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Correlation of oxygen mass transfer and power consumption in an aeration system by a rotating cone

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ABSTRACT

We have experimentally found a pumping-up mechanism, where the thin liquid film flow goes up fully upward along the outer surface of a rotating cone. The mechanism is applied to the atomization of the liquid and to the transportation of oxygen from the air to the water through the atomized water droplets. We measure the dissolved oxygen concentration and axial torque for varying the immersed radius, the total volume of water and the rotation rate. The correlation between the unit volume power consumption and the oxygen mass transfer is examined. It is found that the oxygen transfer increases in power law relationship with the unit volume power consumption. Eventually, an empirical correlation function of the oxygen mass transfer against the power consumption is obtained.

1. Introduction

Aeration is the most important and indispensable action for wastewater treatment because it plays an important role in the enhancement of oxygen mass transfer. The main purpose of aeration is to dissolve the oxygen into the water in order to provide it to the microorganisms decomposing organics as substrate. Many different types of aeration systems have been developed over the years. It is common in the aeration process to pass the air through the water with the Venturi tube, aeration turbines, compressors, etc. In order to evaluate the performance of different types of aeration systems, a standard for the measurement of the oxygen transfer in clean or tap water has been established by American Society of Civil Engineers [1] based on the basic model of Brown and Baillod [2], where the standard describes in detail the experimental apparatus and methods, and recommends the standard conditions such as zero dissolved oxygen level, 20 °C water temperature and 1 atm pressure.

Ashley et al. [3] have examined bench-scale study of oxygen transfer in coarse bubbles on the studies using air bubbles for aeration, while Duchene et al. [4] have focused on fine bubbles for the aeration. A diameter range of coarse bubbles is between 6 and 10 mm and one of fine bubbles is between 2 and 5 mm. They showed that these bubbles were easy to create without much power and energy, and effective for the aeration. Chen et al. [5] have investigated an aeration process that obtains a high oxygen dissolution by applying a gas-inducing reactor, where pure oxygen is introduced into the reactor and is stirred with a 6-blade pitched-blade downward turbine. They obtained a correlation regarding agitation power consumption and oxygen mass transfer coefficient. Similarly, Pittoors et al. [6] have studied an aeration process by using a gas-induced reactor with an air diffuser. They obtained the oxygen mass transfer coefficient in an activated sludge processes as well as in clean water. In addition, Yamada et al. [7] have proposed a method to improve the water quality using micro-bubbles whose sizes are micro order. They studied the relation between distributions of micro-bubbles and dissolved oxygen concentrations, and showed that the method of using micro-bubbles was by far more efficient in supplying oxygen into the water. Druzinec et al. [8] have also used micro-bubbles for aeration in stirred bio-reactors, where oxygen is transferred to an insect culture medium of SF-900 II. Although a large quantity of energy is generally required to create the micro-bubbles, aeration systems based on plastic or ceramic membranes are more and more popular which allows to reduce power consumption [9].

As mentioned above, the aeration systems which directly pass the air into the water have been extensively investigated. Contrary to the aeration systems that use air bubbles, several attempts have been made with liquid surface aeration. Srinivasan and Aiken [10] have investigated the mass transfer and physical absorption in liquids dispersed as droplets in a gas. The droplets were formed by the break-up of a cylindrical jet with a complex and turbulent mechanism. They claimed that the convection due to the formation process significantly

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Nomenclature

D	oxygen diffusion rate (m^2/s)
DO	dissolved oxygen concentration (mg/L)
K_La	volumetric oxygen mass transfer coefficient (h^{-1})
h_1	height of the water surface from the bottom (mm)
h_2	height of the circular tank from the bottom (mm)
P	power, $2\pi\omega T/60$ (W)
r_0	radius of the circular plate (mm)
r_1	radius of the cone base (mm)
r_2	radius of the immersed position of the cone (mm)
R	radius of the circular tank (mm)
$SOTR$	standard oxygen transfer rate (kgO_2/h)
t	time (h)
T	torque (Nm)
V	total volume of water (L)

Greek symbols

ρ	density of water (kg/m^3)
θ	half tip angle of the cone (°)
ω	rotation rate of the cone (rpm)

Subscript

i	initial value
s	saturation value

enhanced mass transfer. Mcwhirter et al. [11] have developed a fundamentally rigorous oxygen mass transfer model using a surface aerator with blades. The model separated the oxygen transfer process into a liquid spray mass transfer zone and a surface reaeration mass transfer zone, which was able to provide the methodology and techniques for quantitatively determining the oxygen transfer rate within each of these important but fundamentally different oxygen mass transfer zones. Recently, Issa et al. [12] and Issa [13] have investigated power consumption, mixing time and oxygen mass transfer with a dual impeller system which consists of an inverted and bladed rotated cone and a pitched-blade up-flow propeller. They gave the oxygen mass transfer coefficient and power number against the Reynolds number. It was shown that a better axial flow interaction could be obtained with a shorter spacing between the impellers.

In this study, a mist flow composed of small water droplets is used for the aeration. It is common to use a liquid jet from a nozzle driven by a high pressure generated with devices such as fans, compressors, pumps, etc. However, the system based on the liquid jet becomes large and inefficient because these several devices are necessary. In addition, it is difficult to control the characteristics of the atomization, i.e. droplet diameter, quantity of the mist flow, etc. Therefore, a new atomization system for generating droplets is required, which should be compact, electricity saving and easily controllable. Adachi et al. [14,15] have proposed a new atomization system that uses an interesting flow phenomena in which the liquid comes rising along the outer (not the inner) surface of a rotating cone, where the cone is immersed in the liquid by turning the top upside down. The liquid rising along the outer surface becomes thinner and forms a film flow, leading to the atomization of the liquid. The interesting flow phenomena was called a pumping-up mechanism caused by the rising film flow in their study. Indeed, it is comprehensible and well known that the liquid rises along the inner surface of a rotating hollow cone due to the centrifugal force (Bruin [16] and Makarytchev et al. [17,18]), but there is only the research of Adachi et al. [14,15] on the phenomena that the liquid rises along the outer surface of the rotating cone and does not separate from the surface. The thin film pumping-up mechanism has preliminary examined on oxygen mass transfer by (Adachi and Arai [19], Adachi [20] and Adachi [21]. They showed that the mist flow generated by the

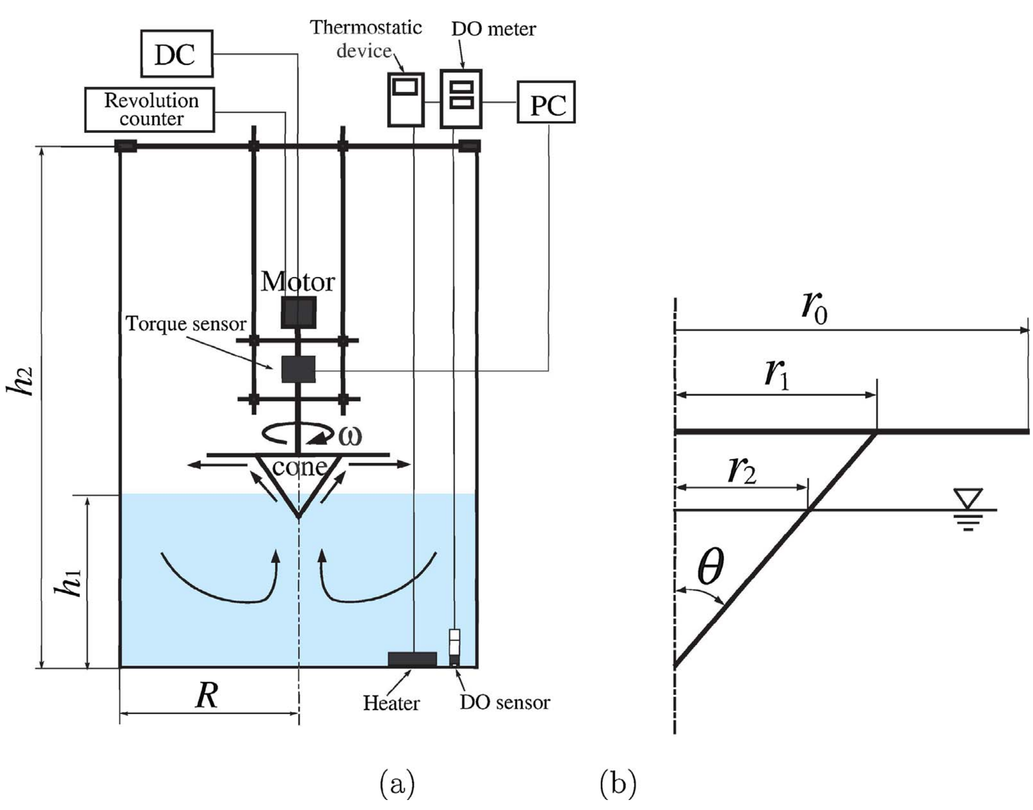

Fig. 1. Experimental apparatus.