International Journal of Industrial Engineering
http://ijie.gjpublications.com/
Vol. 1, No. 4, 2017. Page 146-150.
ISSN: 2456-8449.

Research Article

Performance of Self-ingesting Impeller for High Density Liquid System

C. Gomadurai, K. Saravanan

Department of Chemical Engineering, Kongu Engineering College, Erode,
Tamilnadu – 638 060. India.

*Corresponding author's e-mail: cgomadurai@gmail.com

Abstract

In order to study the effect of density of working fluid on air inducing characteristics of self-inducing impeller, sodium chloride solutions in water at different concentrations in the range of 0 to 10 % (by weight), was used. A conventional mechanically agitated vessel was converted into an air-inducing reactor by attaching a specially designed tube-bundle, fabricated using L-shaped stainless tubes, to the impeller shaft. The effects of stagnation height, impeller speed and concentration of working fluid on critical speed for gas induction, gas holdup and power requirement for air-induction were observed. The density of water was increased by increasing the concentration of sodium chloride which increased the bulk density of the working fluid during gas induction. It was observed that the increase in density lead to slight increase, then a slight decrease in rate of gas induction and hence the gas holdup.

Keywords: Self-inducing reactor; Air-inducing impeller; Gas holdup; High density liquid; Agitated vessel; Sodium chloride.

Introduction

Aeration is one of the most important and indispensable unit operations unit for a variety of processes including the treatment of wastewater using activated sludge [1]. Mechanically agitated reaction vessels are widely used to perform gas–liquid reactions and gas–liquid–solid reactions involving dispersion and dissolution of reactant gas into the liquid phase. The physical/chemical treatments requiring gas–liquid contact include alkylation, ozonolysis, ethoxylation, catalytic hydrogenation, suspension polymerization, oxidative leaching of ores, waste water treatment, chlorination, ammonolysis, oxidation, etc., where it is very much important to have complete utilization of the gas. But, the major problem in these processes is only a small fraction of the feed gas is absorbed/ dissolved in a single pass and the remaining disengages into the headspace of the reactor. Gas liquid contactor with self-inducing impeller is an attractive alternative option to overcome this problem [1-3].

Gas-inducing impellers are advantageous in situations, where internal recycle of unreacted gas is desirable [4]. In self-inducing reactors, the flow and dispersion of gas within the liquid take place only after a critical rotational speed – the speed at which the pressure at the impeller orifice just falls below the pressure of the reactor head space – is exceeded [5, 6]. Power consumption is one of the most important parameters in establishing the efficiency of a reactor system [7]. For reactions involving expensive and/or hazardous solute gases self-inducing reactor is a safer alternative as it minimizes the risk of leaks.

In general, a self-inducing reactor could work on four mechanisms viz., (i) surface aeration in a partially baffled, or unbaffled, vessel [8]; (ii) gas-induction through a hollow-bladed shaft and impeller [6]; (iii) self–induction through a rotor-stator device and concentric standpipe [2]; or (iv) ingestion of gas through the formation of surface vortices. The effect of operating condition on the fractional gas holdup and power consumption in air inducing reactor was studied and shown that the increase in impeller speed and decrease in liquid level in the tank increased the gas holdup and power consumption [9]. The more uniformity in gas distribution at moderate impeller speeds, increase in gas holdup up to 18 %, increase in dissolved oxygen up to 16% and decrease in power consumption up to 5% could be achieved for dislocated-blade Rushton impeller when compared with the standard Rushton turbine

Received: 18.07.2017; Received after Revision: 29.07.2017; Accepted: 29.07.2017; Published: 31.07.2017

[10]. Self-inducing impeller could be used for effectively enhancing the gas utilization efficiency in a gas-liquid operation and also the self-inducing bioreactors could be applied to bioprocesses such as production of fuels and chemicals from gaseous substrates, high-throughput screening microbial strains, fermentation processes etc [11].

The effects of pattern of flow field of liquid on morphology, rheology of broth, mass transfer and production of glucoamylase with radial and axial flow impellers studied. For a given glucose and oxygen uptake rate, relatively homogeneous viscosity and mass transfer fields were obtained for axial flow impellers compared with the radial flow impellers [12]. The interaction between the vortex core of swirling water flows and rising air bubbles in a cylindrical tank was studied and observed that the vibrations associated with the swirling liquid flow could be suppressed with the help of injecting gas bubbles into the flow and also the mixing of swirling liquids could be enhanced by introducing gas bubbles [13].

There are only few literature support available for investigating the effect of density of the working fluid on hydrodynamic characteristics of the air-inducing impeller. In the proposed work, the air inducing characteristics of the sodium chloride solution in water was studied for 0, 5 and 10 % (by weight) sodium chloride concentration.

Material and methods

A specially designed and fabricated tube-set for inducing the atmospheric air is retrofitted to the conventional mechanically agitated reaction vessel and is shown in Fig. 1. The set up consists of a baffled, agitated reaction vessel, with an internal diameter of 45.5 cm made of acrylic material, mounted on a leg support. A solid shaft placed at the centre of the vessel is run by a 2 hp 3 phase induction motor. The motor is controlled by a speed control drive of frequency modulation type, watt meter measures the power and tachometer is used to measure the impeller speed. Baffles are present inside the reactor which helps to overcome vortex formation and increase turbulence. The air-inducing tube-set, having orifices in the horizontal section of the tube, is attached to the impeller shaft. The tube-set has closed bottom end and an open upper end so that the air sucked from the atmosphere does not escape directly.

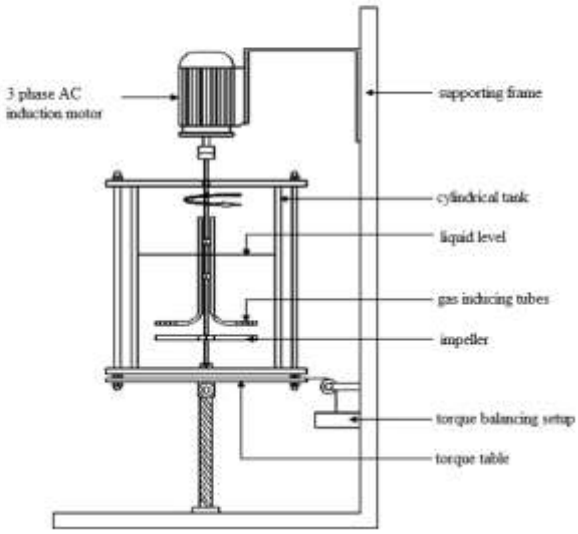

Fig. 1. Experimental setup of the conventional baffled agitated vessel retrofitted with the proposed air-inducing impeller system

In the present study, sodium chloride in water solutions in different concentrations such as 0, 5, and 10% were studied. The working fluid was taken in the vessel. During the experiment, the impeller speed was gradually increased using the speed control drive and the impeller speed and power consumption were measured. At impeller speeds greater than the critical speed, the atmospheric air was sucked into the vessel. Gas holdup was measured by noting down the level of the working fluid in the reactor before and after the air induction. This procedure was repeated by varying the liquid level in the tank and concentration of the working fluid.

The fractional gas holdup (G) was determined by using eq. (1)

$$G = \frac{H_D - H}{H_D} \qquad (1)$$

where, H_D is the height of dispersion, m
H is the total gas-free liquid height, m
The impeller power was determined using the torque table and load cell. The impeller power P was calculated from eq. (2)

$$P = 2\pi NT \qquad (2)$$

where, N = rotational speed of the impeller, s^{-1}
T = Torque, N.m

$$T = ½ D.W \qquad (3)$$

where, D = diameter of the vessel, m
W = load, N

$$W = m.g \qquad (4)$$

where, m = weight added to stop the rotation of the vessel, kg
g = acceleration due to gravity, m/s^2

Results and discussions

The effects of impeller speed, liquid level in the tank and the concentration of the working fluid on gas holdup and power consumption were studied and the results are presented.

Critical speed

The critical speed is the speed of the impeller at which the suction of the atmospheric air into the reaction vessel starts. The effect of stagnation height on critical speed for 0, 5 and 10% sodium chloride concentrations of the working fluid for a liquid height of 30 cm is presented in Fig. 2. It is clear that the critical speed for suction of air increases with increase in stagnation height and with concentration of sodium chloride in the working fluid [9]. Since the increase in stagnation height increases the hydrostatic pressure at the face of the impeller orifice, the critical speed increases with increase in stagnation height. Similarly, the increasing in density of the working fluid increases the hydrostatic pressure and hence the critical speed.

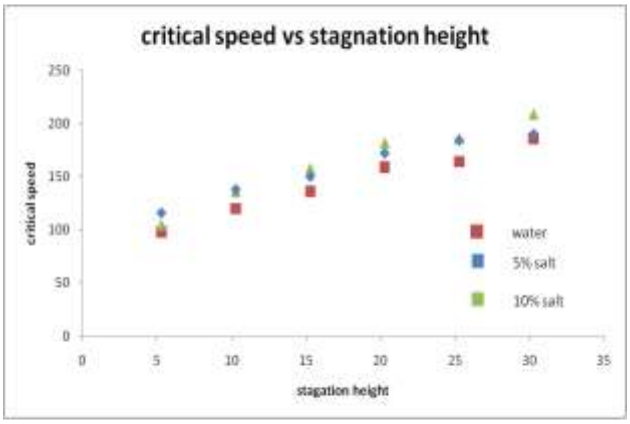

Fig. 2. Effect of stagnation height on critical speed for 30 cm liquid level

Gas holdup

The gas holdup is one of the important characteristics of a gas-liquid contactor, i.e., a high gas holdup is preferable for better mass transfer and reaction. For impeller speeds greater than the critical speed, the gas-phase is found in the liquid in the form of bubbles. The gas holdup is expressed as the volume fraction of the dispersed gas phase in the reaction vessel and is calculated from the volume of the working fluid before and after the gas induction [9]. Fig. 3 shows the gas holdup vs power consumption for agitation for a liquid height of 30 cm. It is observed that the gas holdup increases with power consumption for all the three working fluids used in this study.

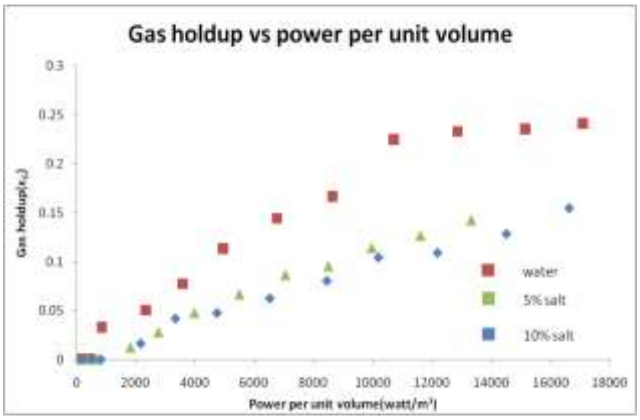

Fig. 3. Effect of concentration of NaCl in working fluid on gas holdup for 30 cm liquid level

Fig. 4 shows the effect of impeller speed on gas holdup for a liquid height of 30 cm. It is noticed from the results that at lower super critical speed, i.e., when the positive difference between the impeller speed and the critical speed is low, the gas holdup is almost equal for 0, 5 and 10% concentrations of sodium chloride of the working fluid for a given impeller speed. However at higher supercritical impeller speeds, the gas holdup increases with increase in concentration. This is attributed to the fact that the bulk density of the working fluid continuously decreases due to the increase in gas-phase content. Since the density of the working fluid is one of the driving forces for the induction of air, at higher supercritical speeds, the gas holdup increases with increase in concentration of the working fluid.

Power consumption

The power consumption is one of the most important aspects for any process as it directly affects the economy of the process. The effect of impeller speed on power consumption for agitation is presented in Fig. 5. It is seen from the graph that there is no much difference in power consumption for 0, 5 and 10% concentrations of sodium chloride in the working fluid. Since the experiments were carried out only up to 10% concentration of sodium chloride in water, the concentration did not show any significant effect on power consumption. However, at higher concentrations of the working fluid, the effect of concentration on power consumption for a given impeller speed might be different. It is also evident that the power consumption drastically increases with increase in impeller speed up to critical speed and then increases gradually. This trend was observed for 0, 5 and 10% concentrations of sodium chloride in water.

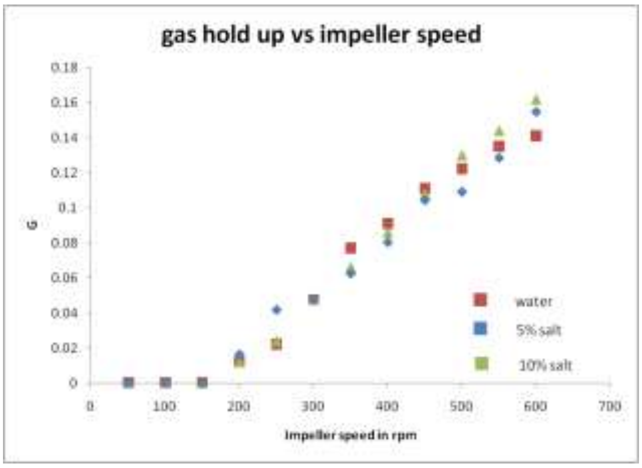

Fig. 4. Effect of impeller speed on fractional gas holdup (ε) for 30 cm liquid level

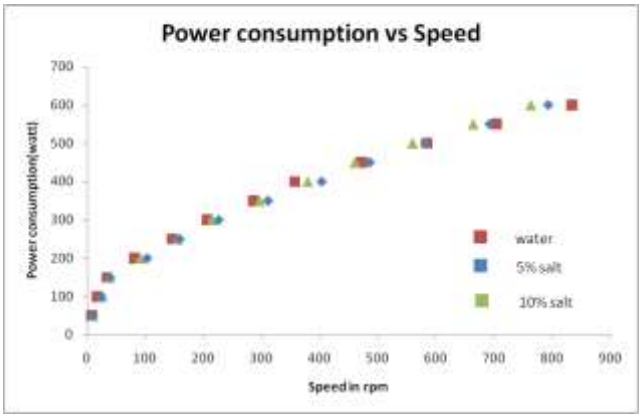

Fig. 5. Effect of impeller speed on power consumption for 30 cm liquid level.

Conclusions

The effects of stagnation height, density of working fluid and impeller speed on gas holdup and power consumption were studied in a conventional mechanically agitated vessel retrofitted with a specially designed air-inducing tube-set. Sodium chloride solutions in water at 0, 5, and 10 % (by weight) concentrations were used as the working fluid. The critical speed for the suction of air increased with increase in stagnation height for all the concentration of the working fluid. The gas holdup was found to increase with increase in power consumption per unit volume. It was found that for water, the gas holdup increased drastically with increase impeller speed up to a certain extent and then increases gradually whereas for sodium chloride solutions in water, the gas holdup continues to increase even at higher impeller speeds, i.e., the gas holdup increases with increase in concentration of sodium chloride in the working fluid for a given supercritical impeller speed. This is due to the fact that the gas induction increases the gas holdup, which, in turn, decreases the bulk density of the working fluid. Increase in density of the working fluid first increases gas holdup and further increase in density lead to a continuous but gradual decrease in gas holdup. The reason for this behavior of the system is that when the impeller is rotated, there is a relative velocity between the orifice in the horizontal section of the air-inducing tube set and the moving fluid, which one of the major reason for creating the difference in pressure between the reactor headspace and the face of the orifice. When the density of the working fluid is increased slightly, the difference in pressure between the reactor head space and the face of the orifice is increased, which, in turn, increases the rate of induction of air into the vessel and hence there is a corresponding increase in fractional gas holdup. However, when the density of the working fluid is increased further, the initial hydrostatic head increases considerably, which acts as the resistance for the induction of air. Therefore, the increase in density of the working fluid beyond a certain value decreases the induction rate of air and hence the fractional gas holdup. It was also noticed that for a given density of the working fluid, the fractional gas holdup increased with increase in rotational speed of the impeller, which indicates the increase in induction rate of air with increase in rotational speed of the impeller.

Conflicts of Interest

Authors declare no conflict of interest.

References

[1] Chen JH, Hsu YC, Chen YF, Lin CC. Application of gas-inducing reactor to obtain high oxygen dissolution in aeration process. Water Res. 2003;37:2919–2928.

[2] Patwardhan AW, Joshi JB. Design of gas-inducing reactors. Ind Eng Chem Res. 1999;38:49–80.

[3] Deshmukh NA, Patil SS, Joshi JB. Gas induction characteristics of hollow Self-inducing impeller. Trans IChemE Part A Chem Eng Res Des. 2006;84(A2):124–132.

[4] Murthy BN, Deshmukh NA, Patwardhan AW, Joshi JB. Hollow self-inducing impellers: Flow visualization and CFD

simulation. Chem Eng Sci. 2007;62:3839–3848.

[5] Ju F, Cheng ZM, Chen JH, Chu XH, Zhou ZM, Yuan PQ. A novel design for a gas-inducing impeller at the lowest critical speed. Chem Eng Res Des. 2009;87:1069–1074.

[6] Forrester SE, Rielly CD, Carpenter KJ. Gas-inducing impeller design and performance characteristics. Chem Eng Sci. 1998;53(4):603–615.

[7] Jafari M, Mohammadzadeh JSS. Power consumption and onset speed for gas induction in a gas-induced contactor. Chem Eng J. 2004;103:1–5.

[8] Lines PC. Gas-liquid mass transfer using surface-aeration in stirred vessels with dual impellers. Trans IChemE Part A Chem Eng Res Des. 2000; 78 (3): 342–347.

[9] Gomadurai C, Saravanan K, Abraham E, Deepa N. Hydrodynamic studies on air-inducing impeller system. Int J ChemTech Res. 2014;6(10):4471-4474.

[10] Yang F, Zhou S, An X. Gas-liquid hydrodynamics in a vessel stirred by dual dislocated-blade Rushton impellers. Chin J Chem Eng. 2015;23:1746–1754.

[11] Ye Q, Li Z, Wu, H. Principle and performance of gas self-inducing reactors and applications to biotechnology. Adv. Biochem Eng Biotechnol. 2015;152:1–33.

[12] Tang W, Pan A, Lu H, Xia J, Zhuang Y, Zhang S, Chu J, Noorman H. Improvement of glucoamylase production using axial impellers with low power consumption and homogeneous mass transfer. Biochem Eng J. 2015;99:167–176.

[13] Uchiyama T, Ishiguro Y. Study of the interactions between rising air bubbles and vortex core of swirling water flow around vertical axis. Chem. Eng. Sci. 2016;142:137–143.

****

