MODELING OF OXYGEN TRANSFER IN FORCED AERATION

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Abstract. *It is known that forced or natural aeration are linked to the self-purification capacity of water bodies. It is also know that the use of less aggressive oxidizing substances results in lower toxicity, and, thus, results on general better characteristics of the final waters. The dissolution of oxygen into water is an important step in the processing of wastewaters. Different equipments can be used to attain adequate levels of dissolved oxygen in water. In the present study, the dissolution is performed in the so called aeration units (tanks) where air is bubbled through the liquid, while the last moves in a continuous flow regime. This research considers the phenomenological modeling of the oxygen transfer from the air bubbles to the liquid, and the numerical simulation of the Ordinary Differential Equations (ODEs) and Partial Differential Equations (PDE) that govern the mass transfer phenomena and the fluid flow. Experimental results obtained from this study and also from the literature will be compared with the simulation data. We understand that such models can contribute to the understanding of the turbulent transport of scalar components in fluids in a practical way, as well as can be used to help in the monitoring of water resources or in control operations during wastewater treatments in treatment plants.*
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Keywords*: aeration,turbulent flow, dissolved oxygen, water treatment.*

1. INTRODUCTION

The mechanisms involving the movements of air bubbles in water are important for the understanding and modeling of the phenomena related to oxygen dissolution.

Oxygen dissolution is the fundamental step in the processing of pollutant effluents. The degrading microorganisms need oxygen to oxidize organic compounds and mineralize them to substances less aggressive to the environment and to human health. In nature the dissolution takes place through the air-water interface, depending on the turbulent condition in the water bodies. In the nature the transfer efficiency can be low, but the contact area is generally big.

To recreate these dissolution conditions in a controlled environment, where the free exposed interface area does not have satisfactory proportions, the easiest way is to bubble air in the flowing liquid medium to enhance oxygen transfer. The so called "aerator" (aeration tank or channel) is the unit responsible for this process and its configurations are extensive and operated in several different ways. The reason for so many variations is the searching for the highest possible efficiency in oxygen transfer to the water.

Aeration is an "old problem", and many contributions has been made to the theme, but there are still many open questions and optimizations to be explored, mainly when more phases or components are present, like processes involving activated sludge. The flows in nature are essentially turbulent, and all transfer mechanisms depend on the intensity of the mixture caused by the eddies. Thus, the oxygen absorption is also a function of the turbulence intensity. Correlations involving the turbulent Schmidt number ($Sc = \nu_T / D_{AB_T}$), in which ν_T is the turbulent viscosity and D_{ABT} is the turbulent diffusivity, allow to estimate the turbulent diffusity needed for the quantification of mass transfer in projects , modeling, process control, among other objectives.

Considering the statement above, we tried to evaluate the turbulent viscosity in forced aeration systems applying the laser velocimetry technique, and developing oxygen transfer models, contributing to the knowledge on recuperation of water quality.

The current research considers, thus, forced aeration phenomena, turbulence, and the use of the laser velocimetry technique (PIV).

The flow structure in the turbulent regime is characterized by random tridimensional movements of fluid particles, added to the main movement. We naturally infer that more agitated flows transfer higher quantities of movement than less agitated flows. This is because there are macroscopic volumes of fluid that randomly move through the flow with higher velocities. Therefore, it is concluded that the turbulent viscosity is a function of the turbulent agitation in the flow. This characteristic is relevant because it shows that the proportionality coefficient in the transport equation can be a function of the position in the flow. That is, a flow can present a turbulent viscosity profile (SCHULZ, 2003) instead of a single characteristic value.

The PIV technique is used to obtain images to determine instantaneous velocity fields and to determine bubble sizes in a bi-dimensional flow field. The PIV technique consists of a beam of light that illuminates the suspended particles in the flow that pass through the bi-dimensional beam. The luminosity of the light source highlights the particles that follow the fluid movement, which may then be photographed by a high speed camera (a high number of frames per second). The correlation between sequential images furnishes the local velocities of the fluid.
The correlation of these data provides the local fluid velocities. Countless studies using the PIV technique can be found [Liu e Zheng (2006), Pereira (2006), Salla (2006), Sousa et al (2006), Fan et al (2005), Baldi e Yianneskis (2004), Fan et al (2004), Bao e Dallamann (2003), Dellauré et al (2003), Weitbretch et al (2002), Cheng e Law (2001), Pan e Meng (2001), Law e Wang (2000), Orlins e Gulliver (2000), Tokuhiro et al (1998), Jun et al (1993)], but few depict the drainage subject to aeration, so this study is to contribute to towards this.

2. MATERIALS AND METHODS

The experiments were conducte in the Laboratory of Environmental Hydraulics, located in the Centro de Recursos Hídricos e Ecologia Aplicada (CRHEA) in the Escola de Engenharia de São Carlos, Universidade de São Paulo.

The experimental device was composed by a cross-flow aerator without mechanical agitation. The channel was 5m long, 350mm tall and 200mm wide, made of acrylic, which makes it easier to visualize the flow of the bubble plumes subjected to turbulent movements. The tank was fed with local supply water and neutral talc powder was used as particles tracer.

The particle image velocimetry (PIV) technique was used to obtain velocity profiles inside the channel. In this technique a light beam in a blade format (light sheet) originated from a cooper vapor laser (Oxford Laser LS-20-10 20W) cuts the tank in the longitudinal direction, and a CCD camera on the side of the tank captures images in the illuminated area. The captured images were then treated in a specific program (Visiflow) which provided velocity values in a number of points of the flow. The use of the laser source illuminated well the flow, allowing to obtain good pictures and to calculate the Reynolds stresses data that are essential for the turbulent flow studies. With these data it is possible to define an aeration rate, aiming to validate possible models. The main objective of this work is to evaluate the turbulent viscosity and the subsequent turbulent diffusivity accordingly to the basic model of the transport equation (presented here in *x* coordinate):

(1)

$$\frac{-\partial \overline{p}}{\partial x}+\frac{\partial}{\partial x}\left(\mu\frac{\partial \overline{V_x}}{\partial x}-\rho\overline{V_x^{'}V_x^{'}}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial \overline{V_x}}{\partial y}-\rho\overline{V_x^{'}V_y^{'}}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial \overline{V_x}}{\partial z}-\rho\overline{V_x^{'}V_z^{'}}\right)+\rho\overline{B_x}= \quad (2)$$

$$=\rho\left(\frac{\partial \overline{V_x}}{\partial x}\overline{V_x}+\frac{\partial \overline{V_x}}{\partial y}\overline{V_y}+\frac{\partial \overline{V_x}}{\partial z}\overline{V_z}+\frac{\partial \overline{V_x}}{\partial t}\right)$$

The terms between parentheses in the first member involve a parcel that represents the molecular diffusion of momentum , while the parcel that involves the turbulent fluctuations represents the turbulent diffusion of momentum. It is possible to define the coefficient of turbulent transfer of momentum (turbulent viscosity), written below (with a positive sign):

$$\tau_{xy}=\mu\frac{\partial \overline{V_x}}{\partial y}+\mu_{txy}\frac{\partial \overline{V_x}}{\partial y}$$

By comparison with the terms in Eq. 2, we have:

$$\tau_{xy}=\mu\frac{\partial \overline{V_x}}{\partial y}-\rho\overline{V_x^{'}V_y^{'}}$$

(2)

From equations 3 and 4 we obtain, immediately:

$$\mu_{txy} = -\frac{\rho \overline{V'_x V'_y}}{\left(\frac{\partial \overline{V_x}}{\partial y}\right)}$$

It is worthy to observe that the desired Reynolds stresses are given by $\rho\overline{v'_x \ v'_y}$, in which v'_x e v'_y are velocity fluctuations following the *x* and *y* directions in the Cartesian system. Having the turbulent viscosity, the turbulent diffusivity follows generally from simple proportionalities involving adequate values for the turbulent Schmidt number.

3. PRELIMINARY RESULTS

The results were obtained by the analysis of the velocity data. The visual quality of the data can be attested when exposing them in vectorial fields, considering the sector studied in the channel. The studies were carried out considering two dimensions, the height and the length of the channel.

The fluctuating velocities compose the Reynolds stresses $\rho\overline{v'_x v'_y}$, which allow to calculate the turbulent viscosity.

The results for the turbulent viscosity are described in Figures (1), (2), (3), (4).

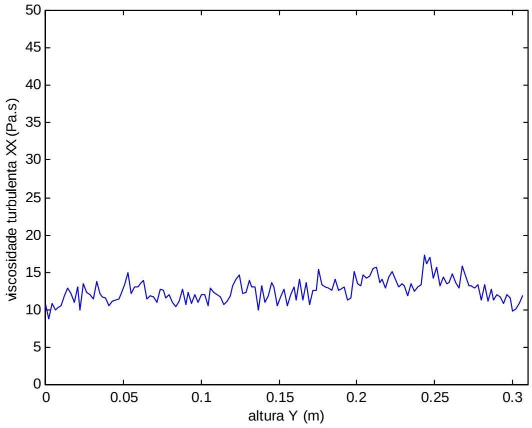

Fig. 1: Turbulent viscosity disposition in the Y direction $\mu_{t\,xx}$ medium in X. Scale in Pa.s.

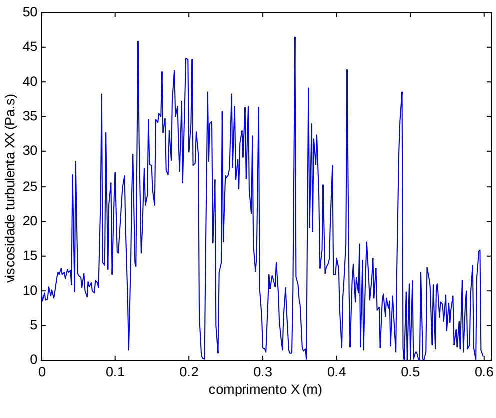

Fig. 2: Turbulent viscosity disposition in the X direction $\mu_{t\,xx}$ medium in Y

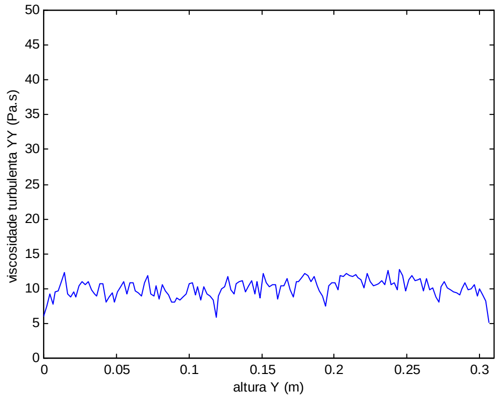

Fig. 3: Turbulent viscosity disposition in the Y direction $\mu_{t\,yy}$ medium in X

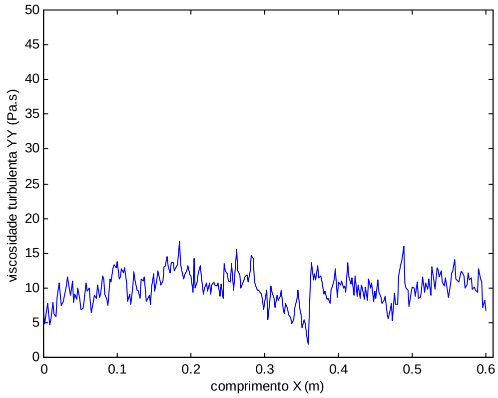

Fig. 4: Turbulent viscosity disposition in the X direction $\mu_{t\,yy}$ medium in Y

The good quality of the data points to the convenience of a numerical model to reproduce the experimental results and to allow predictions for different flow conditions. Further investigations considering the dispersion of the bubbles are intended.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

BALD, S., YIANNESKIS, M. On the Quantification of energy dissipation in thImpeller Stream of a Stirred Vessel from Fluctuating Velocity Gradient Measurements. Experimental an Computational Laboratory for the Analysis of Turbulence (ECLAT), Division pf Engineering, King's College, London, 2004.

BAO, F., DDALLMANN, U.C., Some physical aspects of separation bubble ona rounded backward-facong step. Physicalische Phanomene vom Ablöseblasen einer abgerundeten Stufe. German Aerospace Center, Bunsenstr. Germany. Aerospace Science and Techology 83-91, 2004.

DELAURÉ, Y.M.C., CHAN, V.S.S., MURRAY, D.B. A Simultaneos PIV and Heat Transfer Study of Bubble Interaction with Free Convection Flow. School of Mechanical an Manufacturing Engineering. Dublin City University, 2003.

FAN. J., RAO, Q., WANG, Y. FEI, W. Spatio-temporal Analysis of Macro-Instability in a Stirred Vessel Via Digital Particle Image Velocimetry (DPIV). State Key Laboratory of Chemical Engineering, Department of Chemical Engineering, Tsinghua University, China, 2004.

JUN, K.S., JAIN, S.C. Oxigen transfer in bubbly turbulent-shear flow. Journal of Hidraulic Engineering, v.119, n.1, p 21-36, January 1993.

LAW, A.W.K., WANG, H. Measurement of mixing processes with cpmbined digital particle image Velocimetry and planar laser induced fluorescence. School of Civil and Structural Engineering, Nanyang Technological University, 2000.

LIU, Z., ZHENG, Y., PIV Study of Bubble Rising Behavior. Deprtment of Chemical Engineering, Univerty of New Brunswick, Canada, 2006.

ORLINS, J.J.; GULLIVER, J.S., Measurement of Free Surface Turbulence, In: International Symposium on gas Transfer at Water Surfaces, 4., Flórida, /Comunicação Pessoal/, 2000.

PEREIRA, C.E. Correntes Induzidas em Equipamento de Grade Oscilante: Advecção Interferindo em Difusão e Dissipação. São Carlos-SP, EESC-USP, 2006 (tese).

SALLA, M.R. Sistema de Ozonização em Esgoto Domiciliar Considerando as Reações Intermediárias e a Hidrodinâmica. São Carlos-SP, EESC-USP 2006 (tese).

SOUSA, R.G., PINTO A.M.F.R., CAMPOS, J.B.L.M. Efecct of gás expansion on the velocity of a Taylor bubble: PIV measurements. Centro de estudos de fenomenos de transporte, Departamento de Engernharia Química, Faculdade de Engenharia da Universidade do Porto, Portugal, 2006.

SCHULZ, E. H. Investigação do Mecanismo de Reoxigenação da Água em Escoamento e sua Correlação com o Nível de Turbulência junto à Superfície. São Carlos, SP, EESC-USP, 1985, 299p. (Dissertação).

SCHULZ, E. H. Investigação do Mecanismo de Reoxigenação da Água em Escoamento e sua Correlação com o Nível de Turbulência junto à Superfície. São Carlos, SP, EESC-USP, 1989, 348p. (Tese).

SCHULZ, E. H. O Essencial em Fenômenos de Transporte. São Carlos, SP, EESC-USP, 2003, 381 p.

WEITBRECHET, V.G., KÜHN, G., JIRKA, G.H. Large scale PIV measuments at the surface of shallow water flows, Institute for Hifromechanics, University of Karlsruhe, Germany. Flow measurement and Instrumentation 13, 237-245, 2002.

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