V = volumetric flow rate; L^3/t
W = total weight of particles in the bed, M
Δ = operator indicating a change
ϵ = void fraction = $1 - (W/A_cL\rho_s)$, dimensionless
μ = viscosity, M/Lt
ρ = density, M/L^3
ρ_s = density of solid, M/L^3

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Mass-Transfer Coefficient and Pressure-Drop Data of Two-Phase Oxygen-Water Flow in Bubble Column Packed with Static Mixers

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The mass-transfer coefficient and pressure-drop data of an oxygen-water flow system through a bubble column packed with static mixers (Koch type) are presented. Compared with the data of an unpacked column, the results show that the mass-transfer coefficient is almost doubled, while the pressure drop only increases slightly. A bubble column packed with the static mixers appears to be effective in aeration or oxygenation systems; thus, the data presented here should be of practical value.

The versatility of static mixers has been recognized in recent years (*3, 4*). Several different types of static mixers are available on the market. Among them, the Koch (or Sulzer) static mixer is the latest design. The Koch static mixer may be suitable for use in an aeration or oxygenation system. This communication presents some results on measurements of oxygen transfer rate and pressure drop in a bubble column packed with the static mixers.

The static mixer is constructed of layers of corrugated sheet metal (Figure 1) or plastics. When oxygen passes through the static mixer concurrently with water flow, small and uniform bubbles are generated as can be seen in Figure 2. These bubbles mix thoroughly with water through open and intersecting channels of the static mixer. The rate of oxygen absorption by water should be highly enhanced through the combined effect of increased interfacial surface area, effective radial mixing, and lengthened gas-liquid contact time. However, the increase in pressure drop through the static mixer over the same size of unpacked column should not be excessive because of the uniformity, geometrical simplicity, and relatively large number and magnitude of channel openings in the mixer unit.

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Experimental

The schematic diagram of the apparatus is shown in Figure 3. Koch static mixers with spacers were packed in the bubble column of 4-in. diameter. Tap water was pumped from a water tank through a rotameter to the bottom of the column. Oxygen from an oxygen cylinder flowed through another rotameter to a $^3/_4$-in. nozzle at the bottom of the bubble column.

Dissolved oxygen concentrations at the bottom and top of the bubble column were measured by using a galvanic cell oxygen analyzer marketed by the Precision Scientific

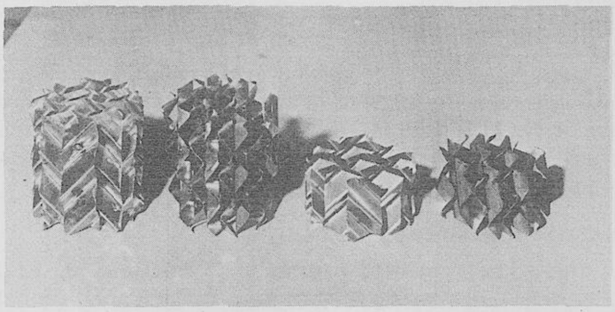

Figure 1. Koch static mixer AY type, whole element (l/D = 1) and half element ($l/D = {}^1/_2$), D = 4 in.

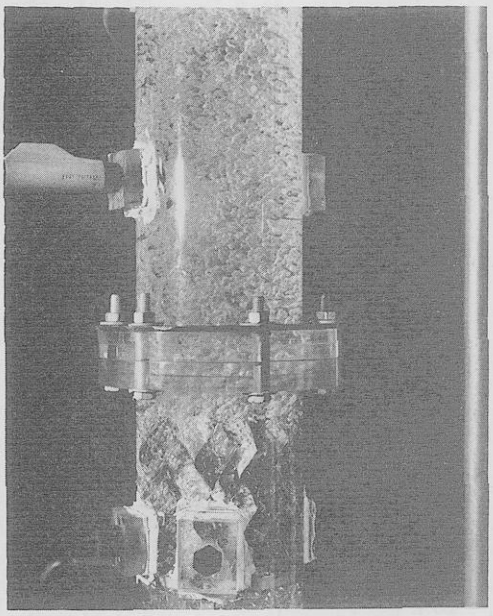

Figure 2. Bubbles in column with Koch static mixers

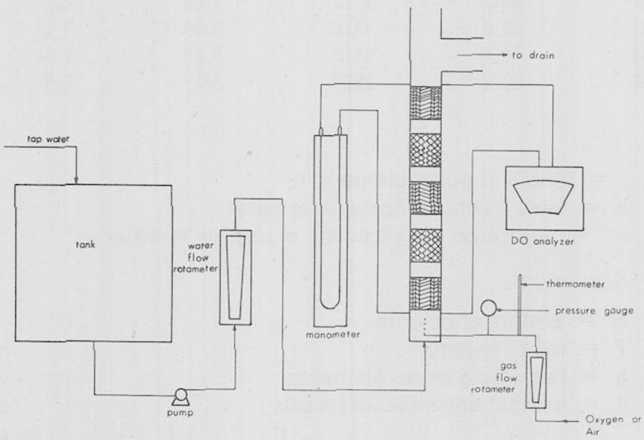

Figure 3. Schematic diagram of apparatus

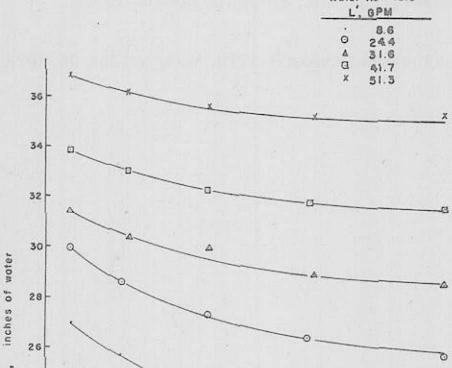

Figure 4. Pressure drop in bubble column with five whole mixer elements

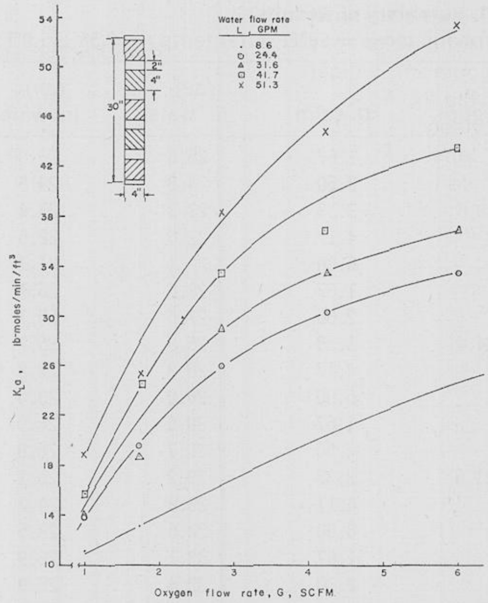

Figure 5. Mass-transfer coefficient in bubble column with five whole mixer elements

Co. The oxygen analyzer has a sensitivity of ±0.1 mg/l. between 5–35°C (40–95°F) with a repeatability of ±0.1 mg/l. The thermistor used along with the oxygen analyzer has an accuracy of ±0.1°C (0.2°F). The pressure drop through the packed section of the column was measured by a manometer. The distance between these two measuring points was 30 in. The static mixers used were AY type (*1*) with layer height 0.5 in. and hydraulic diameter 0.68 in. The experiments were carried out at five water flow rates ranging from 8.6 to 51.3 gpm. At each water flow rate, five oxygen flow rates ranging from 1 to 6 scfm were used.

Results and Discussion

The experimental results of the pressure drop and mass-transfer coefficient in the bubble column with five whole elements are shown in Figures 4 and 5. The values of the pressure drop and mass-transfer coefficient interpolated from these figures at certain selected oxygen flow rates are listed in Table I for comparison. The pressure drop reported here is the net pressure drop due to hydraulic head, frictional force, and buoyant force. Pressure drops through the unpacked column have been obtained separately and are also listed in Table I. As can be seen, the ratio of pressure drop through the bubble column to that through the unpacked one is slightly greater than or close to one.

Because the solubility of oxygen in water is very small and the pressure in the column is nearly constant at 1 atm, the mass-transfer coefficient K_La can be calculated from dissolved oxygen data as:

$$K_La = \frac{L}{Ah} \ln \frac{x^* - x_B}{x^* - x_T}$$

The saturated mole fraction of oxygen in water, x^*, can be calculated from Henry's law (*2*). The experimental values of K_La for the unpacked bubble column, as well as for the packed one, are listed in Table I. As shown in the table, the ratio of K_La values in the packed column to those in the unpacked one varies between 1.4 and 3.0. Since the rate of oxygen absorption is proportional to K_La and the power required is proportional to ΔP, the ratio of $[(K_La)_5/(K_La)_0]$ to $[(\Delta P)_5/(\Delta P)_0]$ can be considered as

Table I. Summary of Results

Atmospheric temp = 90°F; water temp = 63.5° ± 1.0°F; atmospheric press = 29.8 in.

L', gpm	G, scfm	$(\Delta P)_5$, in. water	$(\Delta P)_0$, in. water	$\frac{(\Delta P)_5}{(\Delta P)_0}$	$(K_La)_5$, lb mol/min ft³	$(K_La)_0$, lb mol/min ft³	$\frac{(K_La)_5}{(K_La)_0}$	$\frac{(K_La)_5}{(K_La)_0} \Big/ \frac{(\Delta P)_5}{(\Delta P)_0}$
	1.67	25.6	26.0	0.98	13.0	8.7	1.49	1.52
	2.50	24.3	24.5	0.99	15.5	11.0	1.41	1.42
8.6	3.33	23.3	23.4	1.00	17.6	12.1	1.47	1.47
	4.17	22.6	22.5	1.00	20.2	13.1	1.54	1.54
	5.00	22.1	21.7	1.02	22.4	13.6	1.65	1.62
	1.67	28.6	26.7	1.07	19.2	10.2	1.88	1.76
	2.50	27.5	25.7	1.07	24.3	13.2	1.84	1.72
24.4	3.33	26.8	25.7	1.04	27.8	17.1	1.63	1.57
	4.17	26.3	23.8	1.11	30.0	19.8	1.52	1.37
	5.00	26.0	23.0	1.13	32.0	21.7	1.47	1.30
	1.67	30.5	26.9	1.13	21.0	8.1	2.59	2.29
	2.50	29.7	25.9	1.15	27.0	11.0	2.45	2.13
31.6	3.33	29.2	25.1	1.16	30.9	13.6	2.27	1.96
	4.17	28.8	24.2	1.19	33.4	15.9	2.10	1.76
	5.00	28.6	23.5	1.22	35.2	17.8	1.98	1.62
	1.67	33.1	26.9	1.23	23.2	8.7	2.67	2.17
	2.50	32.4	25.9	1.25	31.0	12.0	2.58	2.06
41.7	3.33	32.0	25.1	1.27	36.2	14.7	2.46	1.94
	4.17	31.7	24.6	1.29	39.2	16.8	2.33	1.81
	5.00	31.5	23.7	1.33	41.6	18.6	2.24	1.68
	1.67	36.2	26.9	1.35	27.0	8.7	3.10	2.30
	2.50	35.6	25.9	1.37	35.2	11.6	3.03	2.21
51.3	3.33	35.4	25.1	1.41	41.8	14.0	2.99	2.12
	4.17	35.2	24.5	1.44	46.4	16.2	2.86	1.99
	5.00	35.0	24.0	1.46	50.2	18.0	2.79	1.91

an indicator of column performance. The values of this ratio range between 1.3 and 2.3 under the conditions of the present study, indicating that a bubble column packed with the static mixers is a very effective aeration or oxygenation system.

Nomenclature

A = cross-sectional area of bubble column, ft^2
a = interfacial surface area per unit volume of column, ft^2/ft^3
D = diameter of mixer element, ft
G = oxygen flow rate at 60°F and 1 atm, scfm
h = height of bubble column, ft
K_L = overall liquid-phase mass-transfer coefficient, lb mol/min ft^2
L = water flow rate, lb mol/min
L' = water flow rate, gal/min (or gpm)
l = length of mixer element, ft
x = mole fraction of oxygen in water
x^* = saturated mole fraction of oxygen in water

Subscripts

B = bottom of column
T = top of column
5 = five whole mixer elements
0 = without any mixer elements

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