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Effect of Temperature and Air flow rate on Xylene Removal from Wastewater using Packed Column Air Stripper

Hamidah Kamarden[a*], Mohd. Ariffin Abu Hassan[b], Zainura Zainon Noor[b], RK Raja Ibrahim[c], Abdullahi Mohammed Evuti[a]

[a]*Department of Chemical Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia*
[b]*Institute of Environmental and Water Resources Management, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia*
[c]*Advanced Photonic Science Institute, Physics Department, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia*

*Corresponding author: hamidahkamarden@gmail.com

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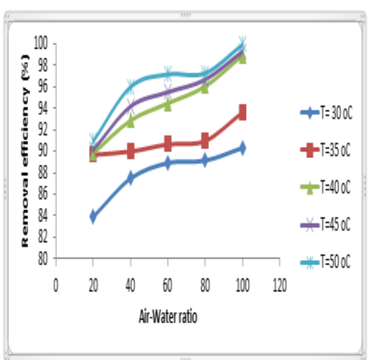
Graphical abstract



Abstract

In this research, the effects of temperature and air flow rate on the removal efficiency of xylene from wastewater using packed column air stripper were investigated at a temperature range of 30 to 50^{0}C and air-water ratios of 20 to 100. The quantities of xylene in effluent from the air stripper were determined using UV-visible spectrophotometer. The effects of increase in temperature on the percentage removal of xylene were found to be more significant at low temperatures (30-40^{0}C) than at higher temperatures (45-50^{0}C). Also, the effects of increase in water-air ratio on percentage removal of xylene were less significant at higher G/L ratio (80-100) and more significant at low G/L ratios (20-60), thus revealing a non-linear trend in the effect of temperature and air-water ratio on xylene removal.The result also indicates that xylene removal efficiency is greatly affected by column temperature and G/L ratio with the highest removal efficiency of 99.93 at temperature of 50^{0}C and at G/L ratio of 100.

Keywords: Air stripper; xylene; wastewater; spectrophotometer; temperature; air-water flow rate

1.0 INTRODUCTION

Xylenes are released to the atmosphere primarily as fugitive emissions from industrial sources (e.g., petroleum refineries, chemical plants), in automobile exhaust, and through volatilization from their use as solvents [1-4]. Discharges into waterways and spills on land result primarily from use, storage, and transport of petroleum products and waste disposal [5]. Xylene or its metabolites have been detected in human urine, blood, and exhaled air samples among members of the general population and long-time exposures to xylene at levels above the maximum limit in drinking water (10 ppm) can cause damage to the central nervous system, liver and kidneys [5-6], hence necessitating their removal [7].

Air stripping is conventionally used because of its simplicity, low operating cost and it effectiveness (over 99% removal efficiencies) in removing volatile organic compounds (VOCs) with high volatility (high Henry's constant). However, air stripper performance is affected by temperature, air to water ratio, hydraulic loading rates, packing materials, size, depth and diameter, gas pressure drop, and Henry's constant of the contaminant [8-10]. Efficient and economic combination of these factors to achieve maximum removal of VOCs remains a challenge. Energy is required to heat up cold stream of wastewater and to power the compressor or air blower which represents a considerable cost [8]. Lin *et al.* [11] observed that the removal efficiency of chlorobenzene from wastewater increased with increase in temperature at each air flow rate condition. More also, Kittikul *et al*. [12] reported that the removal efficiency of toluene from water increased from 76.3% at 5^{0}C to 85% at 25^{0}C.

There is therefore need for further researches to establish basic understanding of the influence of these factors on air stripping efficiency of VOCs. This study therefore is studying the effects of temperature and air-water ratio (G/L) on the removal efficiency of xylene from wastewater and to determine the concentration of xylene in the treated wastewater using ultraviolet- visible (UV-Vis) spectrophotometer.

2.0 EXPERIMENTAL METHODS

Xylene was obtained from Merck Sdn Bhd. Malaysia with purity greater than 99.5%. Synthetic wastewater containing 1500 ppm of xylenes was prepared. This study was carried out in a custom-made pilot scale packed column air stripper (Model 2T4H) from Branch Environmental corp. USA. The stripping column is made of 1.5 m stainless steel tube of 0.05 m internal diameter filled with 6mm ceramic raschig rings packing. The height of the packing is 1.15 m which is equivalent to a packing volume of 2.26 x 10^{-3} m^3. Figure 1 represents the process flow diagram of the air stripping system.

The effects of temperature and air flow rate on xylene removal were investigated according to the following procedure: The air flow rate (2.4 L/min) was set using rotameter and the wastewater inlet was also set to 0.12 L/min by adjusting the rotameter while the wastewater and air heaters were set to 30^0C. The air and contaminated water were then pumped into the air stripper in counter current operation and the VOC rich air was collected at the top while the treated wastewater was collected at the bottom. This procedure was repeated for other runs using air flow rates of 4.8, 7.2, 9.6 and 12 L/min; and temperatures of 35, 40, 45 and 50 ^{0}C at a fixed wastewater flow rate of 0.12 L/min. These air and wastewater flow rates are equivalent to G/L ratios of 20, 40, 60, 80 and 100 respectively. The quantities of xylene in the treated wastewater samples were determined using Ultraviolet-Visible Spectrophotometer (Perkin Elmer Lambda 25). The UV-Vis spectrophotometer was calibrated by plotting the graph of the absorbance of different concentrations of xylene (50, 100, 150, 200 and 250 ppm) at 265 nm wave length. The concentrations of xylene in the treated wastewater samples were determined using the regression line equation.

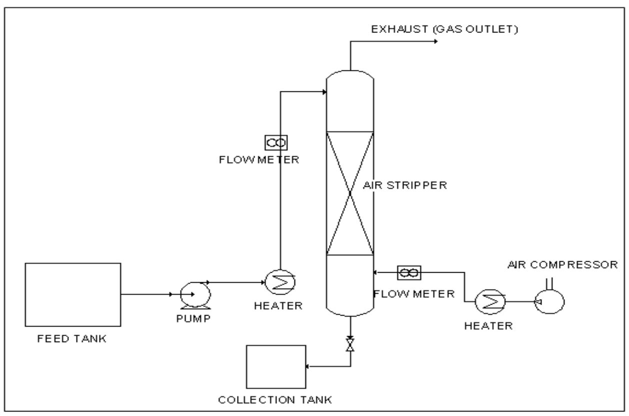


Figure 1 Process flow diagram of the air stripping system

3.0 RESULTS AND DISCUSSION

3.1 Calibration of UV-Visible Spectrophotometer

A double beam UV-Vis spectrophotometer was used for the research, this allows for more accurate readings [13]. The wave length of 265 nm referred to as λ_{max} is the detection wave length for xylene [14]. The data of absorbance versus xylene concentration were treated using linear square regression analysis and the calibration curve is shown in Figure 2 below. The calibration result shows a linear relationship in accordance to the Beer-Lambert Law with a regression equation $y = 0.0001$ and coefficient of correlation (r^2) as 0.9554.

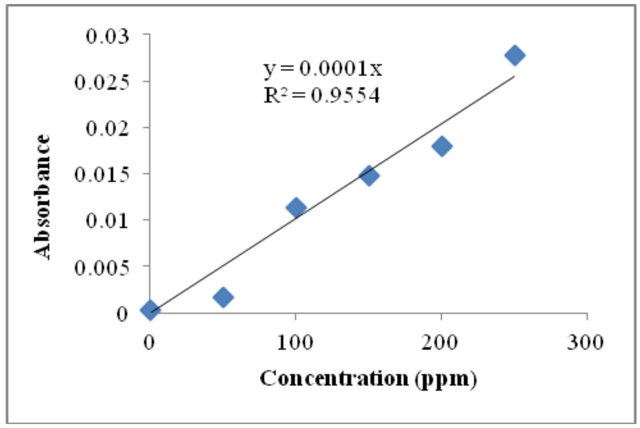


Figure 2 Calibration curve of xylene

3.2 Removal Efficiency

The xylene removal efficiency (η) of the air stripper was calculated using the Equation 1,

$$\eta(\%) = \frac{[xylene]_{inlet} - [xylene]_{outlet}}{[xylene]_{inlet}} \text{ x } 100\% \qquad (1)$$

where, $[xylene]_{inlet}$ and $[xylene]_{outlet}$ is the concentration of xylene in inlet and outlet wastewater stream respectively. Table 1 shows that high removal efficiencies of xylene were obtained at the operating temperatures ranging from 30 to 50^{o}C and air-water (G/L) ratios of 20 to 100 with the highest removal efficiency of 99.93 at temperature of 50^{o}C and G/L ratio of 100 which are in accordance with the literatures [8-10]. The result indicates that high percentage removal of xylene (>90%) can be achieved by stripping at high temperature condition even at relatively lower G/L ratio. Similarly, the result indicates that high percentage removal of xylene (>90%) can be achieved by stripping at high G/L ratio even at relatively lower temperature. These observations are very important in the design and operation of air stripping system [11].

Table 1 Percentages removal efficiencies at different temperatures and air-water ratios

	Efficiency (%)				
	30^0C	**35^0C**	**40^0C**	**45^0C**	**50^0C**
G/L=20	83.89	89.67	89.82	90.13	90.93
G/L=40	87.47	89.98	92.87	94.18	96.00
G/L=60	88.91	90.64	94.47	95.51	97.16
G/L=80	89.13	90.96	96.04	96.67	97.27
G/L=100	90.31	93.62	98.93	99.29	99.93

3.3 Effect of Air-Water Ratio on Xylene Removal Efficiency

Air flow rate is the most important operating parameter in air stripping operation [6, 10]. Figure 3 shows that at a fixed temperature increase in G/L ratio results in higher xylene removal efficiency.

For example, an increase in removal efficiency from 83.89% at G/L = 20 to 90.31% at G/L = 100 was observed at 30^{0}C. This is because increased air flow rate increases the interfacial area, decrease gas phase resistance and hence increase the efficiency of mass transfer. Increased G/L ratio also causes a decrease in partial pressure of the solute in the gas phase, decreases its solubility and improves its removal efficiency [8, 15]. Alam and Hossain, also reported an increase in ammonia removal from industrial wastewater with increase in air-water flow ratio [16].

It can also be observed from the graph that at higher G/L ratios, the difference in percentage removal becomes smaller with increase in G/L ratio. For instance, an increase in G/L ratio from 20 to 40 resulted in an increase in removal efficiency of 3.58%, 0.31%, 3.05%, 4.05% and 5.07% for temperatures of 30^{0}C, 35 ^{0}C, 40 ^{0}C, 45 ^{0}C and 50 ^{0}C, respectively. While an increase in G/L from 80 to 100 resulted in an increase in removal efficiency of 1.22%, 2.66%, 2.89%, 2.62% and 2.66% for the same temperatures. This shows that the effect of increase in G/L ratio on the percentage removal of xylene is more significant at low G/L ratio than at higher water-air ratios. This is because at higher G/L ratios, the stripping efficiency is approaching equilibrium because of accelerated mass transfer of xylene between the liquid phase and the gas phase. This relationship has also been observed by Lin *et al*. [11] in the air stripping of chlorobenzene. This was attributed to the non-linear increasing of interfacial area while the air flow rate increased.

3.4 Effect of Temperature on Xylene Removal Efficiency

Figure 4 shows that the removal efficiency of xylene increases with increase in temperature at all air-water flow rates. For example, the percentage removal efficiency increase from 83.89% to 90.93% at G/L=20 as the temperature was raised from 30^{0}C to 50^{0}C. This is because an increase in temperature causes a decrease in the solubility of organic compounds in water and increases Henry coefficient and hence improves removal efficiency [7, 17-19]. Figure 4 also shows that at high temperature and G/L ratio, higher removal efficiencies of over 90% were observed. This is due to the combined effect of high temperature and G/L ratio which result in accelerated removal. This is similar to the result obtained by Chuang *et al.* [8].

Figure 4 also shows that the difference in percentage removal of xylene at higher temperatures becomes smaller with an increase in the G/L ratio which shows an approach to equilibrium condition. For examples at 50^{0}C, an increase in percentage xylene removal of 0.11% only was observed as G/L was raised from 60 to 80 as against 5.13% when the G/L was raised from 20 to 40. Also, at low temperature conditions (30-40^{0}C), an increase in temperature have more significant effect than at high temperature conditions (45-50^{0}C). This shows a non-linear trend in the effect of temperature on xylene removal efficiency. Lin *et al.* [6] reported a similar trend for the effect of temperature on chlorobenzene removal efficiency using air stripper.

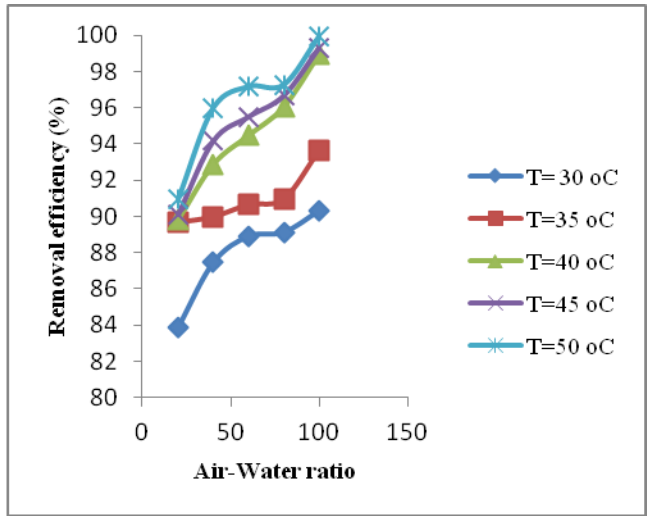


Figure 3 Effect of air-water ratio on xylene removal efficiency

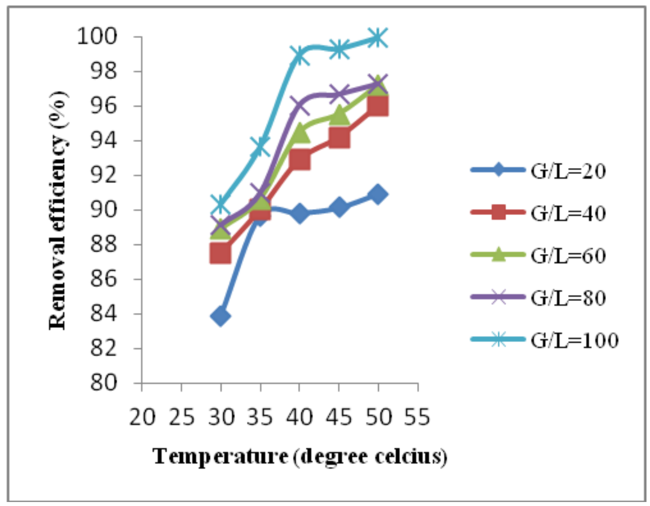


Figure 4 Effect of temperature on the removal efficiency

4.0 CONCLUSION

The effects of temperature and air-water ratio on the on the removal efficiency of xylene from wastewater using packed column air stripper was studied using UV-Vis spectrophotometer as an analytical tool. The following conclusions can be drawn:

i) High percentage removal of xylene (>90%) can be achieved by stripping at high temperature condition even at relatively lower G/L ratio. Also, high percentage removal of xylene (>90%) can be achieved by stripping at high G/L ratio even at relatively lower temperature. This is a very important factor for consideration during design and operation of air stripper.

ii) The effect of increase in temperature on the percentage removal of xylene is more significant at low temperatures (30-40 ^{0}C) than at higher temperatures (45-50 ^{0}C). Also, the effect of increase in G/L ratio on xylene removal was less significant at higher G/L ratio (80-100) and more significant at low G/L ratios (20-60), thus revealing a non-linear trend in the effect of temperature and air-water ratio on xylene removal.

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