EFFICIENCY OF AIR-LIQUID CONTACTOR FOR THE ACTIVATED SLUDGES OXYGENATION

Firas Almoustafa
Belkacem Benadda
Université de Lyon, INSA-Lyon, F-69621;
Université Lyon 1, LGCIE, F-69622; France

ABSTRACT
The aim of this work is to experimentally study a co-current air-liquid downward flow bubble column with air entrainment by liquid injection nozzle in order to use it as aerator in activated sludge treatment plant. The study concerns the determination of mass transfer efficiency by measuring the mass transfer coefficient $k_L a$ in clean water in the first time and in sludge in the second one. In clean water, this parameter is determined by two methods: Gassing out method and absorption with chemical reaction. When using sludge $k_L a$ is measured also by two methods: sludge reoxygenation method and Hydrogen-peroxide method. $k_L a$ obtained in clear water is compared to $k_L a$ obtained in sludge and the alpha factor value (ratio of oxygen transfer coefficient sludge/clean water) is determined. The results are in agreement with those obtained in the literature.
Keywords: aeration, aerobic biological processes, mass transfer coefficient, oxygen transfer, α-factor.

1- EXPERIMENTAL APPARATUS

A schematic diagram of the experimental set-up is shown in Figure 1. It consists of a column made of transparent PVC. A liquid circuit including a pump and a nozzle creates the liquid jet inducing the air entrainment. The liquid-jet flows through an immersed coaxial tube. The liquid-jet sucks down the air and the liquid-air emulsion towards an impact plate near the column bottom. The main dimensions are given in table 1. All details concerning the experimental set-up can be found in our previous study [1]
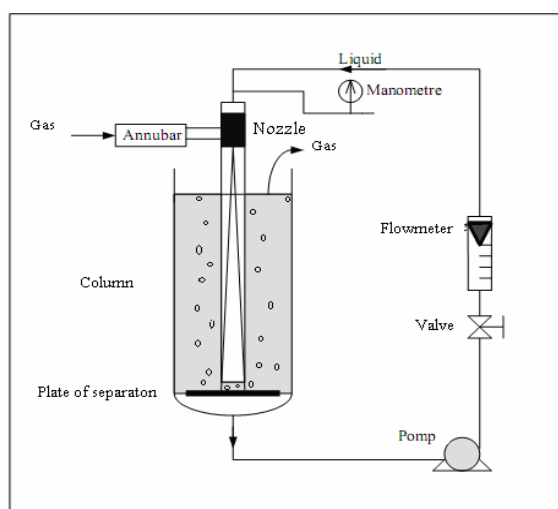

Figure 1. Experimental set-up

Table 1 . Reactor dimensions

Parameters	Values (mm)
Column diameter	300
Column height	1590
Maximum emulsion height	1500
Coaxial tube diameter	40

2- STUDY WITH CLEAN WATER

2.1. Gassing-out method

The water in the reactor is initially deoxygenated by addition of sodium sulphite and cobalt sulphate, the concentration of oxygen will then drop. The aspirated air in the reactor will bring oxygen and the concentration of this component in water will rise slowly in order to reach the saturation. A constant liquid flow rate is maintained in the closed loop and the concentration of oxygen is measured using an oxymeter coupled to recording device. The increase rate of dissolved oxygen is given by the following relationship:

$$\frac{dc}{dt} = k_L a \times (C * - C_t) \qquad (1)$$

The oxygen solubility $C*$ depends on the solution temperature and atmospheric pressure. The minimum oxygen concentration of the solution must be as low as possible. That is why the sodium sulphite is added in order to eliminate all the dissolved oxygen and to approach zero oxygen concentration.

By integration equation (1) we obtain:

$$\ln\left[\frac{(C * - C_0)}{(C * - C_t)}\right] = k_L a \times [t - t_0] \qquad (2)$$

$k_L a$ was calculated by plotting $\ln[(C * - C_0)/(C * - C_t)]$ versus time and was corrected at 20 °C by using the following relationship [3]:

$$(k_L a)_{20°C} = \frac{(k_L a)_T}{1.024^{(T-20°C)}} : \qquad (3)$$

2.2. Absorption with chemical reaction method

The volumetric mass transfer coefficient $k_L a$ was measured by the absorption of oxygen into sodium sulphite catalyzed by cobalt ions. This reaction is by far the mass frequently used chemical technique for determining mass transfer characteristics in gas-liquid contactor. Linek and Vacek [4] have published a very complete article concerning this reaction. In aqueous solution sulphite anions are oxidized by dissolved oxygen according to:

$$Na_2So_3 + \tfrac{1}{2}O_2 \xrightarrow{Co^{2+}} Na_2So_4 \qquad (4)$$

The determination of $k_L a$ was carried out in the slow chemical reaction regime. Under these conditions the absorption rate is expressed by:

$$\phi_{O2} = k_L a \times C * \qquad (5)$$

In this study we consider that the device is perfectly mixed and the reaction takes place only in the tank. The oxygen absorption rate can be determined by following the sulphite concentration in the reactor during the time reaction. This absorption rate can be written as:

$$\phi_{O2} = \frac{1}{2} \times \frac{dC_{SO_3}}{dt} \qquad (6)$$

dC_{SO_3}/dt : Variation of the sulphite concentration in liquide phase which is calculated by sampling of aliquots of the sulphite solution at different times from the reactor. The sulphite concentration was determined by iodometric titration. A plot of the sulphite concentration versus time yields a line. The coefficient $k_L a$ can be calculated by:

$$k_L a = \frac{1}{2} \times \frac{dC_{SO_3}}{C * \times dt} \qquad (7)$$

The same operating conditions used for gassing-out method were used for chemical reaction. The initial sodium sulphite concentration was 0.08 mol/L and cobalt concentration 2.10^{-5} mol/L .

2.3 Results and discussion

Figure (2) presents the variation of $k_L a$ versus Q_L for the two methods. Whatever the method used $k_L a$ values increase with circulation rate. This result is obvious because increase of circulation rates leads to increase both mixing intensity (increase k_L) and the amount of oxygen dispersed into the liquid phase (increase a). This is in agreement with what is found in the literature.

However $k_L a$ values obtained by Sulphite oxidation method are greater than those obtained by gassing-out method. This may be explained by the foam formation caused by the presence of sodium sulphite which increase the interfacial area a [5]
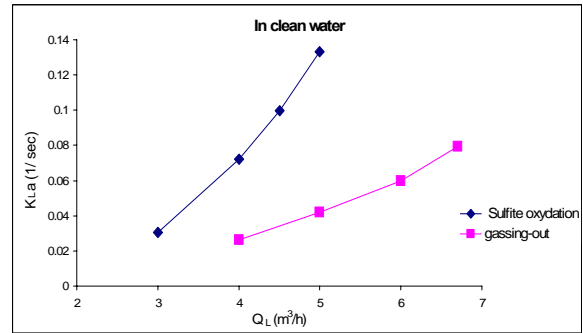

Figure 2. $k_L a$ values in clean water calculated by the gassing-out method and by the sulphite oxidation method

3. STUDY WITH ACTIVATED SLUDGE:

In aeration processes, the measure of performance oxygenation is complicated because the transfer of oxygen from the gas phase to the liquid phase is related to different characteristics of mixed liquor. Different techniques allow to measure of oxygen transfer in activated sludge. Two methods are used in this study to determine this transfer by measuring the coefficient $k_L a'$. Knowing clean water mass transfer coefficient $k_L a$, the α-factor can be calculated.

3.1. Peroxide of hydrogen method

In absence of alimentation of activated sludge during the experience, the masse balance of oxygen in the reactor can be written by:

$$\frac{dC}{dt} = k_l a'(C'_s - C_t) - r \qquad (8)$$

After a sufficient time, the concentration of oxygen becomes stable and the endogenous respiration conditions are reached. This concentration, noted Cs*, is the equilibrium Concentration in sludge.

$$r = k_l a'\left(C'_s - C_s^*\right) \qquad (9)$$

In the presence of catalyzing substances, which is contained normally in sludge, the Addition of peroxide of hydrogen to the reactor, leads to dissociate the peroxide to water and oxygen. This decomposition takes place in a few minutes [6] :

$$2H_2O_2 \rightarrow 2H_2O + O_2 \qquad (10)$$

This addition of hydrogen peroxide allows raising artificially the dissolved oxygen concentration without modifying the conditions of aeration or the hydrodynamics [6]. After adding the peroxide the evolution of oxygen concentration can be given by replacing r from relation (9) in relation (8):

$$\frac{dC}{dt} = k_l a'\left(C_s^* - C_t\right) \qquad (11)$$

By keeping the aeration, the liquid reaches the up-saturation conditions and dissolved oxygen concentration is maximal (C_{max}). After dissociation of all quantity of peroxide, the concentration of oxygen in sludge decreases until reach the concentration (C_s*) obtained before the addition of the peroxide. As in the gassing-out method the record of the evolution of dissolved oxygen concentration allows the determination of the mass transfer coefficient ($k_L a'$) from the following relationships:

$$\ln\left[\left|\frac{(C_s^* - C_{max})}{(C_s^* - C_t)}\right|\right] = k_L a' \times [t - t_0] \qquad (12)$$

Plotting $\ln\left[\left|(C_s^* - C_{max})/(C_s^* - C_t)\right|\right]$ versus time, allows the calculation of $k_L a'$ which is corrected at 20 ◦C by using the relationship (3).

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3.2. Sludge Reoxygenation method

The reactor is putted under condition of endogenous respiration by keeping the aeration until the oxygen concentration stabilizes at the equilibrium concentration C_s*. After this, the alimentation of air is stopped while maintaining the agitation in order to avoid the decantation of sludge. Under these conditions the oxygen concentration decreases until 1 mg/L. then the air alimentation is put back and the oxygen concentration increases again. The evolution of concentration of oxygen is written by the same equation that used in the peroxide method (equation 11).

$$\ln\left[\frac{(C_s*-C_{\min})}{(C_s*-C_t)}\right] = k_L a' \times [t-t_0] \qquad (13)$$

$k_L a'$ was found by plotting $\ln[(C*-C_0)/(C*-C_t)]$ versus time and it is corrected at 20 °C.

3.3 Results and Discussion

As shown in Fig.3 not significant difference can be noticed between the two methods. This can be explained by the fact that both methods use the same principle (increase or decrease) of the dissolved oxygen concentration. As in clean water, $k_L a'$ increases with increase of liquid flow rate.
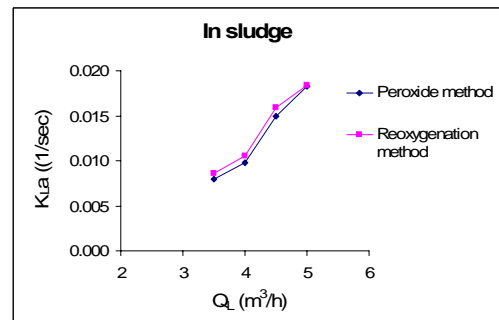

Figure 3. $k_L a'$ values (calculated by the peroxide method and the reoxygenation method).

4. α-FACTOR

α-factor values and $k_L a$ values obtained in clean water and those obtained in activated sludge are collected in Table 2. Generally, the $k_L a$ values obtained in clean water are greater than those obtained in sludge. This difference is due to that the surfactants affect the transfer of oxygen in the activated sludge. These surfactants can result from washing products certainly, but they are also secreted by bacteria [7]. The small value of our α–factor (Table 2) is due to the small value of $k_L a'$ caused by caused by contaminants of organic substances, and antifoaming agents. In fact the activated sludge used provided from an activated sludge treatment plant which used antifoam agents.

Q_L	$k_L a$		α factor	
m³/h	1/sec		our reatcror	Ref [5]
	in clean water	in sludge		
4	0,023	0,011	0,46	0,6
5	0,039	0,018	0,47	

Table 2. α factor values

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