня, продуванная воздухом) при изменяющихся параметрах, таких как: напряжение протекания воздуха, температура, реакция и начальная концентрация аммиака. Целью исследований была разработка некоторых эмпирических данных, существенных во время восстановления использованных соляных регенерационных растворов при помощи метода продувания воздухом или водяным паром.