Parameters Influence on Mixing Time of Gas Liquid Agitation System

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Abstract

An experimental study for turbulent two-phase flows agitated by an impeller in a mixing tank is presented. All the experiments carried out in a stirred tank with three types of impellers. conductivity meter method has been used to evaluate the mixing time, effect of sodium chloride trace, impeller geometry, its speed and flow rate of gas phase on mixing time has been investigated. Results show that the mixing time is dependent on the amount of tracer added to the system, and decreasing with increasing the impeller speed into single and two phase systems. Also, is shown that different flow regimes can affect the final concentration of conductimeter.

Keywords: mechanically agitated, stirred tank, two phase system, mixing time , aeration, conductivity.

الملخص

في البحث المقدم دراسة تجريبية لنظام ثنائي الطور يخلط بواسطة مازج في خزان التحريك . التجارب التي أجريت في خزان التحريك استخدمت ثلاثة أنواع من الموازج لتقييم دراسة تأثير كل من سرعة المازج ونوعه وكمية ملح كلوريد الصوديوم المحقون على زمن الخلط، ، وقد تم تحديد زمن الخلط بقياس موصلية المحلول . اظهرت النتائج أن زمن الخلط يعتمد على كمية الملح المضافة الى النظام، ويتناقص مع زيادة سرعة المازج في النظام الاحادي والثنائي. أيضا، ومع زيادة معدل تدفق الطور الغازي.

كلمات البحث: المزج الميكانيكي، خزان التحريك، نظام ثنائي الطور ، زمن المزج، التهوية، والموصلية. الموصلية

Introduction

Agitation is one of the most common unit operations in industrial practice. There are many ways to carry out this operation. The most common is the use of mechanical mixing. It is carried out in the vessels with an impeller. In a vessel with a centrally located impeller, practice of baffles mounting is widespread. This is aimed in order to break the primary vortex and increase the participation of micromixing [Stręk, F., 1981]. However, the use of the vessels without baffles is preferred in food and pharmaceutical industry [Galletti, C., Brunazzi, E., 2008] Cervantes, et al 2006, in such processes as paints and varnishes manufacturing, wastewater treatment or crystallization [Alvarez, M. et al 2002 Cabaret, F., et al 2008]. These types of agitated vessels are also used for mixing of liquid in laminar regime of the liquid flow, mixing of fluids with high viscosity, as well as non-Newtonian fluids or agitation of systems which include cell culture or other biological materials [Cudak, M., 2004]. The use of the agitated vessels without baffles significantly reduces the mixing efficiency. In such cases, the formation of an unfavorable primary vortex is also possible. This can result in sucking air and dispersion of it in a liquid phase [Galletti, C., Brunazzi, E., 2008 Cabaret, F et al 2008].

The mixing time is often considered as an essential parameter Stirred tanks are widely used in different industries like pharmacies, foods, refineries and chemical process. Using these mixers need to be optimized in designing by applying and selecting the suitable impellers, impeller ratios with tank diameter and other stirred tank ratios. Mixing time is one of the parameters that lead to find the optimum flow regime. Mixing time is defined as the time required to gain a certain homogeneity of two or more content of material that are mixed. For many high-volume industrial scale mixers, proper placement and sizing of impellers becomes critical in satisfying maximum allowable mixing time requirements which are dictated by reaction time. Reactants which react very fast must be accommodated by faster mixing times [Albert D 1996].

Traditionally, gas dispersion in agitated vessels is carried out using radial disc turbines, such as the Rushton turbine or other types of impellers. with the aim of reducing the weaknesses of disc turbines in gas-liquid applications, an increased interest in axial flow impellers for such operations has evolved. Customarily, the axial impellers are used in the down-pumping mode and have provided significant advantages over radial flow agitators [McFarlane C.M 1996]. The four blade (propeller) have a good balance of pumping and shear capabilities and therefore are considered to be a general-purpose impeller. The flow pattern with a propeller becomes closer to radial as the impeller diameter is increased or liquid viscosity is increased [Edward L. 2004]. Marijn M. C. G. Warmoeskerken 1994]. studied the gas-liquid dispersion with pitched blade turbines, they showed there are two distinct regimes by which gas leaving the sparger reaches the impeller: at low gas rates this is indirect via the recirculation loops, while at higher gas flow rates the flow is direct. Piero M. Armenante 1999 investigated on power consumption of propeller and obtained a correlation for power number Kumaresan et al 2006presented an extensive investigation of impeller design effect on the flow pattern and mixing in stirred tanks with using axial impellers and showed that number of blades, blade width, blade angle and pumping direction influence on the mixing efficiency.

Two phase flow

In two phase system, gas was introduced from the sparger by a compressor to the stirred tank in flow rates varied between 150-700 lit/hr. The hydrodynamic regimes were defined with respect to the distribution of the gas phase in the stirred tank. The three classical regimes, flooding, loading, and complete dispersion were observed and the transition conditions are determined by increasing and decreasing the operative parameters (gas flow rate and impeller speed). In low impeller speeds and at a constant gassing rate, bubbles flowing from sparger pass through the impeller without being affected by fluid jet which is introduced by the rotating stirrer. In this case, gas dispersion is undesirable and a sensible power loss toward the ungassed conditions is not observed; indeed, the impeller is said to be flooded (Fig. 1a). As speed increases, bubbles are gently affected by the cavities forming behind the blades; consequently, loading takes place and aggregation of large cavities brings about reduction of the gassed power consumption (Fig. 1b). Complete dispersion regime occurs at the minimum speed for the completely dispersion of gas throughout the vessel (Fig. 1c).

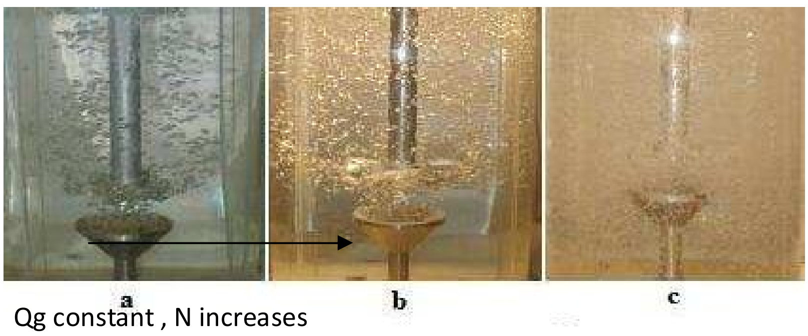


Fig. (1). Flow regimes in a gas- liquid stirred tank: (a) Impeller flooding, (b) Loading, (c) Complete dispersion

Measurements of mixing time

Experimentally, mixing time can be determined using a conductivity meter,[Jaworski Z. et al. (2002). pH meter Guillard F. and Tragardh C. (2003 or decolourisation method [Kuzmanic B. and Ljubicic N. (2001).. For example, the mixing time required to achieve 90% homogenisation (t_{90}) is the time it takes for the fluctuation of the response signal to be below10%of the concentration achieved at perfect mixing, which is adequate for most systems. For the decolourisation method, the visual determination of the point at which the colour changes can be very subjective, and this compromises the reproducibility of such results. This is compounded by the fact that there is no unanimous agreement on the level of homogeneity that the decolourisation method gives. Kraume and Zehner 2001 took the decolourisation point to be equivalent to the 95% homogenisation level, whilst Bujalski *et al.* 2002reported that decolourisation occurs at the 90% homogenisation level, obtained using a conductivity meter. Unfortunately, many authors do not report the level of homogenisation that decolourisation represents. Effect of measurement techniques on mixing time It has been reported that the location of a probe has no influence on mixing time [Rao K.S.M.S.R. and Joshi J.B. (1988). However, more recent studies show that the mixing time depends on the probe and injection locations, probe size Bouaifi M. and Roustan M. (2001) and tracer concentration. Guillard and Tragardh 2003 found that a shorter mixing time could be obtained injecting at the top, compared to injecting at the bottom. However, even with a top injection, Otomo *et al* 2003. obtained results which varied with radial location by as much as 100%. The quality of mixing must be evaluated on the basis of power required to achieve a given level of homogenisation. Homogenisation energy, which is a product of mixing time and the corresponding power dissipated, has been used to evaluate the mixing efficiency Bouaifi M. and Roustan M. (2001). Given the difficulties with experimental techniques, the CFD technique is an important tool that can be used to obtain such data, once the model has been validated.

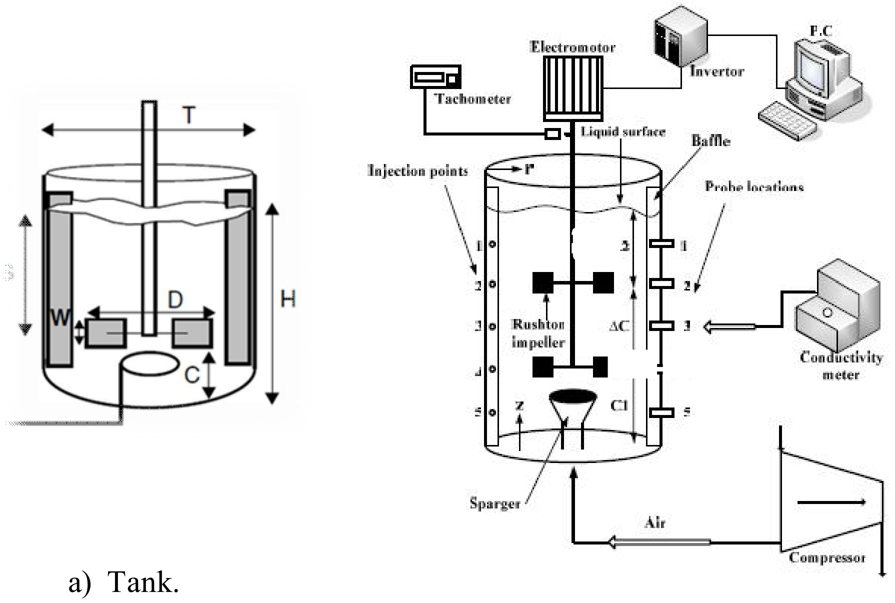
Materials and Methods

Materials and Reagents

The tools used in the present work are tachometer was supplied by Dot tech (Digital Photo type Tachometer model - 792). Conductivity meter was supplied by Systronics, stop watch. Purified sodium chloride pellets. Impellers were fabricated by Mechtrix Engineers. digital weighing balance by Essae-Teraoka ltd (model AQ2130/3EO).

Experimental Setup

The experiments have been performed in a mechanically agitated open top cylindrical poly methyl metha acrylate (Perspex) baffled vessel with an inner diameter of 0.2 m and a height of 0.3 m, the experimental setup is shown schematically in Figure 2 . The vessel is provided with an opening fitted with a drainage valve at the bottom center . The entire setup is supported on a stand that also holds the conductivity meter used for the measurement of the bulk solution conductance. The impeller is mounted vertically on a stand with its shaft positioned at the center of the tank and padded to minimize oscillations of the shaft tip. All impellers were mounted on the shaft with a clearance of 0.03 m from the bottom of the tank. A sparger having perforated distributor of 2 cm diameter and 25 orifices which is used for aeration that is placed of 0.05 m under the bottom of impeller. Aeration is provided by a compressor that supply air with appropriate flow rate controlled by flow meter. All aqueous solutions of sodium chloride were prepared with deionized water.



a) Tank.
b) experimental set up.

Fig. 2. Schematic of the experimental setup.

Procedure

The baffled vessel was cleaned completely and fitted with the stirrer having the first impeller to be studied. 4-5 litres of deionised water were filled in it to have the liquid holding volume as per the standard specifications (Perry and Green, 1997). The electrode of the conductivity meter was kept in place near one of the baffles in a fixed position for all readings. Care was taken that the electrode was never exposed to air to keep it from drying. The agitator was switched on and the speed of rotation of the impeller was controlled by regular mounted on control panel of agitator and satisfy by using the tachometer. The rpm of the agitator was controlled at the desired rate and maintained during the course of the experiment. The measured volume of the tracer (NaCl solution) was added along the stirrer rod axis as a pulse input and the stopwatch was switched on. The time was record when the conductivity meter reading a constant value, The parameters which varied were the position of tracer input, tracer concentration, tracer volume, impeller type and impeller speed to perform the analysis for the present study. The specification of the stirred tank system is listed in Table. 1

The stirring speed is controlled by regulator supported with electromotor . A tachometer was used to measure the impeller speed. A pulse trace of sodium chloride solution is injected along the baffle with manual cerange .

Table (1). Specification of the stirred tank system.

Agitation parts	Symbol	Value
Tank diameter	T	0.2 m
Impeller diameter	D	T/3
Blade height	W	1/5 D
Bottom clearance	C_1	0.55 T
Baffle width	l_{Baffle}	0.1 T
Liquid height	H	0.7T
Tracer concentration	50 – 150 gm NaCl 500 ml solution	
Tracer volume	2 – 8% of bulk volume	
Position of tracer input	Along baffle	
Tracer density	1078 kg/m3	

Results and Discussion

In the present work the effect of following parameters were studied and the results are illustrated below

1.Influence of injected tracer

Minimizing the mixing time in agitation systems is important for optimum design Jafari et al. 2005. The mixing time is found to be dependent on the amount of fluid tracer added to the system, dealing with the effect of volume of tracer fluid on mixing time is restricted to tracer volume of maximum of 2% of the bulk.. The volumes added in the present study in range of 2 to 8 % of the total bulk volume are such that the tracer pocket has sufficient volume to retain the identity even after 3 or 4 circulations and hence if the volume is increased further, larger mixing times are expected. Thus, the study reveals the dependency of mixing time on the amount of tracer added to the system. Similar observations were made on varying the density difference between the tracer input and the liquid bulk Gogate and Pandit, 1999. The effects of tracer volume on mixing times were studied at different pulse injection points in the tank for two concentrations of the tracer (for consistency check of trend) , the results are plotted in Fig.3

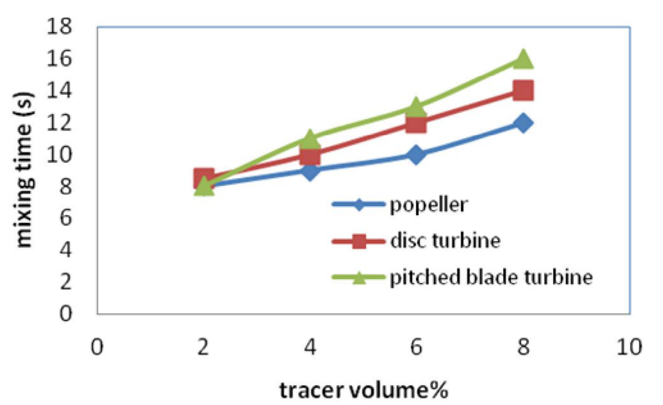


Fig.(3) Mixing time versus tracer conc.

2. Influence of impeller speed

Impeller speed plays a major role in flow regime by increasing the circulation loops , then and turbulence of fluid is observed. Fig.4, shows that mixing time for one phase system , decreases exponentially by increasing of the impeller speed for three types of impeller. The propeller pushes the liquid radially and tangentially with almost no vertical motion at the impeller. The currents it generates travel outwards to the vessel wall and the flow either upward or downward. In process vessels they typically turn at 100 to 600 rpm. The disk turbine, with multiple straight blades mounted on a horizontal disk, like the straight-blade impeller, creates zones of high shear rate; it is especially useful for dispersing a gas in a liquid. A pitched-blade turbine is used when good overall circulation is important , so the later gives a high efficiency of agitation.

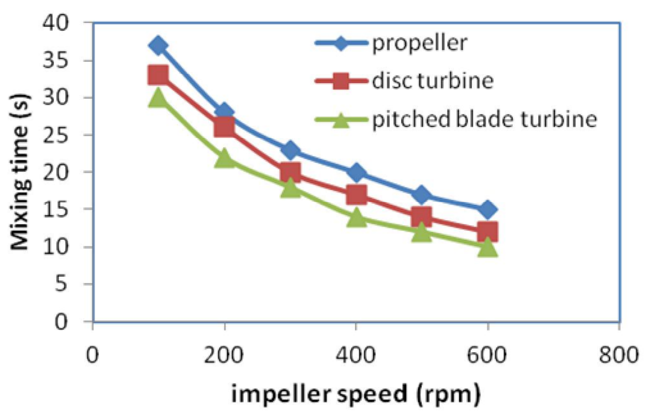


Fig. (4) Effect of impeller speed on mixing time.

3. Influence of aeration rate

The influence of aeration rate on the mixing time is shown in Fig. 5 . It is obvious that the mixing time is decreased due to increasing gas flow rate (aeration rate) at constant impeller speed, at impeller speed of 100 rpm, a primary sharp slope is observed which can be due to the low created turbulence region , however, starting aeration lead to create a portion of turbulence and circulation flow via bubble distribution, by increasing of aeration, the slope of curve is decrease. At high flow rate of gas greater than 300 l/hr, has less effect on mixing time, due to low flow circulation and low power number, so that the bubbles af air concentrated rounded the impeller zone.

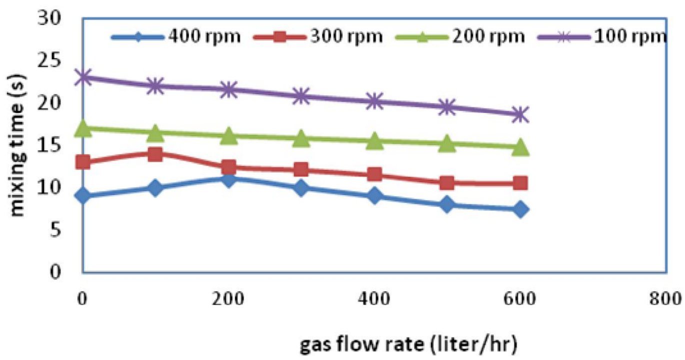


Fig. (5) Effect of gas flow rate on mixing time for different speeds

At higher impeller speed, mixing time has a value more than one phase system, for low aeration rates. This can be due to the low gas volume dispersion in volume content. In the other word, suitable mechanical turbulence distribute the bubbles in whole volume content but it last time to disperse bubbles due to lack of gas volume and low number of bubbles, so that by increasing of aeration, the mixing time is decreased again because of extend gas volume, which agrees with Pandit and Joshi 1983.

Fig.6, is indicated for impeller speed less than 250 rpm, increasing of aeration lead to decreasing mixing time and for gas flow rate(Q_g > 150 lit/hr), increasing of impeller speed lead to decreasing mixing time, too. Also, it's noticeable that for high impeller rotational speed (N>400rpm), the effect of aeration rate on mixing time is negligible. So, it's noticeable that the proper regime is the aeration rate between 150 and 550lit/hr and impeller speed (N) between 200 and 500rpm

4. Power consumption

In order to complete the characterization of the system, the power measurements under gassed conditions were investigated. The well-known equation for impeller power is often modified for gas-liquid systems to give:

$$P = N_p(RPD)\rho N^3 D^5 \qquad (1)$$

Figure 6 illustrates, variation of relative power demand RPD with gas flow number for PB turbine, the decrease of *RPD* with increased gas flow number It can be noticed that *RPD* falls a little at high rotation speeds (*RPD* > 0.9), whereas a significant decrease (from 1 to 0.4) is observed for low speed *N* = 180 rpm. This should be linked to the fact that, for the smallest speeds, the bubbles are regrouped around the shaft, and tend to form some gas cavities behind the blades (loading regime). Working at impeller speed greater than 240 rpm is thus recommended for minimizing the power loss under gassed conditions.

In Figure 6, when the impeller speed increases, the *RPD* curves are shifted vertically towards higher values. For the highest agitation speeds (above 400 rpm), the loss of power is smaller than 10% and than 5% for *N* > 600 rpm. These results confirm the efficiency of this PBT impeller for conserving the power dissipated under gassed conditions. The literature dealing with this kind of impeller (Smith and Gao, 2001; Paul et al., 2004 gives the RPD values only under high load conditions (i.e. □G > 0.1)

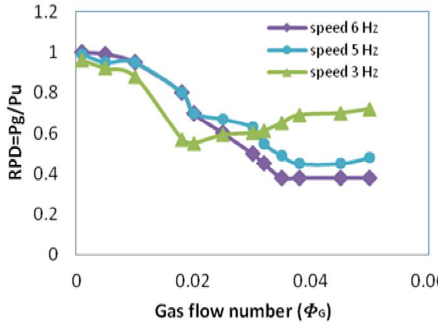


Fig.(6) Relative power demand for PBT versus gas flow number.

In the large-cavity regime of gassed aqueous systems, a good approximation for the gassed power of a Rushton turbine, the well-known equation for impeller power is often modified for gas–liquid systems investigated by Smith 2006,

$$RPD = \frac{P_G}{P_U} = 0.18\Phi_G^{-0.2} Fr^{-0.25} \qquad (2)$$

where RPD is the relative power demand or gassing factor (PG/PU) depends on the blade shape, Qg, N, and D , it generally decreases with increased dimensionless gas rate or gas flow number □G = QG/ND3 and Fr is Froud number Fr = N2D/g

Equations 1and 2, allow to predict the operating conditions in any stirred equipment.

Conclusion

In present investigation , conclusion to that , The mixing time for the addition of the salt tracer into the bulk of agitated liquid is found to be dependent on the amount of tracer added and the density difference between the tracer input and the deionized water, mixing time is decreased by increasing of impeller speed. For low impeller speed, aeration lead to reducing of mixing time but for high impeller speed, low aeration lead to increasing of mixing time. Then, more aeration create two direct pumping capacity and decreasing of mixing time, consequently.

A pitched-blade turbine is used when good overall circulation is important , so the later gives a high efficiency of agitation

Nomenclatures

D	impeller diameter (m)
F_r	Froude number
N	impeller speed (rpm)
N_p	power number
Nt	mixing time factor
P	power consumption (W)
P_G	power consumption with aeration (W)
P_U	power consumption without aeration(W)
Q_G	gas flow rate (m^3/s)
T	tank diameter (m)

Φ_G gas flow number

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