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Research Article

Air Inducing Characteristics of Self-Inducing Reactor with Non-Newtonian Working Fluid

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Abstract

Attempts were made to study the hydrodynamic characteristics of air inducing impeller for systems with non-Newtonian fluids. A simple method was proposed in the design and modification of air inducing impeller aiming at the minimization of power consumption for the suction and distribution of air and better aeration at low operating cost. The proposed method requires only a retrofitting type of modification in the gas inducing impeller which eliminates the inherent complications of the methods suggested in the literature. The complications in the fabrication of the air inducing impeller were eliminated with the use of L-shaped tube set (10 mm OD, SS 304) for the suction of air. Experiments were conducted using L shaped tube set 6 sides and L shaped tube set 3 sides along with the combination of straight blade turbine for the suction and distribution of atmospheric air. The working fluid chosen for the proposed study is Carboxy methyl cellulose with different concentrations viz. 0.1%, 0.2%, 0.3%. Experiments were performed by varying the working liquid level. The other parameters considered for this study are power input to the impeller, gas hold up and impeller speed by taking total liquid height, liquid height above the orifice level and fluid properties (density, viscosity) as the independent variables.

Keywords: Air inducing reactor; Non Newtonian fluid; Hydrodynamics; Gas holdup; Critical speed.

Introduction

Agitated reactor is commonly used for gas-liquid heterogeneous reactions in the process industries. These types of reactors have advantages such as good mixing effect, effective gas liquid contact etc. when it is required to disperse air or gas into a liquid, the effective utilization of the dispersed gas is also important in addition to the power consumption. In conventional reactor, gas is continuously sparged into the vessel and is dispersed into the liquid by the rotating impeller. However, interaction between impeller and baffles consumes more power. Most often only a small fraction of feed gas is absorbed in a single pass and the unreacted gas disengages into the headspace of the reactor. In some cases, unreacted gas may be safely vented, but in other cases reactant gas is costly or hazardous must be recycled back through the sparger, which might increase the operating cost. Thus sparging reactor has disadvantages such as high power consumption, high operating cost etc. It resulted in less than satisfactory performance, due to non-ideal mixing, which led to poor catalyst suspension, negligible gas-liquid interfacial areas, as well as low heat and mass transfer coefficients. When it is required to disperse the unreacted overhead gas phase into the liquid in an agitated reactor without gas outlet, a gas-inducing impeller is usually employed [1]. In a gas inducing reactor, as the liquid submergence increases, the gas hold up decreases due to the reduction of the gas induction rate with height of the liquid in the tank [2].

At low impeller speeds, power consumption decreased significantly by gassing (60% drop in power consumption at speed of 800 rpm), while at higher speeds, because of gas induction, effect of gassing on power consumption was not considerable (15% drop at speed of 1600 rpm). The gassing leads to a considerable drop in power consumption

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especially at low speeds. At speeds higher than 1000 rpm because of gas induction, the effect of gassing on power consumption is not significant. At liquid levels higher than limiting level, the power consumption remains almost constant. Despite the fact that a gas-induced contactor requires a high impeller speed to initiate gas induction, it consumes less power compared to the conventional gas–liquid contactors [3]. The critical speed depends on the impeller type, concentration of the particles in the liquid, and on the gas flow introduced into the system [4].

In case of non-Newtonian fluids, fraction of well mixed zone is slightly lower with reasonable amount of power consumption and the fraction of well-mixed zone increases with the impeller speed and found to remain constant at higher impeller speed of 200 rpm [5]. For the maximization of the gas induction rate, the outlet holes on the impeller need to be located in the low pressure region [6]. The presence of rotor-stator does not influence the power characteristics of the Paravisc for both Newtonian as well as non-Newtonian fluids indicating weak pumping capacity of rotor-stator. The presence of rotor-stator significantly improves the mixing process [7]. Wang et al [8] measured the critical impeller speed and the overall gas holdup for studying the impact of liquid driving flow on the performance of gas-inducing impeller. The results indicates that the optimum gas-inducing properties could be obtained with respect to the lowest value of the critical speed for gas induction and the highest value of the gas holdup when the diameter of the liquid inlet hole was approximately fifty percent of the diameter of the gas inducing pipe.

Hong et al [9] investigated the hydrodynamic characteristic and bio-reaction parameters in self-induced bioreactor for yeast fermentation using Euler-Euler’s two fluid model coupled with mass transfer and biochemical reaction. The results showed that the Euler-Euler’s two fluid model could be used to predict the transient distribution of the liquid velocity, volume fraction of air, component concentration for cell, residual sugar and dissolved oxygen. Gomadurai et al [10] converted a conventional mechanically agitated vessel into an air-inducing reactor and to simplify the mechanism and fabrication of self-air inducing impeller system and found that the critical speed for suction of air into the reactor increased with increase in submergence depth of the orifice and decreased with increase in bottom clearance when water was used as the working fluid. Ye et al [11] described the principles, design and characteristics of self-inducing reactors and the applications in the field of biotechnology and observed that indicated that the 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.

Tang et al [12] investigated 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 and noticed that 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. Uchiyama & Ishiguro [13] studied the interaction between the vortex core of swirling water flows and rising air bubbles in a cylindrical tank 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. Gomadurai et al [14] evaluate the performance of a novel air-inducing impeller system with a specially designed air-inducing tube-set and shown that the air-inducing impeller system used could induce the air at relatively lower impeller speeds. Gomadurai and Saravanan [15] study the effect of density of working fluid on air inducing characteristics of self-inducing impeller, sodium chloride solutions in water at different concentrations and noticed that the gas holdup was found to increase with increase in power consumption per unit volume.

From the literature, it is observed that only very few authors have examined the hydrodynamic behavior air-inducing reactor for non-Newtonian fluids. The objective of the present study is to study the hydrodynamic characteristics of the modified self-inducing reactor using carboxy methyl cellulose solution in water as the working fluid.

Materials and methods

In order to study the hydrodynamic characteristics of self-inducing reactor using carboxy methyl cellulose solution in water as the working fluid, a conventional agitated vessel was retrofitted with a specially designed air-inducing tube set and the experimental setup is given elsewhere [10,14,15]. Carboxy methyl cellulose solutions in water were prepared at three different concentrations viz., 0.1, 0.2 and 0.3 per cent by weight and used as working fluids. The stagnation height was maintained at various levels viz., 10, 15, 20, 25 and 30 cm. For each stagnation height, the impeller speed was increased gradually and the power consumption was recorded using watt meters. The power consumption per unit volume of the working fluid was determined by measuring the total volume of the gas-free working fluid for each stagnation height. When the impeller speed reached the critical speed, the induction of air started and the induction of the air increased gradually for further increase in critical speed of the impeller. For all speeds greater than the critical speed, the fractional gas holdup in the reactor ε was determined from eq. (1).

$$\varepsilon = \frac{H_D - H_L}{H_L} \quad \text{.........(1)}$$

Where, H_D = height of the dispersion, m

H_L = height of gas free liquid, m

Results and discussion

Effect of impeller speed

The variation of fractional gas holdup with the variation of impeller speed for 0.2% carboxy methyl cellulose is presented in Fig. 1. It is clear that the fractional gas holdup increases with increase in impeller speed for all the liquid heights in the vessel. It is noticed that the fractional gas holdup decreases with increase in level of working fluid in the tank. The similar pattern is observed for the other two concentrations of carboxy methyl cellulose in the working fluid.

Specific power consumption and gas holdup

The effect of specific power consumed for gas induction on the fractional gas holdup for 0.3% carboxy methyl cellulose solution in water is presented in Fig. 2. It was observed that the increase in specific power consumption increases the fractional gas holdup in the working fluid. It is due to the fact that the increase in power consumption is due to the increase in impeller speed. Since the gas induction rate increases with the increase in impeller speed, the increase in specific power consumption increases the fractional gas holdup. It is also observed that the fractional gas holdup decreases with increase in liquid level in the reactor. The similar behavior is observed for all the experimental runs.

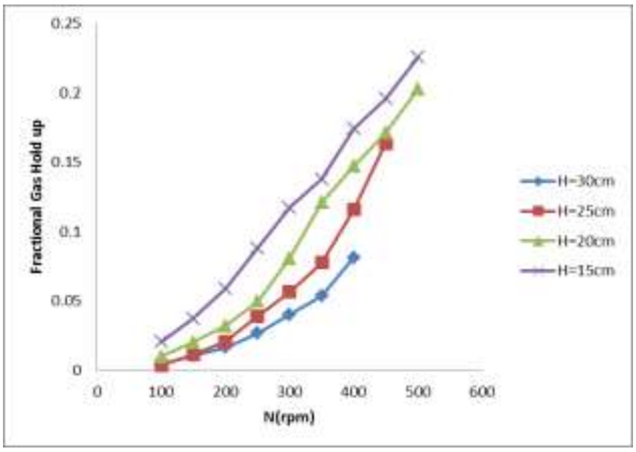

Fig. 1. Effect of impeller speed on fractional gas holdup

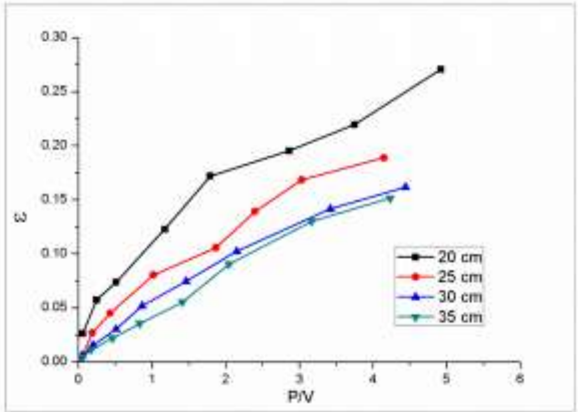

Fig. 2. Effect of specific power consumption on fractional gas holdup for 0.3% CMC

Effect of CMC concentration on fractional gas holdup

The increase in concentration of carboxy methyl cellulose in working fluid decreases the fractional gas holdup as presented in Fig. 3. It is attributed to the fact that the increase in concentration of carboxy methyl cellulose increase the apparent viscosity of the working fluid. The increase in viscosity increases the resistance for the induction of air into the reactor, which, in turn, decreased the gas holdup. Hence, the increase CMC concentration in liquid decreases the fractional gas holdup.

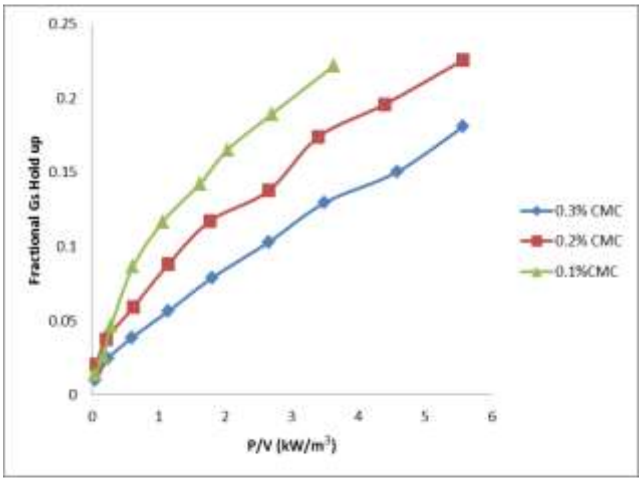

Fig. 3. Effect of CMC concentration on fractional gas holdup

Conclusions

In order to study the hydrodynamic characteristics of self-inducing reactor for non-Newtonian fluids, carboxy methyl cellulose solution in water at three concentrations viz., 0.1, 0.2 and 0.3 % by weight were used as the working fluids. The stagnation height was varied form 10 cm to 30 cm. The effects of stagnation height, carboxy methyl cellulose concentration, and impeller speed on fractional gas holdup and specific power consumption were studied and reported. It was observed that the fractional gas holdup increased with increase in impeller speed but decreased with increase in stagnation height and carboxy methyl cellulose concentration in the working fluid. The power consumption per unit volume of the working fluid increased with increase in carboxy methyl cellulose concentration in working fluid and increase in impeller speed but decreased with increase in level of working fluid in the vessel. This study is expected to be useful in analyzing the behavior of non-Newtonian fluids when used as the working fluid in self-inducing reactor for optimizing the impeller speed for maximum gas holdup at less power consumption.

Conflicts of Interest

Authors declare no conflict of interest.

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