Journal of Industrial Technology 13 (1), 2004, 69-78

MASS TRANSFER PERFORMANCE OF CURVE BLADE IMPELLER IN GAS-LIQUID MIXING

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RINGKASAN: *Dalam kajian ini, nilai pekali pemindahan jisim berisipadu, k_La bagi pengaduk berbilah enam separa bulatan (6CB) telah dibandingkan dengan pengaduk berbilah enam Rushton (6RT) dengan mengukur kandungan oksigen terlarut dalam tangki berbentuk selinder dengan diameter 20 cm. Hasil kajian menunjukan bahawa k_La bagi julat kadar aliran gas 5 liter/min hingga 15 liter/min dan julat putaran pengaduk dari 300 rpm hingga 700 rpm, 6CB mencatatkan nilai k_La 30 hingga 50% lebih dari 6RT bagi kadar aliran gas dan putaran pengaduk yang sama. 6CB juga didapati memberikan nilai k_La perunit kuasa spesifik 61 hingga 130% lebih dari 6RT bagi julat kadar aliran gas dan putaran pengaduk yang sama. Pemerhatian ini bermakna 6CB dapat mengantikan 6RT tanpa mengubah saiz motor dan sistem aci dalam tangki teraduk untuk mendapatkan pemindahan jisim yang baik bagi sistem cecair-gas.*

ABSTRACT: In this work the volumetric mass transfer coefficient, k_La of a six bladed curve blade impeller (6CB) was compared with a standard six bladed Rushton Turbine (6RT) by measuring dissolved oxygen content in 20 cm diameter cylindrical tank. It was found that for gas rates in between 5 litre/min to 15 litre/min and rpm in between 300 to 700 rpm, 6CB gives 30 -50% higher volumetric mass transfer compared to 6RT at the same gas rate and impeller rotational speed. For the same range of gas rates and impeller speed, volumetric mass transfer coefficient per unit power input for 6CB was found to be higher than 6RT by 61% to 130% hence making 6CB as a perfect candidate for retrofitting 6RT in order to obtain better mass transfer performance for liquid-gas system without changing motor and shaft assembly.

KEYWORDS: Stirred vessel, mass transfer, curve blade impeller, gas-liquid contacting.

INTRODUCTION

In general, mechanically agitated gas-liquid mixer is the preferred reactor configuration for various biochemical and chemical processes, due to its high mass and heat transfer coefficients and capability in handling a wide range of gas flow rates. In such mixers, radial flow impellers have been the focus of much research with the Rushton Turbine being the most popular. Rushton Turbines in general are recognised as good gas dispersers, however reduction in power input under gassed conditions limits its mass transfer capabilities (Brujin *et. al, 1974,* Warmoeskerken & Smith 1985).

To overcome these shortcomings, it has been suggested that large diameter impellers be used to improve liquid pumping and gas handling capabilities. However the replacement of standard disc turbines with larger ones is not a simple retrofitting operation. A better solution to this is to use an axial flow impeller. Research paved the way for the development of down-pumping axial hydrofoil impellers of high solidity ratio which were specifically developed for gas liquid systems. However, power reduction problem in many of these impellers remain and it causes large gassed power and torque fluctuations (Gary, 1991).

Researchers have since introduced the concave or curved blade impellers (Van't Riet *et. al*, 1976) to overcome this deficiency. This impeller has superior power stability compared with a Rushton Turbine (Abdul Aziz *et. al*, 1998). Its superior gas handling capacity and gassed power characteristics can be utilised to give enhanced mass transfer performance (Warmoeskerken & Smith 1989). In this work, a standard sized six bladed curve blade impeller was studied to confirm these observations. A standard six bladed Rushton Turbine was also studied under similar conditions for comparison.

METHODOLOGY

The experiments were conducted in a 20-cm diameter cylindrical tank with four equally spaced baffles. The experimental setup used in this work is shown in Figure 1. The impellers used in this work were fabricated locally and their features and dimensions are shown in Table 1. Water and compressed air were used as liquid and gas phase, respectively.

Table 1: Impeller Detail

Description	**6RT**	**6CB**
Length	D/4	D/4
Width	D/5	D/5 (Tip to tip distance)
Swept area	$\pi D^2/20$	$\pi D^2/20$
Angle	0	180°
Thickness	3 mm	3 mm

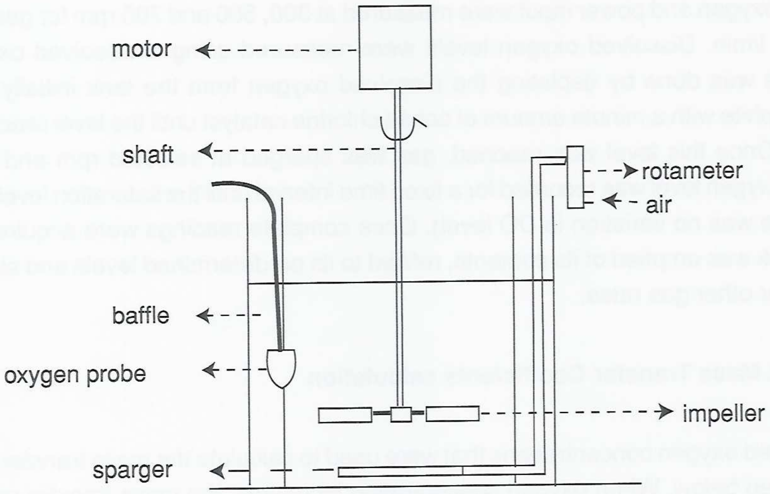
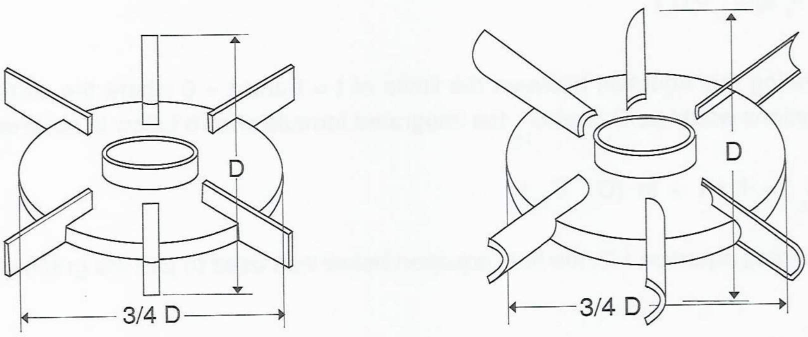
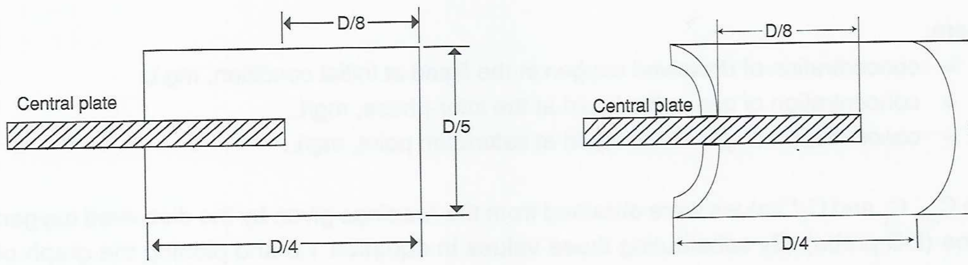


Figure 1. Experimental Setup



6 bladed Rushton Turbine

6 bladed curve blade



Flat plate in 6RT

Semi-circle in 6CB

Detail of the blades

Dissolved oxygen and power input were measured at 300, 500 and 700 rpm for gas rates of 5, 10 and 15 l/min. Dissolved oxygen levels were measured using a dissolved oxygen (DO) probe. This was done by depleting the dissolved oxygen from the tank initially by adding sodium sulphite with a minute amount of cobalt chloride catalyst until the level reaches almost 0.1 mg/L. Once this level was reached, gas was sparged at selected rpm and the rise in dissolved oxygen level was recorded for a fixed time interval until the saturation level is reached (when there was no variation in DO level). Once complete readings were acquired for each run, the tank was emptied of its contents, refilled to its predetermined levels and similar steps repeated for other gas rates.

Volumetric Mass Transfer Coefficients calculation

The dissolved oxygen concentrations that were used to calculate the mass transfer coefficient are explained below. When oxygen concentration increases, the mass transfer rate is given by the following equation:

$$\frac{dC_L}{dt} = k_L a(C^*_L - C_L) \qquad (1.1)$$

By integrating this equation between the limits of t = t and t = 0 where the corresponding concentrations would be C_L and C_{L0}, the integrated formula shown below is obtained.

$$\ln(C_L^* - C_L) = -k_L a\, t + \ln\,(C_L^* - C_{L0}) \qquad (1.2)$$

By rearranging equation 1.2, the final equation below was used to plot the graphs:

$$-\ln\left(\frac{C^*_L - C_L}{C^*_L - C_{L0}}\right) = k_L a\, t \qquad (1.3)$$

Where,

C_{L0} = concentration of dissolved oxygen in the liquid at initial condition, mg/L.
C_L = concentration of gas in the liquid at the inter-phase, mg/L.
C_L^* = concentration of gas in the liquid at saturation point, mg/L.

The C_{L0}, C_L and C_L* values were obtained from the readings given by the dissolved oxygen probe (DO probe). By substituting these values in equation 1.3 and plotting the graph of $\{-\ln[(C_L^* - C_L)/(C_L^* - C_{L0})]\}$ against time, t, the $k_L a$ value can be directly obtained from the slope. In the results and plots the value of $-\{\ln[(C_L^* - C_L)/(C_L^* - C_{L0})]\}$ is symbolically represented by 'ln A'.

Power Measurement

The power drawn by the impeller for agitation at a particular speed was determined by measuring equivalent weight generated by the torque as a load. The motor was attached to a L shaped plate and the plate itself was connected to a shaft via pillow bearing as shown in Figure 2. When the impeller rotates, it imparts a force to the medium and in return the impeller also imparts an opposite force of a similar magnitude. With the counter weight arrangement, this rotational force will also be felt by the lever arm attached to the motor assembly.

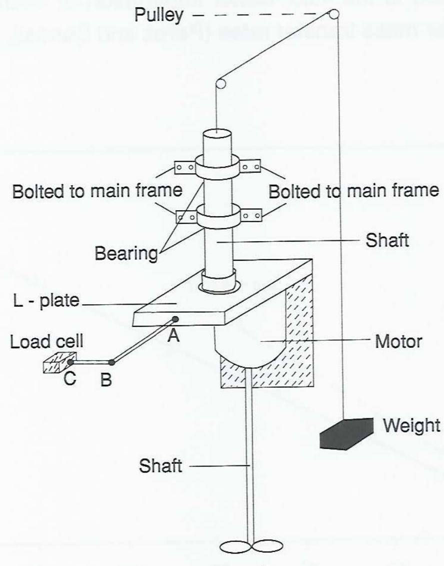


Figure 2. Power Measurement

Load cell at the end of the lever arm stops the movement of the lever arm and also measures the magnitude and direction of the force. Power was than calculated using the following formula:

$$P = 2\pi N \tau \qquad (1.4)$$

where N is rotational speed and t is torque on the shaft. The torque can be obtained using the following formula :

$$\tau = mgd \qquad (1.5)$$

where mg is weight measured by the load cell and d is the distance between the load cell and the centre of the shaft.

Results and Discussion

k_La values at constant rotational speeds

Figure 3 shows an example of lnA vs. time plot to obtain k_La values. The figure shows that for the constant operating conditions of 500 rpm and gas flow rate of 10 litre/min, the k_La values for curve and Rushton blade impellers were 0.051 and 0.039s^{-1} respectively. Curved blade impellers produced higher k_La values due to their hydrodynamic design, which allowed for more power to be imparted to the fluid. Better impartation of energy means better bubble breakage and hence better mass transfer rates (Perez and Sandall, (1974), Nishikawa *et al.,* 1981a, 1981 b).

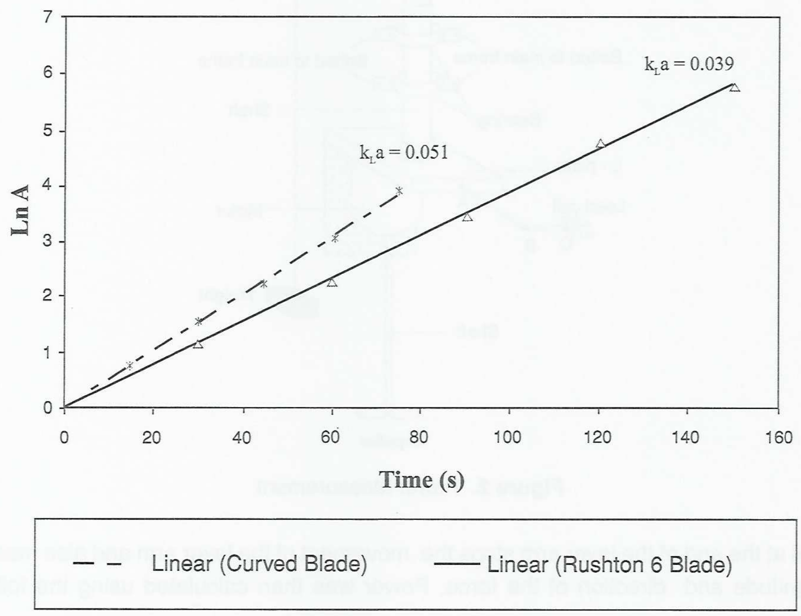


Figure 3. k_La values at 500 rpm and 10 l/min

Similar plots were drawn for all other conditions and Table 2 shows a summary of volumetric mass transfer coefficients at other speeds and rates studied.

From the data shown in Table 2, the k_La values were found to increase with increasing gas flow rates and rotational speed for both impellers. The values ranges from 0.013 to 0.079 s^{-1} for 6RT and for 6CB it ranges from 0.017 to 0.100 s^{-1} at extreme conditions (lowest gas rate and lowest rpm on one end and highest gas rates and highest rpm on the other).

Table 2. k_La values at constant speeds and gas rates

Speed (rpm)	300			500			700		
Gas rates(l/min)	5	10	15	5	10	15	5	10	15
	Volumetric mass transfer values (s^{-1})								
6CB (k_La)	0.017	0.020	0.022	0.033	0.051	0.060	0.079	0.091	0.100
6RT (k_La)	0.013	0.015	0.017	0.022	0.039	0.048	0.052	0.067	0.079

It was also observed that in all cases the k_La values for 6CB was higher by 30% to 50% than for 6RT for all conditions (Table 3). At lower rpm (300rpm) the k_La values for 6CB was consistently higher by 30% compared to 6RT and are independent of the gas rates experimented. When the speed increased to 500 rpm, the ratio increased to 1.5 at 5 l/min gas rate and levelled off at 1.3 at 10 and 15 l/min gas rates. Similar values were observed at 700 rpm .

Table 3. Ratio of k_La for curve blade over Rushton turbine

Speed (rpm)	300			500			700		
Gas rates(l/min)	5	10	15	5	10	15	5	10	15
Ratio of k_La values (k_La_{6CB} / k_La_{6RT}) at similar speed and gas rate.	1.3	1.3	1.3	1.5	1.3	1.3	1.5	1.3	1.3

Generally, it can be concluded from Table 3 that 6CB gives 30% higher volumetric mass transfer coefficient values than 6RT for all the rotational speed experimented and these values could be higher at a lower gas rate where 6CB performed up to 50 % higher than the 6RT.

k_La per unit specific power input

In above analysis, only the rpm values of the impellers were mentioned and used for comparison. This is due to the fact that the end users in the industries commonly use rpm as the monitoring and controlling parameter in their respective operations. However for in-depth analysis, rpm may not be a fair comparison for impellers as different impellers imparts different power to the content of the tank at similar rpm. Therefore the observed increment in mass transfer for constant rpm as discussed above may be due to the fact that particular impeller is imparting higher power and if this is so, there is no saving in terms of mass transfer gain per unit of power used. Therefore the k_La per unit specific power values were determined and summarised in Table 4. Specific power is defined as power input per unit kg of the suspension.

Table 4. Specific power input and mass transfer coefficient per unit specific power at various speed and gas rates

Speed (rpm)	300			500			700		
Gas rates (l/min)	5	10	15	5	10	15	5	10	15
Specific power (Watt/kg)									
i 6CB	0.09	0.08	0.08	0.37	0.36	0.33	0.99	0.94	0.91
ii 6RT	0.13	0.12	0.11	0.57	0.52	0.50	1.36	1.26	1.12
k_La per unit specific power (kg/Watt.s)									
iii 6CB	0.19	0.24	0.27	0.09	0.14	0.18	0.08	0.10	0.11
iv 6RT	0.10	0.12	0.15	0.04	0.07	0.10	0.04	0.05	0.07
Ratio of k_La per unit specific power (k_La_{6CB} / k_La_{6RT}) (dimensionless)									
v	1.94	1.94	1.81	2.30	1.89	1.85	2.10	1.86	1.61

From Table 4 above it can be seen that at same rpm and gas rate, 6RT imparts higher specific power to the suspension compared with 6CB at all gas rates and rpm studied (see row i and ii). It was also observed that at constant rpm, the net power input reduces as the gas rates increases for both impellers. This reduction rate is generally greater in the 6RT than the 6CB. For example, at 300 rpm specific power reduces 15% (from 0.13 to 0.11 Watt/kg) for 6RT when gas rate was increased from 5 l/min to 15 l/min. For the same change, reduction in specific power input for 6CB was only 11% (from 0.09 to 0.08 Watt/kg).

At higher speed and gas rate the reduction in specific power input is even greater where at 700 rpm the specific power reduction for 6RT was 18% (from 1.36 to 1.12 Watt/kg) when gas rate was increased from 5 l/min to 15 l/min. For the same change, the reduction was only 8% (from 0.99 to 0.91 Watt/kg) for 6CB. Row (iii) and (iv) in Table 4 gives k_La per unit specific power input for 6CB and 6RT respectively. It can be noted that in all cases studied, 6CB performed greater than 6RT in terms of k_La per unit specific power by 61 -130% as indicated by row (v) in Table 4 which ranges from 1.61 (at 500 rpm and 15 l/min) to 2.3 (500 rpm and 5 l/min).

Significance of observation

The observations made in this study may be significant for retrofitting existing Rushton Turbines with Curve blade without any modifications to existing motor, shaft assembly and sparging equipment in liquid-gas contactors. This is due to the fact that the unaerated power consumption for Rushton turbine is always greater than the curve blade and motor power is selected based on unaerated power consumption. A 6RT can hence be replaced by a 6CB without other modification to achieve higher mass transfer values.

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