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Ammonia removal by air stripping in a semi-batch jet loop reactor

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ABSTRACT

Ammonia is very toxic chemical and it can be removed by air stripping at high pH. JLRs have found applications in wastewater treatment processes due to their high mass transfer rates. In JLRs, intrinsic high turbulence result in a very large air-liquid surface area for greater mass transfer. Therefore, in this study, ammonia removal by air stripping from synthetically prepared ammonia solution at the high pH in a semi-batch JLR due to its high mass transfer capabilities have been investigated. Investigated parameters in a JLR were initial ammonia concentration (10–500 mg/L), temperature (20–50 °C), air flow rate (5–50 L/min) and liquid circulation rate (35–50 L/min). While it was demonstrated that temperature and air flow rate have a significant effect on the ammonia removal, it was determined that initial ammonia concentration and liquid circulation rate have no significant effect on the ammonia removal. The overall volumetric mass transfer coefficients (K_La) have been calculated from obtained model and it was determined that increasing temperature and air flow rate have a very significant effect on K_La. It was concluded that JLR provides higher mass transfer capabilities than other type of reactors even if less air is given.

1. Introduction

Ammonia and its compounds in natural or industrial waste waters have become a major environmental problem. When discharged without any treatment, even small amounts ammonia has negative effects on aquatic life. Because of the toxic nature of the wastewaters containing ammonia, it is generally difficult to treat these kind of wastewaters by biological processes. The recovery and removal of ammonia and its compound from wastewaters can be accomplished by biological, physical, chemical, or a combination of these methods such as adsorption, chemical precipitation, membrane filtration, reverse osmosis, ion exchange, air stripping, breakpoint chlorination and biological nitrification [1].

In order to remove the ammonia from water under high pH values stripping by aeration is a generally used process. This operation is performed in stripping towers and high amount of air is needed to be introduced into tower. Stripping towers are filled with filling materials in order to form higher surface area and there may be precipitates of ferrous and magnesia oxides. Similarly carbonates and bicarbonates lead to the formation of insoluble scales and these scales may cause a drop in the mass transfer. Also the lower temperature values in the stripping towers result in lower removal efficiencies. Temperature, pH, air flow rate, volumetric loading rate and reactor configuration are among the important parameters effecting the efficiency of ammonia removal by air stripping. It has been determined in the literature that the efficiency of stripping increased by increasing the temperature and air flow rate [2–9].

Jet loop reactors (JLRs) are classified as innovative reactors and remarked by their high mass transfer capabilities. These type of reactors are able to provide high specific interfacial areas and high mass and heat transfer without employing mechanical stirrers [10–13]. Because of these mentioned advantages their usage in wastewater treatment has been started and they were gradually developed. When JLRs are compared with classical reactors they have more advantages with respect to performance and yield. Simple and lower construction and operational costs, much more flow circulation over the classical reactors under the same energy input, high level of gas dispersion, higher mass and heat transfer availability, rather homogenous concentration and temperature profile availability, including of non movable parts inside the reactors and easiness of the adaption from the pilot scale to industrial scale are among to major advantages of JLRs over classical type reactors [14–16]. Due to the high internal mixing and bigger contact area in JLRs, mass transfer coefficients are higher than classical type reactors [13,15,17–19]. Considering above mentioned specifications of JLRs, volatile chemicals may be

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Nomenclature

Q_G	air volumetric flow rate (L/min)
C_{Gin}	the ammonia concentration in the air inlet of JLR (mg/L)
C_{Gout}	the ammonia concentration in the air outlet of JLR (mg/L)
V_L	the liquid volume (L)
C_L	ammonia concentration in liquid phase (mg/L)
ε_G	gas holdup or the volume fraction of the gas bubbles entrained in the liquid
K_La	the overall volumetric mass transfer coefficient based on liquid phase (h^{-1})
S	the JLR cross-sectional area (m^2)
dz	the differential height (m)
a	the specific interfacial area of bubbles per unit volume of gas–liquid mixture (m^2/m^3)
C_L^*	ammonia concentration in the liquid phase in equilibrium with the gas bubbles (mg/L)
K_H	the Henry's law constant
Le	the effective height of gas–liquid mixture (m)
C_{Lt}	ammonia concentration in liquid phase at any time (mg/L)
C_{Lo}	initial ammonia concentration in liquid phase (mg/L)

Subscripts

JLR	jet loop reactor
LCR	liquid circulation rate

transferred rapidly to the gas phase from the water phase. In this work it was aimed to strip ammonia in a semi-batch JLR under high pH values. By using a model of prediction of ammonia removal, volumetric mass transfer coefficients were estimated in order to evaluate the efficiency of the proposed reactor designed for applications of ammonia stripping.

2. Materials and methods

2.1. Experiments

The chemicals used in the experiments were obtained from Fluka Co., and NH_4CI was used to prepare the synthetic ammonia solution and NaOH was used to adjust pH of liquid phase. The experimental setup is shown in Fig. 1. The reactor (the outer tube) and the draft tube (the inner tube) were made of Perspex cylinders of 10 cm and 4 cm in diameter and 4 mm and 3 mm in thickness, respectively. The reactor was 105 cm in overall height. The bottom section of the reactor was served as an impact plate. The draft tube was positioned radially in the centre of the reactor above 10 cm from the impact plate and 30 cm from the top of the reactor using supporting rings at the top and the bottom of the draft tube (not shown in the figure). The supporting rings had three arms of 120° distance from each other securing the draft tube firmly in the central position. The liquid containing ammonia was withdrawn from bottom of wide section at top of the reactor and circulated back to the reactor through the annular space of the two-fluid nozzle via a liquid flowmeter by means of a circulation pump. The top chamber of the reactor, which is wider than lower part, has acted as degassing chamber. The nozzle, of which details are given by the inset shown in Fig. 1, consisted of two concentric tubes. The outer one was rectangular in cross section and 1.4 cm in diameter. The inner one was a stainless steel tube of 6.4 mm in diameter and 1 mm in thickness. The air to the reactor was provided from the compressor through the inner stainless steel tube via a gas flowmeter. Gas and liquid flow rates were controlled by the valves and flowmeters on their respective pipelines. Air given to the reactor during the experiment was supplied by a air compressor. The two-phase (liquid–gas) jet then passed down the reactor draft tube and up the outer annulus of the reactor. Two-phase liquor was withdrawn from top of the reactor and pumped back to the reactor by the circulation pump. Cooling coils situated in the degassing chamber at top of the reactor, and the temperature of the reactor content was adjusted by changing of flowrates of outer cooling liquid circulation. In order to adjust the pH around constant values Alpha pH 1000 model pH controller (EUTECH) was used and also the liquid level was controlled by Cole Parmer 7188 model liquid level controller. In batch studies, synthetic ammonia solutions (10–500 mg/L) were introduced into a 9 L reactor set at pH 11. Samples were taken from the outlet of the reactor followed by ammonia analysis through Thermo Orion A^+ Ion-meter and Spectrophotometer (Analytic Jena 1100). The experimental parameters and their levels given in Table 1 were determined in the light of both preliminary testing and a literature review on the subject [2–9].

2.2. Determination of mass transfer coefficient and efficiency of ammonia removal

The overall ammonia balance over jet loop reactor is given by Eq. (1):

$$Q_G C_{Gin} - Q_G C_{Gout} = V_L \frac{dC_L}{dt} + \varepsilon_G V_L \frac{dC_G}{dt} \quad (1)$$

where Q_G is the air volumetric flow rate (L/min), C_{Gin} and C_{Gout} are the ammonia concentration in the air inlet and outlet of JLR (mg/L), V_L is the liquid volume (L), C_L is the ammonia concentration in liquid phase (mg/L), and ε_G is the gas holdup or the volume fraction of the gas bubbles entrained in the liquid (dimensionless).

For accumulation the terms of ammonia in gas phase and C_{Gin} are zero, Eq. (1) is reorganized in a form given in Eq. (2):

$$-Q_G C_{Gout} = V_L \frac{dC_L}{dt} \quad (2)$$

For a dilute system, differential material balance for the ammonia over a differential height dz of the jet loop reactor gives Eq. (3):

$$Q_G C_G - Q_G(C_G + dC_G) + K_L a S(C_L - C_L^*)dz = \varepsilon_G S dz \frac{dC_G}{dt} \quad (3)$$

where K_La is the overall volumetric mass transfer coefficient based on liquid phase (h^{-1}), S the JLR cross-sectional area (m^2), dz the differential height (m), a the specific interfacial area of bubbles per unit volume of gas–liquid mixture (m^2/m^3) and C_L^* is the ammonia concentration in the liquid phase in

Table 1
Parameters and their levels.

	Levels					
Parameters	1	2	3	4	5	6
Initial concentration (mg/L)	10	20	50	75	100	500
Liquid circulation rate (L/min)	35	40	50			
Air flow rate (L/min)	5	10	20	30	50	
Temperature (°C)	20	30	40	50		