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In situ characterization of local hydrodynamic parameters in closed-loop aeration tanks

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ABSTRACT

The objective of this experimental study was to collect and to interpret data in order to better understand the oxygen mass transfer phenomena occurring in full-scale aeration tanks equipped with fine bubble diffusers and slow speed mixers (inducing horizontal liquid flows). Bubble size, local depth and oxygen mass transfer coefficient were measured *in situ* for a given air flow rate ($1555\,N\,m^3\,h^{-1}$) and for two different axial liquid velocities. The increase in the global oxygen transfer coefficient is of 29% when the mean axial liquid velocity varies from 0 to $0.42\,m\,s^{-1}$. The small influence of the liquid velocity on the local bubble Sauter diameter (about −4%) cannot explain the increase in k_La_{20}. This increase in k_La_{20} with the axial liquid velocity is mainly due to the attenuation of the vertical liquid circulation induced by the gas injection.

1. Introduction

Activated sludge systems are widely used in wastewater treatment. In such processes, aeration can represent up to 70% of the energy expenditure of the all plant. In order to minimise this consumption and to improve the treatment efficiency, optimising aeration devices is essential.

To this aim, syntheses of measurements performed on full-scale aeration tanks pointed out the main parameters affecting oxygen transfer in clean water [1,2]. In addition, computational fluid dynamics (CFD) is more and more used to interpret the obtained results [3–6]. However, no set of data including all the parameters required to understand and to simulate the phenomena (bubble size as input data; gas hold-up, axial liquid velocity and oxygen transfer coefficients as validation data) has ever been proposed for full-scale closed-loop aeration tanks.

In situ measurements (bubble size, axial liquid velocity, oxygen transfer coefficient, local depth) have therefore been performed on full-scale plants, in order to obtain precise information on the physical phenomena occurring in closed-loop aeration tanks and to optimise their operation. The objective of this paper is to present and to analyse the obtained results.

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2. Materials and methods

Measurements have been performed on a full-scale aeration tank. The development of the measurement methods is described in detail in a previous paper [7].

2.1. Aeration tank

The studied basin was chosen as representative of close-loop reactors with classical configuration and water depth. The aeration tank is of annular type (volume of liquid $[V] = 1493\,m^3$; internal diameter $[D_{in}] = 7.83\,m$; external diameter $[D_{out}] = 20.25\,m$; water depth $[d_w] = 5.45\,m$), and is equipped with six grids of 26 fine bubble EDPM membrane diffusers (tubes of 0.8 m length) and one large blades slow speed mixer (2.5 m diameter), mounted at the bottom of the tank (Fig. 1). The tank was filled with tap water.

Each grid of diffusers is divided into two zones of equal surface with a different diffuser density (10 tubes in the zone near to the inner diameter of the tank and 16 tubes in the zone near to the outer diameter).

In the following, the grids of diffusers are designed by a number corresponding to their location. As example, grid 2 corresponds to the second grid in the direction of the liquid flow, indicated by the arrow in Fig. 1.

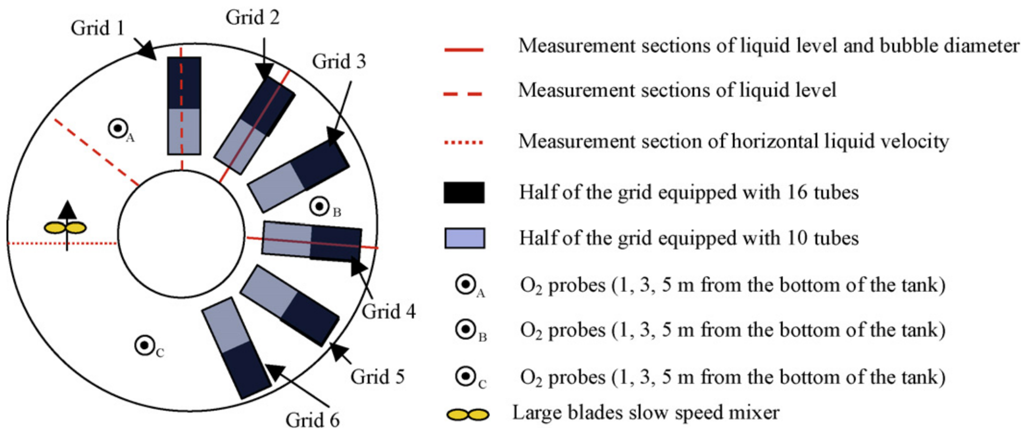

Fig. 1. Annular loop reactor.

2.2. Axial liquid velocity measurement

The axial liquid velocities were determined with and without aeration using an electromagnetic flow-meter (corresponding to one point/m^2 of section, [8]) on 35 points regularly distributed on one vertical section of the tank away from the bubble plume (Fig. 1). The measurement section was orthogonal to the flow direction.

The mean velocity represents the arithmetic average of the local velocities obtained on the 35 measurements points. The sampling time was fixed to 60 s, and allows determining the local liquid velocity with a confidence interval of ±3%.

2.3. Oxygen transfer coefficient measurement

The oxygen transfer coefficient was determined according to the non-steady state method integrated in the American and European standards [9,10]. The method consists of monitoring the dissolved oxygen concentration increase after the addition of sodium sulfite in the presence of a catalyst (cobalt chloride).

For each measurement, the addition of sodium sulfite was performed without aeration. Appropriate mixing was provided by built-in mixers to prevent settling of the sulfite powder and to allow a uniform distribution of the reactant.

The dissolved oxygen concentration was measured on 9 points using dissolved oxygen probes (YSI 57), located on 3 water depths (1, 3 and 5 m from the bottom of the tank), on 3 verticals (see Fig. 1). The sampling frequency was set to 5 s. The oxygen transfer coefficient was then deduced from the obtained curves using a non-linear regression analysis.

In the following, the oxygen transfer coefficient is expressed at standard conditions (20 °C, 1013 hPa) as follows:

$$k_L a_{20} = k_L a_T \times 1.024^{20-T} \tag{1}$$

where $k_L a_T$ is the oxygen transfer coefficient at the temperature T (°C), $k_L a_{20}$ is the oxygen transfer coefficient at 20 °C.

2.4. Bubble size measurement

Bubble diameters were determined from images obtained by an immersed camera (Canon Powershot G6) inserted in a waterproof Plexiglas box located in the bubble plume (see Fig. 2). Lighting was carried out by two 600 W spots mounted on the immersed structure, on both sides of the camera. The scale for the bubble size determination was obtained with the help of a ruler placed in front of the lens. Only the sharp bubbles located in the plan of the ruler are taken into account in the bubble size determination.

Fig. 2. Bubble size measurement tool.

The bubbles (Fig. 3) have an ellipsoid shape in clean water, and an equivalent diameter, $d_{eq,i}$, is defined as the diameter of a spherical bubble having the same volume as the ellipsoid, as follows:

$$d_{eq,i} = \sqrt[3]{a_i^2 . b_i} \tag{2}$$

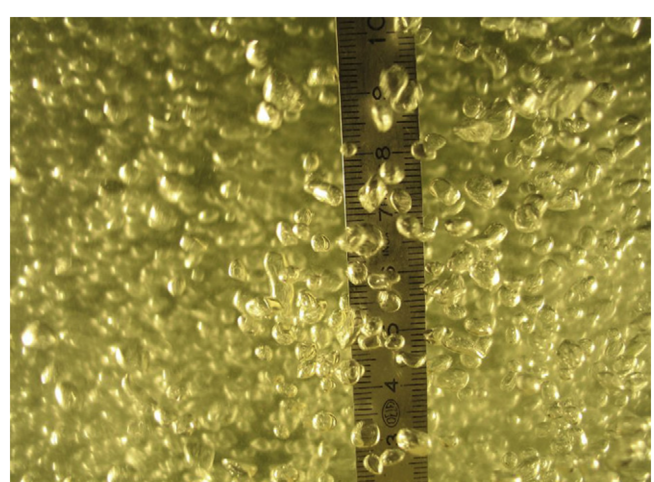

Fig. 3. Typical picture obtained in the bubble plume.