Pergamon

0043-1354(93)E0050-3

Wat. Res. Vol. 28, No. 9, pp. 2011–2019, 1994
Copyright © 1994 Elsevier Science Ltd
Printed in Great Britain. All rights reserved
0043-1354/94 $7.00 + 0.00

BATCH STUDIES ON A CLOSED LOOP AIR STRIPPING PROCESS

MADHUMITA BHOWMICK and MICHAEL J. SEMMENS*
University of Minnesota, Department of Civil and Mineral Engineering, 500 Pillsbury Drive S.E., Minneapolis, MN 55455, U.S.A.

(First received December 1992; accepted in revised form November 1993)

Abstract—Ultraviolet photooxidation is an effective process for the destruction of organics in air. In this paper we examine the use of u.v. photooxidation to treat the exhaust air from a stripper. VOC contaminated water was air stripped using a hollow fiber membrane module and the VOC laden air was u.v. photooxidized and recycled to the stripper in a closed loop. Batch experiments were conducted under different operating conditions. A mathematical model was developed for the process and model predictions of process performance compared favorably with the experimental results.

The closed loop air stripping process (CLASP) offers a number of potential advantages over conventional air stripping with off-gas treatment: no VOCs are released to the atmosphere; the VOCs are oxidized to harmless end-products; no adsorber is required; and no adsorbent regeneration or disposal costs are incurred.

Key words—u.v., volatile organic compounds, photooxidation

NOMENCLATURE

a = specific surface area
C = VOC concentration in water phase at any point in the stripping module
C^* = VOC concentration in water in equilibrium with the air phase concentration
C_0 = VOC concentration in the mixed water reservoir at any time
C_1 = VOC concentration in water at the outlet of the stripper at any time
d = inside diameter of the hollow fiber
H = Henry's constant
k = oxidation rate constant
K_L = overall mass transfer coefficient
L = length of the module
Q_w = water flow rate
Q_g = air flow rate
R = stripping factor
v = velocity
V_r = volume of the photoreactor
X = VOC concentration in the gas phase at any point in the stripping module
X_1 = VOC concentration in gas at the inlet of the reactor
X_0 = VOC concentration in gas at the outlet of the reactor

INTRODUCTION

Air stripping is an economical and widely used process for the removal of VOCs from water, however, this process simply transfers the pollutants from the water to the air phase. The exhaust air is commonly treated by granular activated carbon to remove the VOCs by adsorption, but this increases the operating costs dramatically. In this paper we examine a novel closed loop air stripping process that may offer a less expensive approach to VOC removal from water. The closed loop air stripping process combines the use of an air stripping process to separate the VOCs from water with the direct air-phase photooxidation of the stripped organic compounds in the presence of u.v. light. The VOC-free air is then returned to the stripper for the extraction of additional volatile organics; no air is vented to the atmosphere.

The objectives of this work were: (1) to characterize the performance of the photooxidation process in a CLASP operating in a batch mode; (2) to model the CLASP and; (3) to compare the experimental results with model predictions of process performance.

THEORY

The theoretical development of the CLASP is based on the schematic in Fig. 1. A hollow fiber membrane module was used as a laboratory-scale air stripping tower. The membrane module has several advantages that makes its use attractive: the air stripping performance of hollow microporous polypropylene membranes has been well characterized (Semmens *et al.*, 1989); membrane modules can be operated over a wide range of air-to-water ratios without flooding or channeling problems; and the use of membranes is ideal for small-scale applications.

In the batch recirculating system the VOC concentration, C_0, in the stripper influent changed with time. The water was pumped through the lumen of the hollow fibers while air was blown countercurrently

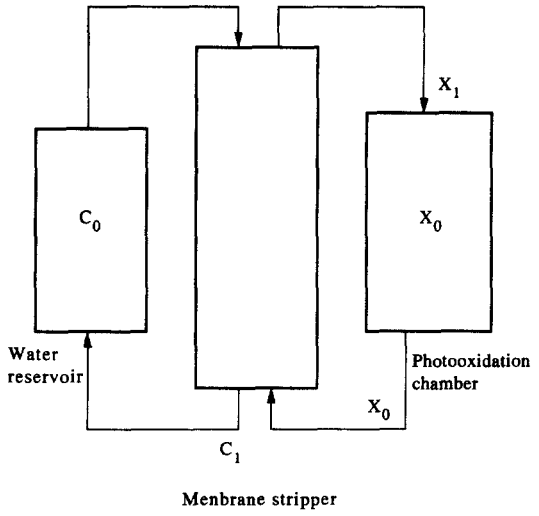

Fig. 1. Flow-diagram of the batch closed loop air stripping process (CLASP).

over the outside, and contact between the water and air phases occurred at the membrane interface. The headspace in the water reservoir was minimized to avoid the complication of VOC exchange with the air phase.

The change in VOC concentration in the water reservoir was due only to stripping and could be described by a mass balance on the water reservoir:

$$V_w \frac{dC_0}{dt} = Q_w(C_1 - C_0) \tag{1}$$

Mass transfer across a single hollow fiber can be described by the following equation:

$$\frac{dC}{dt} = -v\frac{dC}{dZ} - K_L a(C - C^*) \tag{2}$$

where C^* is the equilibrium concentration of the VOCs in water corresponding to the gas phase concentration X at any point within the fiber, and z is the distance along the length of the fiber. C^* may be determined from Henry's law, as $C^* = X/\mathrm{H}$, where H = Henry's constant for the compound considered.

If we assume the VOC concentrations in the water reservoir changed slowly compared to the concentration change in the stripper, a steady state approximation may be assumed and equation (2) becomes:

$$v\frac{dC}{dZ} = -K_L a(C - C^*) \tag{3}$$

Integrating over the length of the stripper for the conditions in Fig. 1, equation (3) becomes:

$$\int_{C_0}^{C_1} \frac{dC}{C - C^*} = -\frac{K_L aL}{v} = -\alpha \tag{4}$$

Thus VOC removal depends on K_L, the mass transfer coefficient, L, the length of the module, v, the water velocity within the fiber, a, the surface area-to-water volume ratio within the module and C^*, which varies along the fiber length. For water flow within the hollow fibers the value of a is given by,

$$a = \frac{4\pi n dL}{\pi n d^2 L} = \frac{4}{d} \tag{5}$$

In addition, a mass balance at any point within the stripper yields,

$$Q_w(C_0 - C) = Q_g(X - X_0) \tag{6}$$

Using equation (6) the value of C^* is expressed in terms of C and this is incorporated in equation (4) and solved for the VOC concentration in the stripper effluent, C_1:

$$C_1 = \frac{\frac{X_0}{\mathrm{H}}[1 - \exp(\alpha\delta)] - \delta C_0}{[R - \exp(\alpha\delta)]} \tag{7}$$

where $\delta = 1 - R$ and R, the stripping factor, is defined as the ratio of $Q_w/(Q_g H)$.

A mass balance over the completely mixed photooxidation chamber gives:

$$V_r \frac{dX_0}{dt} = Q_g(X_1 - X_0) - kX_0 V \tag{8}$$

Equations (1), (6), (7) and (8) are solved by a fourth-order Runge–Kutta method for the initial conditions: $t = 0$, $C = C_0$; $C_1 = 0$; $X_0 = 0$; and $X_1 = 0$.

K_L values were measured experimentally for the module tested following the technique of Semmens *et al.* (1989). The values of K_L may be extended for other compounds and operating conditions using known mass transfer correlations for flow inside and outside the fiber, and the membrane resistance as shown in Table 1.

Table 1. Empirical correlations employed to predict the overall mass transfer coefficients*

Flow	Correlation	Resistance
Water in fiber lumen	$\mathrm{Sh} = 1.62\,\mathrm{Pe}^{0.33}$	$\frac{1}{k_L} = 0.617\left(\frac{Ld}{vD^2}\right)^{0.33}$
Air on shell side	$\mathrm{Sh} = 0.022\,\mathrm{Re}^{0.60}\mathrm{Sc}^{0.33}$	$\frac{1}{k_g\mathrm{H}} = 45.5\frac{d^{0.40}v^{0.27}}{v^{0.60}D^{0.67}\mathrm{H}}$
Membrane		$\frac{1}{k_m\mathrm{H}} = \frac{l}{D_G\mathrm{H}}$

*Obtained from Semmens *et al.* (1989).

Download English Version:

https://daneshyari.com/en/article/4489653

Download Persian Version:

https://daneshyari.com/article/4489653

Daneshyari.com