Effect of Rotational Speed on Liquid-Solid Mixing and Operating Conditions

Saiful Islam[#1], Mohd Danish[*2]
[#]Lecturer, Department of Civil Engineering, KKU, Abha, KSA
[1]saiful.islam.iitr@gmail.com
[*]Lecturer, Department of Chemical Engineering, KKU, Abha, KSA

***Abstract*— Significant efforts have been devoted to better understand the solid liquid mixing phenomena, because of the large number of industrial applications of this operation. The important point in designing a solid-liquid suspension is choosing a high performance impeller for achieving both the dispersion of the particles and their suspension, at the same time. In the present study pallet is mixed with 20 liters of water. Flat paddle impeller (0.075 x 0.06m) an experimental investigation is carried out to characterize the mixing performance. The study is perform to show relationship between two dimensionless parameter (power number and Reynolds number).Moreover the effect of angular speed on Torque, Power and Balancing weight is also studied in this research work.**

***Keywords*—Power number, Reynolds number, Mixing, Torque.**

I. INTRODUCTION

Flat blades Turbines generate a pair of trailing vortices at the rear of each blade (Suzukawa, Mochizuki, and Osaka 2006). The generated vortices are considered as the major flow mechanism for mixing process. But, the trailing vortices results in high power requirements and operating costs. In order to overcome such problems, various modifications in the blade design were performed such as shaping the blade from the flat plate to one with different degrees of curvature (Zhao, Gao, and Bao 2011). The concave-bladed turbine (CBT) was more efficient in term of power consumption compared with the flat bladed impeller, either for Newtonian fluids (Ghotli et al. 2013), non-Newtonian fluids (Ameur and Bouzit 2013; Woziwodzki, BroniarzPress, and Ochowiak 2010) or multiphase flows (Nienow 1996). The CBT is the most energy efficient stirrer for solid suspension at aeration numbers above 0.08 (Frijlink, Bakker, and Smith 1990). However, a blade with a large curvature yields a longer residence time of the vortex at the blade tip (Zhao, Gao, and Bao 2011), and a bad axial circulation (Ameur and Bouzit 2013). For gas-liquid mixing and at the same un-gassed power, the CBT can handle high gas rates, for example the 6SRGT can handle around three times the gas when compared to the Rushton turbine (Saito et al. 1992; Cooke and Heggs 2005). The CBT was found also efficient for mixing highly viscous non Newtonian fluids (Pakzad, Ein-Mozaffari, and Chan 2008a, 2008b; Ameur, Bouzit, and Helmaoui 2011). For Newtonian and shear thinning fluids, Bao et al. (2015) compared experimentally the performance of a three curved bladed turbine (the so-called Pfaudler) with CDY impeller in a coaxial configuration. They combined the Pfaudler or CBY turbine (as the inner mixer) with helical ribbon (HR) or anchor (as the outer one). Their results showed that Pfaudler-HR is the optimized combination which gives the shortest mixing time for the same power demand

A number of designs concerning the concave bladed impellers are commercially available such as the Scaba 6SRGT, BT-6, the CHEMINEER CD-6 and the ICI Gas foils designs used in US patent. Some researchers interested to the mixing of viscous fluids by concave bladed impellers, including those of Galindo and Nienow (1992, 1993) for Lightnin A315 and Scaba 6SRGT impellers; Amanullah, Hjorth, and Nienow (1997) for a SCABA 3SHPI impeller; Pakzad et al. (2013a, 2013b) for Scabaanchor coaxial mixers, Benmoussa, Bouanini, and Rebhi (2014) for two-curved-bladed impeller with a great height, Luan, Chen, and Zhou (2014) for 6PBT, Ameur, Bouzit, and Ghenaim (2015) for Scaba 6SRGT impellers in multistage. For several mixing processes, many studies have been conducted with experiments. The experimental method is usually costly and sometimes is not an easy task. However, with the CFD (Computational Fluid Dynamics) method, various parameters can be examined with less time and expense (Ameur, Bouzit, and Helmaoui 2012; Sossa-Echeverria and Taghipour 2015). CFD method was used by many researchers in the last decades to predict the mixing characteristics within a stirred tank (Sbrizzai et al. 2006; Lamarque et al. 2010; Qi et al. 2013; Halidan et al. 2014; Kulkarni and Patwardhan 2014; Cudmore, Holloway, and Gerber 2015) and a successful achievement of this tool and satisfactory results were found. Our survey in the literature shows that much effort was done for mixing by impellers with concave blades. However, the mixing characteristics of impellers with retreat blades still need a detailed knowledge. Although the retreat-bladed impeller find widespread applications, less research has been conducted into how these impellers behave, and no paper has been published for this kind of stirrer with shear thinning fluids. Therefore, the objective of the present paper is to predict numerically the performance of retreat-bladed impellers for different operating conditions. We focus on the effects of the impeller blade curvature, shaft velocity and impeller rotational direction. Trailing vortices, well-stirred region size and power consumption were studied in detail.

II. INVESTIGATED SYSTEM

The mixing system investigated is presented in Figure 1. It consists of a flat bottomed cylindrical vessel of diameter D = 300 mm and height H = D. the liquid height is equal to the vessel height. The vessel is equipped by a six-bladed turbine of diameter d = D/2 and height h = D/10, placed at clearance from the vessel base c = D/2. The blade thickness is 2.0 mm. The origin of the coordinate system is taken at the center of the vessel base. Effects of the blade design were explored in this paper. Three different degrees of streamlining is the blade cross section were considered and which are: $\alpha = 15°$, 30° and 45°, respectively. The Reynolds number is ranged from 1 to 22000 covering the laminar, transitional and turbulent regimes..

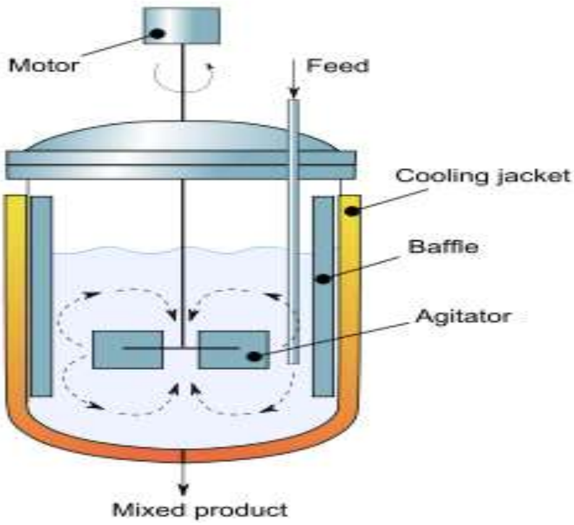

Fig. 1 Mixing operation

III. BACKGROUND

Mixing is one of the most widely used unit operations in the chemical and allied industries. There is a general acceptance of the importance of mixing processes for the commercial success of industrial operations. A stirred tank unit typically consists of a rotating impeller in a vessel. Fluid motion is promoted by the transfer of energy from the impeller into the process fluid. The process fluid may be single phase (eg viscous, Newtonian and non-Newtonian) or multiple phases (eg solids, liquid and gas) and, in some cases, physical changes may take place during the operation (eg suspension polymerisation and dissolution of solids in liquid). Mixing processes are usually classified according to the type of the process materials, eg viscous liquid, solid-liquid, gas-liquid, liquid-liquid, etc, and of these, solid-liquid is certainly one of the most important. The main objectives of agitation in solid-liquid systems can be divided into three categories; a) to avoid solids accumulation in a stirred tank b) to maximise the contacting area between the solids and liquid c) to ensure the solids particles are uniformly distributed throughout the vessel

In many operations, it is essential to ensure that all the solids are kept in motion in order to prevent the building up of solids on the vessel base which may, in extreme cases, invoke system malfunction. Examples of such operations include settling tanks for filter cakes and absorber sump of a flue gas desulphurisation process. The stirred tank may also be used as a reactor, for example when catalysts are to be suspended for mass transfer operations. The mass transfer rate per unit energy input is at its maximum when the interfacial area between the solids and liquid is maximised. This happens when the fluid motion is vigorous enough to keep all particles in motion. Even though the design objectives for (a) and (b) set out to achieve different goals, both require good knowledge of the just suspension speed (Np) prediction, that is the impeller speed at which no solid particle rests on the vessel base. However operating the stirred vessel at the just suspension condition may not be sufficient in certain processes. For example, the ratio between the mean solids concentration in the vessel and that in the withdrawal tube depends on the position of the tube thus, solids distribution information is required to ensure good mass balance between inward and outward flow in a Continuous stirred tank reactor. Sometimes the product characteristics depend on the distribution quality, knowledge of which is then becomes vital for quality control. In this work, flow pattern, power consumption, solids suspension and distribution for a wide range of geometries and scales were investigated.

IV. METHODOLOGY

In industrial process engineering, mixing is a unit operation that involves manipulation of heterogeneous physical system with the intent to make it more homogeneous.

Firstly the model is tested to achieve the flow patterns or mixing quality desired then the speed is determined of the full size mixer from one of the following relationships

Rotational speed is computed out and corresponding balancing weight reading is taken for each set of reading.The angular speed (w) is computed by following relation

Angular speed (w)=Rotational speed(rpm)x 2Л/60

Also torque developed by angular rotation is given by

Torque (T)=Force(F)xTorque arm Radius(r)

=Balancing reading in kg x 9.81(N)x0.11(m) (Nm)

Power absorbed is given by =Torque (T) x Angular Speed (w) (watts)

The dimensionless parameter Reynold Number is given by relation $R_e=\rho ND^2/\mu$

Also the power Number is described by the relation as follows $P_0=P/ \rho N^3 D^5$

Torque arm radius = 0.11m

Density of Water is taken as 1000kg/m^3

Dynamic viscosity is taken as $\mu= 1x10^{-3}$ Ns/m^2

N= w= rotation speed

Diameter of impeller is 12.5cm

V. RESULTS

Mixing is basically a process in which components are treated in such manner so that particles of each component are available to the adjacent particles of the other component that are required to be mixed.

In the present research work the input parameter is rotational speed and balancing weight reading which is shown in table I. The torque developed, power absorbed and dimensionless parameters Reynold Number and Power Number is obtained by the help of rotational speed and balancing weight. These parameters are computed and tabulated as Table II. The variation of power number with Reynolds number is shown in figure 2. Moreover the variation of torque, power and balancing weight with angular speed is shown in figure 3-5.

TABLE I
INPUT PARAMETERS

Sno	Rpm	Angular Speed (w)	Balancing reading (Kg)
1	166	17.37	0.09
2	322	33.70	0.29
3	535	56.00	0.69
4	540	56.52	0.7
5	597	62.49	0.78

TABLE III
OUTPUT PARAMETERS

Sno	Torque (Nm)	Power(Watt)	Power no	Reynold No
1	0.097119	1.68741	0.010542	271479
2	0.312939	10.54688	0.009028	526604
3	0.744579	41.69394	0.007781	874948
4	0.75537	42.69351	0.007748	883125
5	0.841698	52.59434	0.007064	976344

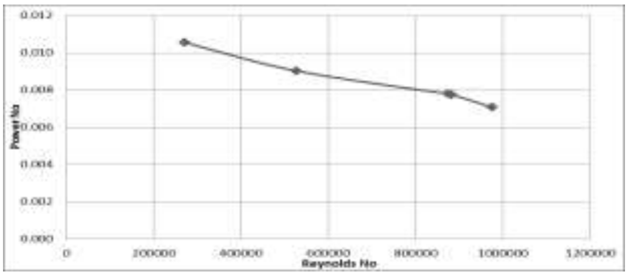

Fig. 2 Showing variation of Power Number with Reynolds Number

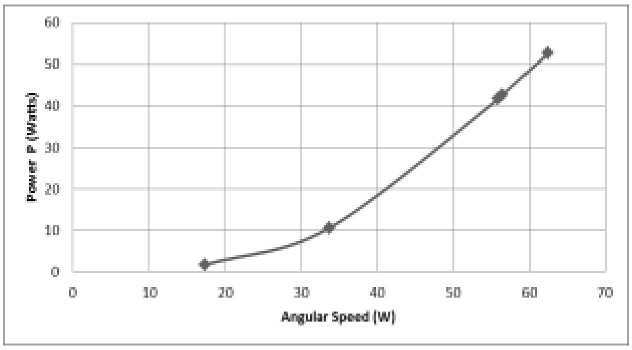

Fig.3 Showing variation of Power with Angular Speed

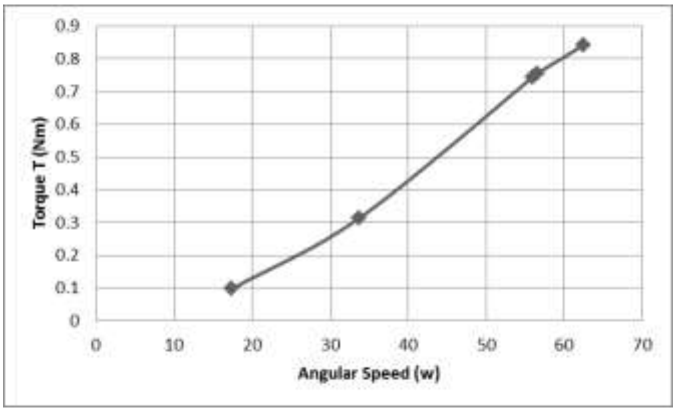

Fig. 4 Showing variation of Torque with Angular Speed

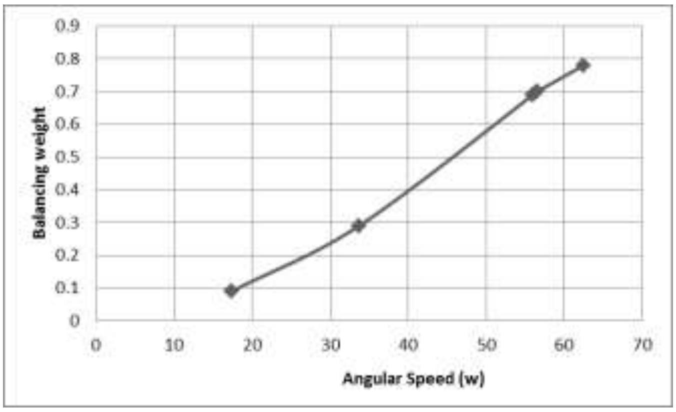

Fig. 5 Showing variation of Balancing Weight with Angular Speed

VI. CONCLUSION

Speed of impeller affects the homogeneity of the mixture. As with less rpm mixture is more homogenous than with greater rpm. Mixing power for fluids depends on the stirrer speed, the impeller diameter and geometry, and properties of the fluid such as density and viscosity. The relationship between these variables is usually expressed in terms of dimensionless numbers such as the impeller Reynolds number and the power number. From the fig 2 it is clear that for laminar condition the power number is inversely proportional to Reynolds number (As Reynolds number increase power number decreases and vice versa).

Moreover the effect of rotational angular speed on Torque, power and balancing weight has been taken into account. From figure 3-5 it is very clear that as angular speed increases the power, torque as well as balancing weight increases. The graph is parabolic in nature.

The amount of torque applied to a fluid mix is one of the most important factors in determining mixing results. At constant power, a relatively high rotational speed and small impeller diameter will result in lower torque than a larger impeller rotating at lower speed

REFERENCES

[1]. Amanullah, A., Hjorth, S.A., Nienow, A.W., 1997. The performance
of the Scaba 6SRGT agitator in the mixing of simulated xanthan gum broths. Food & Bioproducts Processing 75,232–238.
[2]. Ameur, H., Bouzit, M., 2013. Numerical investigation of flow induced by a disc turbine in unbaffled stirred tank. Acta Scientiarum Technology 35, 469–476.
[3]. Ameur, H., Bouzit, M., Ghenaim, A., 2015. Numerical study of the performance of multistage Scaba 6SRGT impellers for the agitation of yield stress fluids in cylindrical tanks. Journal of Hydrodynamics 27, 840–847.
[4]. Ameur, H., Bouzit, M., Helmaoui, M., 2012. Hydrodynamic study involving a Maxblend impeller with yield stress fluids. Journal of Mechanical Science and Technology26, 1523–1530.
[5]. Bao, Y., Lu, Y., Liang, Q., Li, L., Gao, Z., Huang, X., Qin, S., 2015. Power demand and mixing performance of coaxial mixers in a stirred tank with CMC solution. Chinese Journal of Chemical Engineering 23, 623–632.
[6]. Benmoussa, A., Bouanini, M., Rebhi, M., 2014. Characterization of Laminar Flow and Power Consumption in a Stirred Tank by a Curved Blade Agitator. Proceeding of the International Conference on Heat Transfer and Fluid Flow, Prague, Czech Republic, August 11–12.
[7]. Cooke, M., Heggs, P.J., 2005. Advantages of the hollow (concave) turbine for multi-phase agitation under intense operating conditions. Chemical Engineering Science 60, 5529–5543.
[8]. Cudmore, G.C., Holloway, A.G.L., Gerber, A.G., 2015. A model of impeller whirl for baffled mixing vessels. Journal of Fluids and Structures. 54, 719–742.
[9]. Frijlink, J.J., Bakker, A., Smith, J.M., 1990. Suspension of solid particles with gassedimpellers. Chemical Engineering Science 45, 1703–1718.
[10]. Galindo, E., Nienow, A.W., 1992. Mixing of highly viscous simulated xanthan fermentation broths with the Lightnin A-315 impeller. Biotechnology Progress 8, 233–239.
[11]. Galindo, E., Nienow, A.W., 1993. Performance of the Scaba 6SRGT agitator in mixing of simulated xanthan gum broths. Chemical Engineering and Technology 16, 102–108.
[12]. Ghotli, R.A., Abdul Aziz, A.R., Ibrahim, S., Baroutian, S., Niya, A.A., 2013. Study of various curved-blade impeller geometries on power consumption in stirred vessel using response surface methodology. Journal of the Taiwan Institute of Chemical Engineers 44, 192–201.
[13]. Halidan, M., Chandratilleke, G.R., Chan, S.L.I., Yu, A.B., Bridgwater, J., 2014. Prediction of the mixing behavior of binary mixtures of particles in a bladed mixer. Chemical Engineering Science 120, 37–48.
[14]. Kulkarni, A.L., Patwardhan, A.W., 2014. CFD modeling of gas entrainment in stirred tank systems. Chemical Engineering Research and Design 92, 1227–1248.
[15]. Lamarque, N., Zoppe, B., Lebaigue, O., Dolias, Y., Bertrand, M., Ducros, F., 2010. Large-eddy simulation of the turbulent freesurface flow in an unbaffled stirred tank reactor. Chemical Engineering Science 65, 4307–4322.
[16]. Luan, D., Chen, Q., Zhou, S., 2014. Numerical Simulation and Analysis of Power Consumption and Metzner-Otto Constant for Impeller of 6PBT. Chinese Journal of Mechanical Engineering 27, 635–640.
[17]. Nienow, A.W., 1996. Gas-liquid mixing studies: A comparison of Rushton turbine with some modern impellers. Chemical Engineering Research and Design 74, 417–423.
[18]. Pakzad, L., Ein-Mozaffari, F., Chan, P., 2008a. Using computational fluid dynamics modeling to study the mixing of pseudoplastic fluids with a Scaba 6SRGT impeller. Chemical Engineering and Processing 47, 2218–2227.
[19]. Pakzad, L., Ein-Mozaffari, F., Chan, P., 2008b. Using electrical resistance tomography and computational fluid dynamics modeling to study the formation of cavern in the mixing of pseudoplastic fluids possessing yield stress. Chemical Engineering Science 63, 2508–2522.
[20]. Pakzad, L., Ein-Mozaffari, F., Upreti, S.R., Lohi, A., 2013a. Characterization of the mixing of non-Newtonian fluids with a Scaba 6SRGT impeller through ERT and CFD. Canadian Journal of Chemical Engineering 91, 90–100.
[21]. Pakzad, L., Ein-Mozaffari, F., Upreti, S.R., Lohi, A., 2013b. Agitation of Herschel–Bulkley fluids with the Scaba–anchor coaxial mixers. Chemical Engineering Research and Design 91, 761–777.
[22]. Qi, N., Zhang, H., Zhang, K., Xu, G., Yang, Y., 2013. CFD simulation of particle suspension in a stirred tank. Particuology 11, 317–326.
[23]. Saito, F., Nienow, A.W., Chatwin, S., Moore, I.P.T., 1992. Power, gas dispersion and homogenisation characteristics of Scaba and Rushton turbine impellers. Journal of Chemical Engineering of Japan 25, 281–287.
[24]. Sbrizzai, F., Lavezzo, V., Verzicco, R., Campolo, M., Soldati, A., 2006. Direct numerical simulation of turbulent particle dispersion in an unbaffled stirred-tank reactor. Chemical Engineering Science 61, 2843–2851.
[25]. Sossa-Echeverria, J., Taghipour, F., 2015. Computational simulation of mixing flow of shear thinning non-Newtonian fluids with various impellers in a stirred tank. Chemical Engineering and Processing 93, 66–78.
[26]. Suzukawa, K., Mochizuki, S., Osaka, H., 2006. Effect of the attack angle on the roll and trailing vortex structures in an agitated vessel with a paddle impeller. Chemical Engineering Science 61, 2791–2798.
[27]. Woziwodzki, S., Broniarz-Press, L., Ochowiak, M., 2010. Transitional mixing of shear-thinning fluids in vessels with multiple impellers. Chemical Engineering and Technology 33, 1099–1106.
[28]. Zhao, J., Gao, Z., Bao, Y., 2011. Effects of the blade shape on the trailing vortices in liquid flow. Chinese Journal of Chemical Engineering 19, 232–242.

