Monitoring the Impact of Dissolved Oxygen in a Bioreactor and the Evolution of Purifying Biomass

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Abstract— the objective of the work presented is to define the hydrodynamic conditions of Dissolved oxygen (DO) consumption by biomass in order to understand their importance on the proliferation of cells responsible for biodegradation of tributary pollutants. Modeling by adimensional analysis proves to be a crucial tool in the prediction of the K_La transfer coefficient that will allow us to make a temporal follow-up. The results showed that K_La decreases with the proliferation of biomass. The consumption of oxygen is present in the process of purification of the fact that Dissolved oxygen constitutes one of the vital substrates to biomass. A global model, derived from dimensional analysis, is proposed for the prediction of the transfer coefficient and mixed liquor of volatile suspended solids (MLVSS) at 26 °C only applies in ranges where the concentration of Dissolved oxygen varies between 4.08 and 6.15 mg O_2 / L.

Key Words — Dissolved oxygen, mixed liquor, modeling, oxygen consumption, oxygen transfer coefficient.

I. INTRODUCTION

Wastewater treatment using the activated sludge process, various methods are widely used to improve the efficiency of aeration [1] who is closely related to sludge characteristics (mixed suspended solids (MLSS), microbial community concentrations), and operating conditions (airflow and dissolved oxygen levels). This process must meet several basic requirements and create favorable conditions for biological material; this will lead to the desired production. However, the interaction between aeration and mixed liquor of volatile suspended solids (MLVSS) deserves special attention if it can be modeled anytime, because it will open a new vision towards the control and the optimization of the aeration performances. Compressed air, which is used for mixing, is injected into the base of the bioreactor using a well-defined diffuser [2]. This type of bioreactor belong to bubble columns design which provide a simple and inexpensive method for mixing and contacting different phases [3]. Each bioreactor design attempts to produce a very specific set of conditions applicable to a certain type of cell or bacteria.

Considerable attention has been devoted to the determination of the volumetric oxygen transfer coefficient (K_La) where many studies involve methods [4] that can be applied with difficulty in a biological system. Among these, the dynamic method [5] and the steady-state oxygen equilibrium method [3] can be used. The comparison of the results obtained with those obtained with the experimental process in a small bubble column based on the formulations proposed by Painmanakul and al. (2009) [6] makes it possible to give a better description of the mass transfer in the cylindrical tanks [7]. In the range of parameters considered, the oxygen transfer coefficient is an increasing linear function of the airflow rate. For a given airflow and a given reservoir area, K_La decreases with depth of water (submersion of the diffusers) while an increase of MLVSS is observed. Baquero-Rodríguez et al, (2018) [8] were unable to find mathematical models that could be used to develop predictions of dynamic factors and predictions of fouling of diffusers. This is why, in the work that we propose, we proceeded differently by using respiratory parameters related to the studied system which is a bioreactor, to lead to define a suitable mathematical model.

II. MATERIALS AND METHODS

A tank 40 x 45 x 47 cm filled with 54 liters of wastewater is set up for the follow-up of the aeration. This one is assured with diffusers having orifices of 1 mm diameter submerged at 23 cm of depth. It is connected to an LZB10 ice rotameter, a vertical thermometer (ISO 9001) and an air filter. Sludge recycling is provided by a TAIFU circulation pump (GRS12 / 9-Z) (ISO 9001) and flow rates of fluids entering and leaving the pond are continuously monitored by GARDENA flow meters.

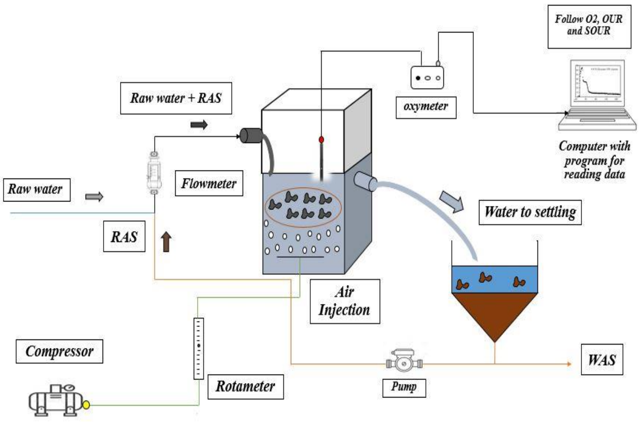


Fig. 1. Experimental configuration at the pilot scale.

Respirometric analyzes. The concentration of dissolved oxygen (DO), oxygen consumption (OUR), specific oxygen consumption (SOUR) and temperature, were measured using a waterproof Oximeter with integrated barometer, USB port (HI 98193) equipped with program (HI 92000).

Measurement of oxygen transfer coefficient. In our case, the volumetric oxygen transfer coefficient in water K_La has been measured in the presence of activated sludge. The aeration performance has been determined by a method based on the rate of oxygen consumption by the micro-particles [9]. The gas insufflation conditions maintained at 28°C, 101325 Pa and a flow rate between 430 and 1000 L/h. A SEA STAR HX-906 thermostat was also placed inside the basin to set the temperature of the water at 26°C.

Gas transfer modeling. The modeling was based on the use of the gas velocity estimation [10, 11] and the dissolution of the gas in the liquid phase generates turbulences with the fluid thus characterizing a relative importance of the kinetic energy of its particles with respect to its gravitational potential energy which is defined by the number of Froude [12]. For this, we used equations:

$$U_{GS} = Q_G/N_{OR} \cdot A_{OR} \tag{1}$$

$$F_r = U_G{}^2/g \cdot h \tag{2}$$

With Q_G, is the flow of the gas entering the tank. N_{OR}, the number of orifices located on the diffuser and A_{OR}, the surface of the orifice. U_G, the superficial velocity of the gas, h, the submersion depth of the diffuser, and g, the acceleration due to the gravity.

III. RESULTS AND DISCUSSIONS

Respirometric analyzes. The first reported tests were carried out on wastewater in a two-phase medium (gas-liquid) at a concentration of DO ranging from 4.08 to 6.15 mg O_2 / L. The respirometric analysis (Fig. 2), shows that the interaction between DO, OUR, SOUR and MLVSS reflects the actual response of the microbial community to the use of electron acceptors under the operating conditions of the bioreactor. The gas flow rate varies between 430 and 1000 L / h. This increase in flow was necessary to ensure the proliferation of biomass that is related to the increase in DO and OUR. In addition, the decrease in SOUR supports the consumption of oxygen that is very present in the purification process because DO is one of the vital substrates for biomass.

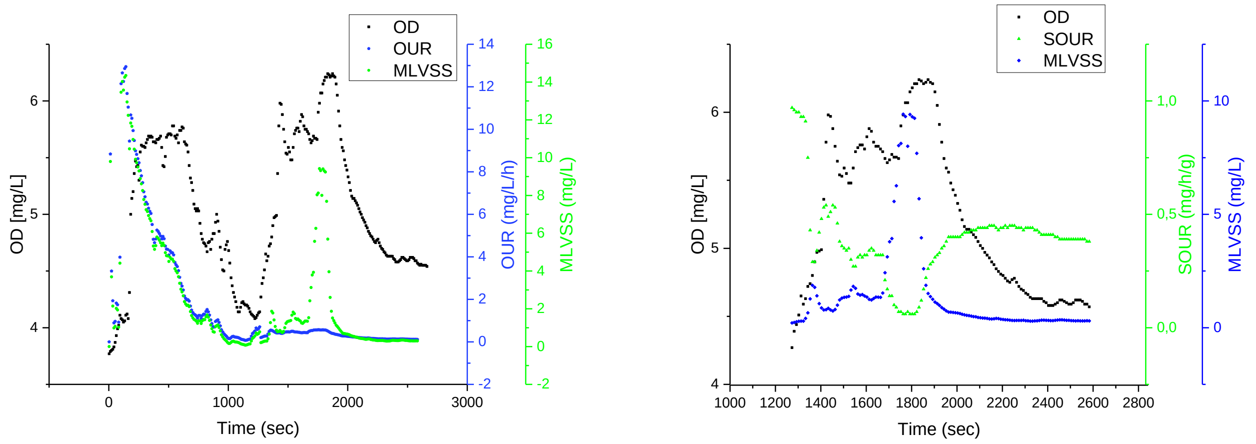
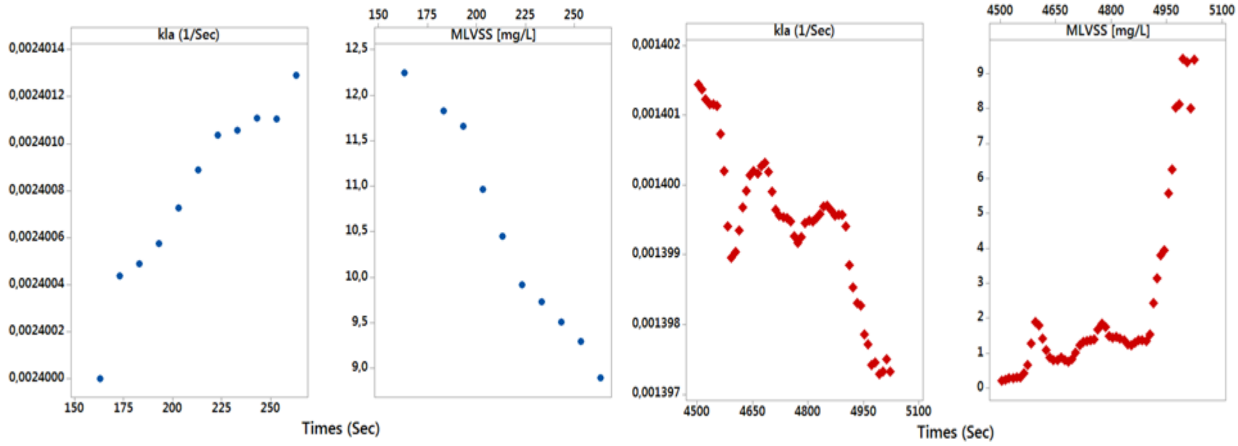


Fig. 2. Evolution of biomass and parameters of respirometry.

Measurement of oxygen transfer coefficient. Experimental K_La values were calculated as reported by Mueller et al. (2002) [9]. The values retained, 0.0024 and 0.0014 s-1 corresponding to 430 and 1000 L/h respectively, confirm that K_La decreased with the proliferation of biomass, which contributes to the decrease of oxygen in the wastewater (Fig. 3).



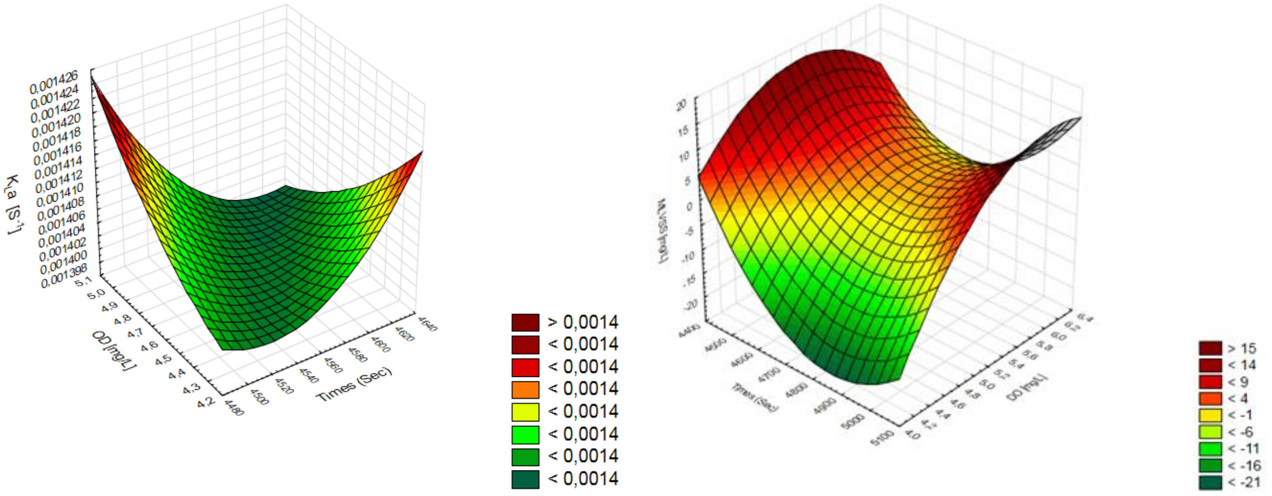


Fig. 3. Evolution of MLVSS compared to K$_L$a

Gas transfer modeling. At 26 ° C, a global model was proposed for the prediction of the transfer coefficient as a function of dimensionless numbers. It is established for the study of parallelepipedic bioreactors and for a height of submergents immersions less than 35 cm using the formalism proposed by Delaplace et al., (2013) [6]. We obtain the following model:

$$K_L a = A(U_G/h)\left[\left(MLVSS/DO^{e_1}\right)\cdot F_r^{\,e_2}\right]^{e_3} \qquad (3)$$

Another empirical model correlating transfer and biomass production at 26°C in the bubble column and using the formalism commonly used for model fluids [11, 13, 14] was developed (Eq. 4). The number of transfers proposed by Roustan, (2003) [15] was used.

$$MLVSS = -a\cdot(K_L a\cdot h\cdot[DO]/U_G) + b\cdot[DO] \qquad (4)$$

With A, a, b, constant and e$_i$, exponent whose values are shown in Table 1. They were determined by minimizing the sum of the squares of the differences between the results of the calculations and the experimental results giving K$_L$a (26°C) and MLVSS.

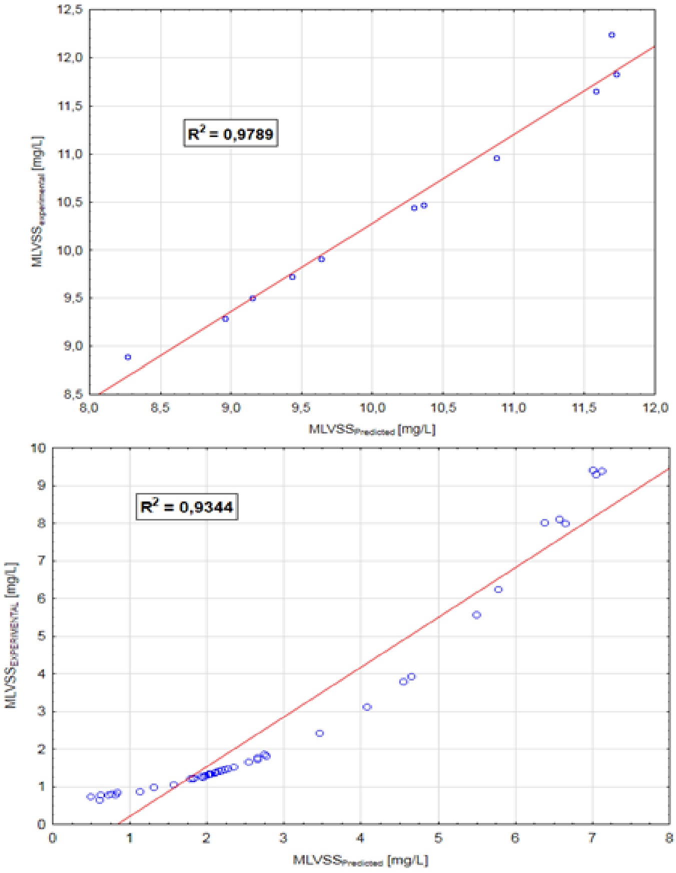


Fig. 4. Agreement between experimental and modeled values of MLVSS.

Table 1. Empirical values of the proposed models at 26 °C.

Superficial gas velocity [L/h]	K_La model [s^{-1}]						MLVSS model [mg/L]		
	A	e_1	e_2	e_3	K_La	R^2	a	b	R^2
$U_G = 430$	0,11	0,0024	0,5	-0,36	0,0024	0,986	-935,43	2560,9	0,9789
$U_G = 1000$	0,11	0,0024	0,5	-0,36	0,0014	0,898	-135,28	502,05	0,9344

Fig. 4, shows the experimental MLVSS as a function of the values calculated from the eq.4: The regression coefficient R^2 is 0.9789 for microorganism mortality and 0.9344 for biomass proliferation. The relative differences between measured and calculated values are on average 1% and 26.23%, respectively. The correspondence between the calculated values and the experimental values is therefore considered as moderately satisfactory in the context of the proliferation of biomass. The differences obtained are due to the empirical nature of the established relation, to the measurement errors (K_La, geometrical magnitudes, airflow, etc.) and the concentration of OD ranging from 4.08 to 6.15 mg O_2/L at 26°C.

VI. CONCLUSION

This study clearly showed that operating conditions in the bioreactor could lead to a better understanding of the parameters that influence the dissolved oxygen transfer mechanism. By using empirical correlations to estimate biomass production it is clear that hydrodynamics has an important place in the proper functioning of the activated sludge process. Nevertheless, the empirical nature of the established relationship includes its rate of measurement errors due to physicochemical parameters affecting environments where microorganisms feed to proliferate.

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