Energy Conversion and Management 71 (2013) 69–75

Contents lists available at SciVerse ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Volumetric mass transfer coefficient and hydrodynamic study of a new self-inducing turbine

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ARTICLE INFO

Article history:
Received 9 January 2013
Accepted 19 March 2013
Available online 16 April 2013

Keywords:
Mass transfer
Mixing
Fluid mechanics
Chemical reactor
Hydrodynamics
Multiphase flow

ABSTRACT

The self-inducing turbines are among mobile agitations which present a very interesting potential in terms of energy in the field of wastewater treatment by activated sludge. Often, the reactions involved in this type of contactors are limited by the gas–liquid mass transfer. The objective of this experimental work is the determination of the oxygenation capacity of a new self-inducing turbine, a holed hollow cylinder, having a thickness of $W = 1.5$ cm and a diameter $D = 9$ cm, with 6 holes having a diameter of 0.5 cm each. During this experimental work, we evaluated the volumetric mass transfer coefficient k_La, which is directly related to the oxygenation capacity (OC) and this for various rotational speeds of the turbine as well as for various submergences. We finally succeeded to find an empirical correlation for our new self inducing turbine. The most common method used to estimate experimentally the coefficient k_La is the technique of dynamic oxygenation and deoxygenation. We finally concluded that this new turbine had a satisfying aeration capacity, which increases with the increase of the rotational speed, and decreases when increasing the submergence of the impeller.

1. Introduction

Several chemical and metallurgical industries have focused on operations of stirring and gas dispersion. The problem now involves other industries such as pharmaceutical, food and water treatment. The interest of mixing is related to both the quality of products of these processes as well as the energy aspect (safety and environment). The self-inducing turbines are simple, easy to use and present the lowest cost in terms of manufacturing, maintenance and energy consumption. This is the reason why they are increasingly solicited in industrial processes, and mainly batch processes. The stirring plays a dual role, it allows mixing both the liquid phase and dispersing air bubbles aspirated into the tank. It is in this context that this study is conducted. The process of stirring, as mentioned above, is frequently used in the chemical area, with various type of reactors [1–3] and various state of the flow [4]. So far, many works have focused on self-inducing turbines by presenting experimental or numerical studies. Several geometries and design of self-inducing turbines have been studied numerically [5–8]. The gas induction characteristics as the flow visualization and power consumption in this type of impellers were also thoroughly studied [6,9–11]. There were also researches focusing on the gas–liquid–solid dispersion when using a self inducing turbine [12]. The same interest has been paid to the volumetric mass transfer coefficient k_La, where most of the works were experimental, for example by using a dynamic method based on the absorption kinetics of solute gas physics [13] or by changing the nature of the fluid using nitrogen and oxygen as gas and cyclohexane as liquid [14] or by using a new type of self-inducing reactor [15,16]. A research [17] studied the effect of rotational speed and immersion on the hydrodynamic and mass transfer in a stirred tank equipped with a self-inducing turbine. They proposed, therefore, a new expression of k_La by introducing the modified Froude number. Another work [18] proposed a basic approach for estimating the volumetric mass transfer coefficient in stirred reactors. Mass transfer a correlation for multiple-impeller gas–liquid contactors were given [19] and the k_La was measured using the method of dynamic pressure (dynamic pressure method DPM). They concluded that the axial turbine provided a more effective homogenization performance than the radial or combined flow turbine. The aim of this work is the determination of the oxygenation capacity of a new self-inducing impeller, to study the hydrodynamics of this new turbine geometry and to give an empirical correlation of the mass transfer coefficient k_La and its variation with the rotational speed and the turbine's position in the stirred tank.

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http://dx.doi.org/10.1016/j.enconman.2013.03.018

Nomenclature

C_L	concentration of the liquid (g/L)
C_{L0}	initial concentration of the liquid (g/L)
C_L^*	critical concentration of the liquid (g/L)
D	diameter of the turbine (m)
d	diameter of the hole (m)
Fr^*	the modified Froude number, dimensionless
Fr_c^*	the modified critical Froude number, dimensionless
g	acceleration due to gravity (m/s^2)
H	tank height (m)
h	height of the liquid in the tank (m)
k_La	the volumetric mass transfer coefficient (s^{-1})
N	rotational speed of the turbine (rpm)
N_A	aeration number, dimensionless
N_c	critical rotational speed (rpm)
N_{PG}	the gassed power number, dimensionless
Q_g	gas flow rate (m^3/s)
S	submergence of the turbine (m)
T	tank diameter (m)
t	time (s)
w	width of the baffle (m)
W	height of the turbine (m)
ε_G	gas hold up

2. Experimental set-up

Experiments are carried out to determine experimentally the volumetric mass transfer coefficient k_La which is directly connected to the oxygenation capacity (OC). In this part of our work, we will present our experimental device, the used method to measure the volumetric mass transfer coefficient and the experimental manipulation.

2.1. Experimental device

Fig. 1 shows the experimental setup used in this work. It essentially comprises:

- A Plexiglas tank of height $H = 45$ cm and of diameter $T = 36$ cm, with the height of liquid $h = 27$ cm.
- A self-inducing impeller, a holed hollow cylinder with 6 holes, with a height of $W = 1.5$ cm and a diameter of $D = 9$ cm. The hole diameter is $d = 0.5$ cm.
- A motor for rotating the moving agitator, with an adjustable speed of 50–2000 rpm.
- The deoxygenation is produced with N_2 through a diffuser at the bottom of the tank.
- An oxygen sensor used to record the values of dissolved oxygen concentration.
- A switchboard can read the dissolved oxygen concentration.
- Four baffles of width $w = T/10$ and of height $H = 45$ cm and

This device includes other elements, but these were not used here.

In this study we used a baffled tank: baffles break the vortex which could be created by the impeller rotation, so no effect of surface aeration was noticed in our experimental work. As already mentioned, in this work, we use a new self-inducing impeller with 6 holes, as shown in Fig. 2.

2.2. Methods of measuring the volumetric mass transfer coefficient

The value of k_La is determined via the dynamic method, using an oxygen meter probe, by measuring the change in the concentration of dissolved oxygen over time. Indeed, this method is based on the monitoring of the signal of an oxygen sensor over time, for example during reoxygenation by continuous aspiration of air through the moving agitator, or upon deoxygenation of a reactor saturated with oxygen by continuous injection of nitrogen. Determining k_La supposes the following assumptions:

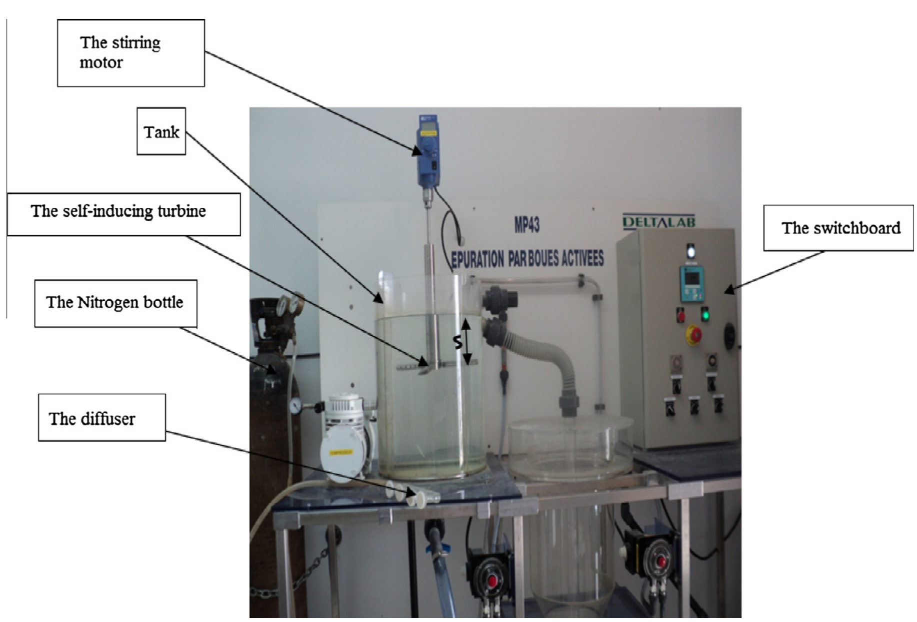

Fig. 1. Experimental setup.