A significant volume of research publications is found in the field of invention, design, development and modification of gas inducing mechanically agitated contactors. Research works in the field of gas-inducing reactor are evident over the past three decades and many investigators have contributed to the invention of various types of gas-inducing impellers.

Joshi & Sharma (1977) studied power consumption, rate of gas induction, fractional gas holdup and mass transfer characteristics of a gas inducing type of agitated contactor. From the results, it was observed that the rate of gas induction increased with increase in impeller speed, increase in impeller diameter and increase in orifice area on each impeller blade but decreased with increase in viscosity of the working fluid. The results also indicated that the surface tension had no effect on the rate of gas induction.

Harris & Mensah-Biney (1977) studied the pressure generated by impeller rotation and the aeration characteristics of laboratory floatation machine impellers. The results showed that the power and the pressure generated by the rotating impeller decreased with increase in frother concentration.

White & De Villiers (1977) measured the rate of the induced air in agitated vessel using stator and rotor. The results indicated that the aeration in a floatation machine began once the Froude number exceeded a critical value.
It was observed the results that the increase in viscosity of the solution or introducing the surfactant lead to an increase in rate of aeration.

Riet (1979) reviewed the measuring methods and results in non-viscous gas-liquid mass transfer in stirred tanks. The review results showed that the increase in diameter of the sparger larger than that of the stirrer lead to an increase in power consumption and decrease in mass transfer. The observation also showed that the power consumption per unit volume of the liquid decreased with increase in liquid level in the tank, the mass transfer coefficient decreased with increase in liquid height but became independent of the liquid height for higher liquid levels with the impeller placed close to the bottom of the tank. The review results also showed that the power consumption decreased when the impeller was placed close to the bottom of the tank but at the same time the mass transfer coefficient decreased at low impeller speeds. Based on the review results, it was suggested that the optimum position of the impeller for low power consumption and high mass transfer coefficient was the middle of the vessel and one stirrer diameter away from the bottom.

Sawant & Joshi (1979) conducted experiments to determine the critical impeller speed for the onset of gas induction in stator-rotor type gas inducing agitated contactor. From the results, it was observed that the onset of gas induction depended only on the impeller diameter, liquid height above the orifice and liquid viscosity and was independent of the vessel diameter, impeller design, liquid density and surface tension.

Joshi et al. (1982) reviewed hydrodynamic, heat and mass transfer characteristics of mechanically agitated contactors. From the results, it was inferred that the fractional gas holdup and the bubble diameter affect the performance of the mechanically agitated contactors. It was noticed that the presence of gas makes suspension of solid particles more difficult.
Linek et al. (1982) compared the $k_a$ values determined by the dynamics methods for water, sodium sulphate, potassium chloride and sodium chloride solutions and glucose solutions having the enzymes catalase and glucose oxidase in a mechanically agitated bubble tank. The results showed that the simultaneous interfacial transfer of components between the gas and liquid phases and the flushing of the gas holdup by the newly supplied gas were found to affect the $k_a$ values.

Albal (1983) studied the effects of total pressure, power input per unit volume of the liquid/slurry, solid concentration and liquid phase properties on volumetric mass transfer coefficient by gas-absorption technique for gas-liquid and gas-liquid-solid systems in a mechanically agitated contactor. The results showed that pressure had no influence on both liquid side mass transfer coefficient and gas-liquid volumetric mass transfer coefficient. It was noticed that the gas-liquid volumetric mass transfer coefficient increased by the presence of small amount of solid particles but decreased at higher concentrations of solid particles. It was also observed that the influence of particle size on power consumption increased with increase in solid concentration. The results also showed that a decreased in surface tension increased the gas-liquid mass transfer coefficient.

Warmoeskerken & Smith (1985) investigated the flooding transition of a Rushton turbine operating in a gas-liquid system. From the results, it was observed that the flooding transition coincided with the cavity breakdown and also the onset of flooding could be detected from changes in the gassed power demand.

Raidoo et al. (1987) measured the rate of gas induction, static pressure, mixing time and power consumption in a gas inducing agitated contactor with stator-rotor system. The result showed that the rate of gas
induction increased and the mixing time decreased while using the pitched blade turbine impeller as the gas was induced both radially and axially.

Galindo & Herrera (1989) studied the effects of different impeller combinations and agitation speeds on the culture of Bacillus subtilis (a viscous broth which is highly sensitive to oxygen and mixing effects). From the results, it was observed that the use of Rushton turbines in combination with low-power-number impeller appeared to be an effective and economical way to improve fermentation when those were closely related to mixing and mass transfer characteristics.

Lee & Foster (1990) reviewed the methods for the estimation of mass transfer in bubble column reactors and agitated vessels by observing the effects of superficial velocity of gas, column diameter, types of sparger and electrolytes on mass transfer coefficient. The results showed that in bubble column reactors, the mass transfer coefficient increased with increase in superficial velocity of the gas whereas in sparged agitated vessels there were three mass transfer regimes, namely, surface diffusion, surface convection and surface entrainment which depended on agitation speed of the impeller.

Rewatkar & Joshi (1991a) studied the effect of sparger type and the location of the sparger with respect to impeller on power consumption in an agitated vessel with pitched blade down flow impeller. From the results, it was observed that after exceeding the critical speed for dispersion of gas, the power number remained practically constant.

Rewatkar & Joshi (1991b) investigated the influence of sparger type on liquid phase mixing time in mechanically agitated gas-liquid reactors. The results indicated that the critical speed for gas dispersion increased with decrease in distance between sparger and impeller. The results also showed
that the number and size of the holes on the sparger had no effect when the sparger was placed close to the impeller.

Chang & Morsi (1992) measured mass transfer coefficients and volumetric mixing power input for methane in n-hexane/coal slurries in the pressure range of 1 – 50 bar. The results indicated that the mass transfer coefficient decreased with solid particle loading in n-hexane. It was noticed that the equilibrium gas solubility increased with increase in partial pressure but decreased with increase in temperature.

Rielly et al. (1992) developed a theoretical model to predict the pressure at the gas outlet of a gas-inducing impeller, to determine the minimum speed at which a gas induction occurs and to predict the flow rate of the gas induced at higher impeller speeds. The results indicated that for gas flow rate measurements at higher impeller speeds, the pressure driving force depended on the radius of the detached bubbles.

Chang & Morsi (1992a) measured equilibrium gas solubility and volumetric liquid-side mass transfer coefficients for carbon monoxide in n-hexane, n-decane and n-tetradecane under various operating conditions in a gas inducing agitated autoclave. The results showed that the $k_{L,a}$ values for carbon monoxide increased with increase in speed and pressure but decreased with increase in liquid volume.

Forrester & Rielly (1994) examined the effect of number of gas outlet orifices on each blade on the gas induction rate and mass transfer performance of a concave-bladed self-inducing impeller. From the results, it was found that increasing the number of orifices significantly increased the rate of gas induction and mass transfer performance.
Aldrich & Deventer (1994) studied air induction in slurries composed of ore and synthetic particulates using hollow pipe and shrouded Ruston turbine impeller. The results showed that the presence of solid particles less than about 15% by mass did not affect the gas induction and concentration of solids beyond that critical point the induced aeration decreased with increase in particle concentration, particle size and particle density.

Dong et al. (1994) compared the mean tangential velocity, mean radial velocity, mean axial velocity and turbulent energy predicted by Corolcis computer model with those measured experimentally for the flow induced by an eight-bladed-flat-paddle impeller in an unbaffled tank. The results indicated that for the region close to the impeller shaft and in the impeller stream, discrepancies were found between the predicted and measured values, which were attributed to the limitations of the numerical model used for prediction.

Saravanan et al. (1994) measured the rate of gas induction in gas inducing type of mechanically agitated contactor by varying the ratio of impeller diameter to the vessel diameter, impeller submergence depth and off-bottom clearance of the impeller using stator-rotor method of gas induction. From the results, it was observed that the rate of gas induction increased with increase in impeller speed and the critical speed for gas induction increased with increase in impeller submergence depth.

Heim et al. (1995) determined the initial conditions of gas induction, mixing power, mass transfer coefficients and gas flow rate in bioreactors with self-aspirating impellers using hollow impeller and hollow impeller shaft. The results showed that the suction rate of air and the mass transfer coefficient increased with increase in rotational speed of the impeller.
up to certain value and did not increase with further increase in impeller speed.

Vasconcelos et al. (1995) modelled the liquid hydrodynamics in multiple turbine aerated tank in the loading regime by compartments-in-series model with backflow streams. From the results, it was noticed that for a given value of gas glow number, the predicted valued of dimensionless mixing time increased with increase in agitation speed of the impeller. It was also observed that the ratio of agitation power under gassed condition to that under ungassed condition decreased with the increase in rotational speed of the impeller and increase in gas flow number.

Hsu & Huang (1996) developed an unbaffled gas inducing reactor with dual 45° pitched blade down flow turbines enclosed in a draft tube for the heterogeneous ozonation reaction of a reactive dye varying the impeller speed, inlet concentration of ozone, inlet flow rate of ozone and liquid volume. The results indicated that under stable gas induction conditions, the inlet concentration of ozone had no effect on ozone utilization ratio. The results also indicated that at impeller speeds above the critical speed for gas induction, the gas utilization ratio and power consumption decreased slightly with increase in inlet flow rate of ozone.

Tekie et al. (1997) studied the performance of surface aeration and air-inducing reactors for the oxidation of cyclohexane. From the results, it was noticed that the density of the liquid decreased with increase in temperature and the solubility of nitrogen and oxygen in hexane and hence the gas-liquid mass transfer coefficient increased with increase in pressure. The results also indicated the mass transfer coefficient for the gas-inducing reactor was higher than that for the surface aeration reactor.
Hsu et al. (1997) presented the effects of operational variables on the onset of gas induction and power consumption post gas induction and investigated the gas holdup and mass transfer. The results showed that the impeller speed, the liquid level and the impeller diameter had significant effects on the onset of gas induction and the power consumption post gas induction. From the results, it was observed that higher working liquid levels lead to a decrease in mass transfer coefficients owing to the smaller gas holdup.

Hsu & Huang (1997) studied the mass transfer for ozone in draft tube type air inducing reactor with dual pitched blade turbines. From the results, it was observed that the mass transfer of ozone increase with increase in impeller speed and increase inlet flow rate of ozone. It was also noticed that the liquid levels beyond a certain limit decreased the mass transfer coefficient.

Patwardhan & Joshi (1997) observed the hydrodynamic characteristics of a sparged agitated vessel equipped with a stator-rotor type gas inducing impeller. It was found from the results that the rate of gas induction decreased with increase in superficial gas velocity and that the decrease in submergence depth decreased the critical speed for gas induction and increased the rate of gas induction. The results also indicated that the critical speed for gas induction increased with increase in superficial gas velocity and the fractional gas holdup increased with increase in superficial gas velocity.

Forrester et al. (1998) investigated the experimental measurements for the power consumption, rate of gas induction, mass transfer coefficient and detached bubble size for a six-bladed concave gas-inducing impeller. The results indicated that the gas induction rate increased significantly by adding more outlet orifices to each blade. The results also exhibited that multiple
orifices produced bubbled of similar sizes compared to the single orifice and generated larger interfacial areas.

Sedahmed et al. (1998) studied the rate of mass transfer at four blade 45° pitched turbine, four blade flat turbine and disc turbine in order to investigate the role of mass transfer in the kinetics of flow induced corrosion of agitated vessel impellers considering the rotation speed of the impeller, physical properties of the working fluid, impeller diameter, presence of baffles in the cylindrical agitated vessel, the presence of solid particles and the effect of drag reducing polymers. It was observed from the results that the presence of baffles increased the rate of diffusion controlled corrosion. It was also noticed that the presence of solid particles increased the rate of corrosion but the presence of drag reducing polymers reduced the corrosion rate.

Hebrard et al. (1999) studied axial liquid mixing in gas-liquid and gas-liquid-solid systems. From the results, it was noticed that in two-phase systems, the type of gas sparger had a strong effect on the gas flow regime and the axial liquid and in the gas-liquid-solid system, the effect of gas sparger is less pronounced in the turbulent bed than in the inverse turbulent bed.

Patwardhan & Joshi (1999) presented a process design algorithm for the design of gas-inducing impellers and described the guidelines for the desired geometry of gas-inducing impellers for achieving different design objectives such as heat transfer, mass transfer, mixing, solid suspension, froth flotation etc. From the reviewed literature analysis, it was shown that for air inducing impellers of all types, the critical impeller speed for gas induction increased with increase in submergence depth of the orifice and that the critical impeller speed for gas induction was the highest for the impeller of aerofoil type and that was the least for the paddle type.
Lines (2000) measured dissolved oxygen for determining the gas-liquid mass transfer for air-water system using surface aeration in stirred vessels with dual impellers. It was observed from the results that the mass transfer coefficient decreased with increase in liquid height and increased with increase in specific power consumption of the impeller.

Hiraoka et al. (2001) measured power consumption in an agitated vessel with double impeller over a wide range of Reynolds from laminar to turbulent flow regions and mixing time in turbulent flow regions using decolourization method of sodium thiosulphate and iodine reaction. The results showed that for double impeller, the power consumption was maximum and almost twice that of single impeller for the impeller clearance to liquid depth ratio was greater than 0.35 and the power consumption was the minimum for the impeller clearance to liquid depth in the range of 0.18 to 0.25. It was also noticed that at the minimum mixing time the relationship between the mixing time and the power consumption for both single and double impeller was equal.

Bouaifi et al. (2001) measured the gas holdup, mass transfer coefficient, volumetric interfacial area, bubble size and bubble size distribution in two bubbles and stirred vessel with various combinations of dual impellers. From the results, it was noticed that for both dual-impeller reactor and bubble column equipped with perforated plate the bubble diameter decreased with increase in specific power consumption. It was also observed that for both reactors, the interfacial area ranged from 20 to 133 m² m⁻³ for the specific power consumption in the range of 50 to 1000 W m⁻³ and the interfacial area created by bubble column was 30% greater than that created by stirred vessel.

Smith & Gao (2001) compared the power demand of conventional Rushton turbine with that of three hollow blade dispersing impellers under
high load conditions. From the results, it was observed that the gas loading was large when hot water was used as the working fluid due to the formation of water vapour. It was also noticed that for a give flow rate of gas, the power consumption was higher for hot water than for water at ambient temperature.

Khare & Niranjan (2002) investigated the effect of impeller design on gas holdup in carboxy methyl cellulose solution and castor oil along with polypropylene glycol as surfactant. From the results, it was observed that the total gas holdup increased with increase in impeller speed. It was also observed that the tiny bubble holdup increased and reached a maximum at lower gas velocities and progressively decreased at higher velocities of gas. It was noticed that the presence of polypropylene glycol increased the gas holdup in carboxy methyl cellulose and the increase in gas holdup was higher at higher gas velocities, whereas, the presence of polypropylene glycol in castor oil decreased the gas holdup and the decrease in gas holdup was higher at lower gas velocities.

Poncin et al. (2002) studied the effect of rotation speed and the submergence depth of impeller on hydrodynamic and mass transfer parameters in a gas-liquid stirred tank provided with a radial gas-inducing turbine. The results indicated that the gas holdup, the rate of gas induction, and the volumetric gas-liquid mass transfer coefficient increased with increase in rotation speed of the impeller and decreased with increase in liquid submergence.

Conway et al. (2002) presented an experimental characterization of vortex-ingesting gas–liquid stirred reactor operated with solid particles. The results showed that the presence of low solids fractions increased the minimum speed required for vortex ingestion of the gas. From the results, it was also noticed that at low impeller speeds and low solid mass fractions, accumulation of particles in the annulus surrounding the draft-tube reduced
the pumping capacity of the impeller, which lead to the decrease in both gas holdup and gas–liquid mass transfer coefficient.

Yawalkar et al. (2002) experimentally determined the gas-liquid mass transfer coefficient in stirred tank reactor. From the results, it was observed that for a given superficial gas velocity and for a given relative dispersion parameter, the gas-liquid mass transfer coefficient was found not to change much considerably, irrespective of the size of the reactor, type and size of the impeller and size and type of the sparger.

Ruthiya et al. (2003) investigated the gas-liquid mass transfer enhancement in a gas inducing stirred slurry reactor by dynamic gas absorption experiments without reaction and pseudo-steady-state gas absorption experiments with reaction. The results exhibited that the enhancement of mass transfer by shuttling of particles between the gas-liquid interface and the bulk liquid was insignificant as it was observed that the enhancement factor decreased with stirring rate and reached a plateau after some critical particle concentration.

Lemoine et al. (2003) predicted the gas-liquid volumetric mass transfer coefficients in surface aeration and gas-inducing reactors using neural networks. From the results, it was observed that the increase in liquid viscosity decreased the mass transfer coefficient in surface-aeration reactors and whereas in gas-inducing reactor, the mass transfer coefficient increased and then decreased with increase in liquid viscosity. It was also observed that the mass transfer coefficient decreased with increase in liquid density in both reactor types and increased with increase in surface tension in surface-aeration reactors but decreased with increase in surface tension in gas-inducing reactor.
Chen et al. (2003) investigated the oxygen dissolution in water in a draft-tube gas-inducing reactor. From the results, it was observed that the rate of mass transfer increased with increase in agitation speed and reached a limiting value, and that was not affected by the oxygen pressure.

Lin & Wang (2003) investigated the industrial wastewater treatment by ozonation in a gas-induced reactor in conjunction with chemical coagulation pretreatment. The results indicated that the COD removal increased with increase in reaction time and increase in input ozone mass flow rate. The results also indicated that the COD removal decreased with number of repeated use of regenerated activated carbon.

Kluytmans et al. (2003) studied mass transfer characteristics in a stirred tank reactor with a flat gas-liquid interface, and in a stirred tank reactor with a gas inducing impeller. From the results, it was noticed that the bubble diameter, gas holdup and the overall mass transfer coefficient increased with increase in superficial gas velocity and gas-liquid interfacial area attained a peak value and decreased with increase in superficial gas velocity.

Moucha et al. (2003) presented the gas hold-up, mixing intensity of dispersion characterized by exchange flows between adjacent impellers and a volumetric mass transfer coefficient for 18 impeller configurations in triple-impeller vessel. Results showed that the gas holdup increased with increase in specific power consumption for the impeller systems studied. It was found that the impeller with low power number had maximum dispersion mixing intensity but the impeller with high power number had high gas-liquid mass transfer. It was also shown that the impeller configuration with higher power number gave the higher mass transfer coefficient at lower impeller speed.

Ma et al. (2003) developed a gas inducing a reactor to improve the efficiency of ozone utilization in water treatment by treating the aqueous
phenol solution using ozone with and without the use of hydrogen peroxide. The results showed that the gas inducing reactor was suitable for efficient utilization of ozone, effective treatment of phenol at all pH values and all initial concentrations of ozone and phenol and the optimum pH for the treatment was found to be 11. It was also observed that at pH 7 and 10, the best molar ratio of hydrogen peroxide to inlet ozone was 20.

Lin & Wang (2003) investigated the treatment of wastewater by ozonation in a surface-aeration gas-inducing impeller with draft tube with a fixed granular activated carbon bed. The results exhibited the combined effect of adsorption, catalytic reaction and ozonation for decomposition of phenol by 99% and reduction of chemical oxygen demand by 87% with an ozone utilization efficiency of 90%.

Dohi et al. (2004) investigated the power consumption and solid suspension performance of large-scale impellers under turbulent conditions using Maxblend and Fullzone impellers with and without aeration. The results indicated that the Maxblend impeller showed better performance for solid suspension compared with the Fullzone and triple impellers. It was inferred from the results that large scale impellers are suitable for solid suspension.

Rishell et al. (2004) carried out experimental work in a membrane aerated reactor and measured the rate of organic carbonaceous pollutant oxidation and volatile organic compound biodegradation. It was found from the results that the choice of operating conditions depended on the membrane characterization.

Jafari & Mohammadzadeh (2004) examined the effects of impeller speed, gas induction, gassing and liquid level on power consumption in a gas-induced contactor. The results showed that at low impeller speeds, power consumption decreased significantly by gassing, while at higher speeds,
because of gas induction, the effect of gassing on power consumption was not considerable. The results also indicated that at liquid levels higher than limiting level, the power consumption remained almost constant.

Patil et al. (2004) studied the effect of liquid submergence on mass transfer coefficient in surface aerators and self-inducing type reactors. The results indicated that for a given value of power consumption per unit volume, the self-inducing impeller was found to have $k_{la}$ values 27% higher than that for surface aeration reactors.

Patil et al. (2005) studied the effects of impeller speed, impeller submergence and gas line resistance on the volumetric flow rate of liquid and the rate of gas induction for a stator-rotor type self-inducing impeller. The results revealed that the ratio of radial liquid velocity to the total velocity of the liquid remained constant for almost all impeller tip speeds.

Kumar et al. (2005) investigated the phenomena of induction of air using ultrasonic horn and measured the gas entrainment rate and gas-liquid mass transfer coefficient for the transfer of air into the system. From the results, it was observed that the entrainment rate of air and the mass transfer coefficient increased with increase in power density in the system. It was noticed that the dissolved oxygen concentration increased with time and then reached a constant value.

Jafari & Mohammadzadeh (2005) studied the effects of sensor location, impeller speed, gas induction, and gassing on mixing time in gas-in-a gas-induced contactor. The results indicated that gas induction and gassing increased the pneumatic mixing and decreased the mechanical mixing but the locations of injection and detection devices had no significant effect on perfect mixing time. From the results, it was also noticed that at a given volumetric power consumption and at low impeller speeds, mixing time did
not differ in gassing and non-gassing conditions but at higher speeds the mixing time in gassing condition was slightly higher than that of non-gassing condition.

Hsu et al. (2005) carried out experiments in order to study the effects of preozonation on the biodegradability of mixed 2-chlorophenol/4-cresol solution in a gas-inducing reactor for high ozone utilization efficiency. From the results, it was observed that the increase in pH increased the decomposition rate of phenolic mixture, chemical oxygen demand removal and total organic carbon removal.

Lemoine & Morsi (2005) developed an empirical model and back-propagation neural network correlations for predicting the hydrodynamic and mass transfer parameters in gas–liquid agitated reactors. The results indicated that the increase in liquid phase viscosity increased the bubble diameter, decreased the gas holdup and decreased the gas-liquid interfacial area.

Girgin et al. (2006) measured the effect of impeller speed on bubble size in a self-aerated laboratory floatation cell. It was found from the results that the bubble size increased with increase in impeller speed because of the increase in gas-induction rate.

Deshmukh et al. (2006) investigated the mechanism of self-induction in hollow pitched blade down-flow turbine impellers. The results showed that the rate of gas induction increased with increase in number of orifices, increase in radial distance of the orifices, increase in blade angle and increase in impeller speed. The results also showed that the liquid side pressure loss increased with impeller speed and rate of gas induction.

Junmei et al. (2006) proposed the mechanism model to describe the mass transfer rate for a gas-liquid-solid system containing fine catalyst
particles and presented the enhancement of gas-liquid mass transfer by heterogeneous chemical reaction near interface. The results showed that the enhancement factor increased with decrease in distance of the particle to the gas-liquid interface.

Deshmukh & Joshi (2006) measured mass transfer coefficient, power number and gas holdup for the surface aeration in three flat-bottomed cylindrical tanks of 0.5, 1.0 and 1.5 m diameter. From the results, it was observed that at a given submergence, the power number was independent of the off bottom clearance and that the power number increased with increase in submergence depth and decreased with increase in rotational speed of the impeller.

Kumaresan & Joshi (2006) studied the effect of impeller blade shape on flow pattern and mixing in stirred tanks. The results showed that the presence of blade twist decreased the power number and flow number. It was also found from the results that the average shear rate, average normal stress, and turbulent kinetic energy were found to be higher for the down flow impellers.

Shewale & Pandit (2006) measured the fractional gas holdup, power consumption and mass transfer coefficient and studied the effect of density and volume of tracer pulse on mixing time for two impeller combinations in the presence of gas in gas-liquid contactor. The results indicated that the effect of solute on fractional gas holdup was mainly due to the property of coalescence and the presence of coalescence inhibiting solutes resulted in an increase in fractional gas holdup.

Jin et al. (2006) investigated the impacts of operating conditions and liquid properties on the hydrodynamic and volumetric mass transfer coefficient in activated sludge air-lift reactor. From the results, it was
observed that the activated sludge exhibited a non-Newtonian rheological behavior. It was found from the results that an increase in superficial gas velocity increased the liquid circulation velocity, gas holdup and mass transfer coefficient increased decreased the residence time.

Murthy et al. (2007) performed experimental fluid dynamics and computational fluid dynamics for hollow self-inducing agitator system. The results showed the existence of low pressure zones at the top of the rear side of the hollow impeller blades. From the results, by experiments and simulations, it was observed that the gas induction rate increased with increase in agitation speed of the impeller.

Gourich et al. (2007) investigated the influence of operating conditions and design parameters on the hydrodynamics and mass transfer properties of an emulsion loop venture reactor. From the results, it was observed that the increase in flow rate of the liquid increased the induced-gas flow rate to a certain maximum level and gradually decreased. It was also noticed that the increase in liquid flow rate increased the mass transfer coefficient.

Scargiali et al. (2007) measured the Power number, gas holdup and mass transfer coefficient of a high aspect ratio self-ingesting reactor for gas-liquid operations. The results indicated that the gas holdup and mass transfer coefficient increased with increase in rotational speed of the impeller and the gas holdup increased with increase in power density.

Azizi & Taweel (2007) simulated the gas-liquid dispersion under turbulent flow conditions. From the results, it was observed that the presence of amphiphilic constituents retarded the coalescence and resulted in higher average interfacial areas.
Cabaret et al. (2008) investigated the mass transfer performance of unbaffled dual impeller mixers with low and high viscosity Newtonian and non-Newtonian liquids. The results revealed that the dual shaft mixer consisting of two off-centered shaft was suitable for Newtonian liquids with large range of viscosity and for gas-liquid dispersion in non-Newtonian liquids, off-centered shaft configurations were not found suitable.

Murthy et al. (2008) carried out experimental and computational studies for hollow self-inducing three-phase stirred tank systems. The results showed that the critical speed for solid suspension increased with increase in average particle size and increase in solid loading. It was observed that the increase in impeller speed uniformly increased the rate of gas induction.

Vesselinov et al. (2008) carried out experimental investigation and numerical analysis of a gas-liquid two-phase flow to a non-baffled stirred tank reactor, mechanically agitated by a gas-inducing turbine. The results indicated that both the flow rate of the gas and the gas holdup increased with increase in impeller speed.

Kasundra et al. (2008) investigated the hydrodynamic and mass transfer characteristics of single and multiple impeller hollow self-inducing reactors using hollow pitched blade down-flow turbine and double-disc impeller. The results showed that the fractional gas holdup increased with the gas induction rate and the increase in average liquid circulation velocity.

Junmei et al. (2008) studied the effect of solid on gas-liquid mass transfer in slurry system accompanied by hydration of isobutene over fine cation exchanger resin in three phase slurry catalytic reactor. From the results, it was noticed that the mass transfer coefficient decreased with increase in size of catalyst particle size and increased with increase in solid volume fraction.
Cooke et al. (2008) carried out experiments to examine the effects of solid concentration and superficial gas velocity on gas holdup in a mechanically agitated vessel with solid-liquid-gas system. The results indicated that the gas holdup increased with increase in superficial gas velocity and decreased with increase in solid particle concentration. It was also observed that the mass transfer coefficient and volumetric gas holdup decreased with increase in volumetric solid holdup.

Montante et al. (2008) investigated the turbulent two-phase flow and the bubble size distribution in aerated stirred vessel by experiments and computational fluid dynamics modeling. From the results, it was observed that the Reynolds averaged Navier-Stokes based approach was found to be suitable for obtaining realistic information on the mean flow field of the two phases.

Fakuda et al. (2009) examined the vapour generation in a boiling stirred tank with electric heater and multiple impeller systems. The results showed that the vapour was generated from the impeller besides the heater at higher impeller speeds in the boiling stirred tank, the mechanical power consumption decreased due to vapour generation, and that the increase in impeller speed resulted in smaller bubbles formed by bubble breakup causing an increase in vapour holdup.

Kielbus-Rapala & Karcz (2009) investigated the effect of presence and concentration of solid particles on the gas-liquid volumetric mass transfer coefficient in a mechanically agitated gas-liquid-solid system. The results indicated that the presence of solid particles at lower concentrations increased the mass transfer coefficients but decreased at higher concentrations.

Ju et al. (2009) demonstrated the hydrodynamics of air inducing impeller using horizontal tubes attached to the hollow vertical shaft of the
impeller and analyzed the factors affecting the critical impeller speed for gas induction. From the results, it was observed that an increase in impeller speed increased the rate of gas induction and hence the gas holdup and an increase in liquid level increased the critical speed for gas induction.

Chakraborty et al. (2009) investigated the hydrodynamics of the down flow of high pressure water jets. The results showed that the ceramic type of sparger had better gas holdup compared with the spargers made of metal, brick and polymeric materials. The results also showed that the gas holdup with the addition of frother was 70% and that without the addition of frother was only 20%.

Nevares et al. (2010) quantified the gradients of dissolved oxygen in 15% hydroalcoholic solution during the micro-oxygenation process. The results showed the existence of gradients in dissolved oxygen concentrations within the tank up to 0.5 mg/L and the gradients were more when oxygen dosage was lower.

Rapala & Karcz (2010) evaluated the superficial gas velocity and solids concentration on the critical agitator speed, gas holdup and average residence time of gas bubbles in stirred gas-liquid-solid system. From the results, it was noticed that the increase in superficial gas velocity caused a significant increase in gas holdup in both coalescing and non-coalescing three-phase systems.

Linga et al. (2010) demonstrated the capture of carbon dioxide via hydrate crystallization using a modular mechanically agitated gas-inducing crystallizer. From the results, it was noticed that the crystallizer enhanced the contact of hydrate forming gases with water and increased the rate of hydrate crystallization.
Ferreira et al. (2010) experimentally evaluated the effects of size and density of the solid particles and temperature on gas-liquid mass transfer characteristics in a bubble column. The results indicated that the mass transfer coefficient increased with increase in temperature and in addition, for the same particle size of polyvinyl chloride and expandable polystyrene, the mass transfer coefficient decreased with increase in solid loading.

Rapala et al. (2011) studied the effect of physical properties of liquid phase on the volumetric gas-liquid mass transfer coefficient in mechanically gas-liquid and gas-liquid-solid systems. The results showed that the mass transfer coefficient increased with increase in electrolyte concentration at lower concentrations but continuous increase in electrolyte concentration lead to a decrease in mass transfer coefficient.

Abdullah et al. (2011) made tomographic analysis for hydrodynamic study of the gas–liquid–solid mixing in a stirred-tank equipped with a 4-blade gas-entrainment impeller to obtain the dispersed phase hold-up distribution as a function of stirring speed and solid particle loading. The results showed that the solid holdup increased with increase in agitation speed of the impeller and with the increase in radial position.

Achouri et al. (2012) simulated the fluid flow characteristics of a stirred tank with a self-inducing 45º and 60º pitched blade download turbines for an impeller speed of 480 rpm. The results showed the existence of low pressure regions on the upper part of the rear face of the impeller blades. The results also indicated that the air inducing performance of the pitched blade with 60 º was better than that with 45º despite its higher power requirement.

Souidi et al. (2012) studied the effect of impeller configurations on gas dispersion in agitated column with narrow annular gap equipped with right-angle cross paddle impellers. The results revealed that the impeller
configuration did not affect the mean diameter of the bubble and the bubble mean diameter decreased from 19 µm to 15 µm when the impeller speed increased from 200 rpm to 1600 rpm for all the impeller configurations studied.

Jafari et al. (2012) described the limitations of applying conventional measurement techniques for the accurate characterization of critical impeller speed for just off-bottom suspension at high solid concentrations using gamma-ray densitometry. From the results it was noticed that at low clearance, both axial and radial flow impellers were efficient in particle suspension and for a given clearance both impellers had different patterns for solid suspension. It was also noticed that there existed a critical off-bottom clearance that changed the pattern of the axial flow impeller.

Sivaiah et al. (2012) studied the effects of slurry liquid jet velocity, separator pressure, gas velocity and the concentration of solid on gas entrainment rate and gas holdup in a modified down-flow slurry liquid jet three-phase contactor. The results indicated that the entrainment ratio increased with increase in jet velocity but decreased with increase in solid concentration in slurry.

Cheng et al. (2012) presented the effects of tracer injection position, impeller speed, impeller type, off-bottom clearance of the impeller, volume fraction of the oil and physical properties of the dispersed phase on mixing time of continuous phase and power consumption of gas-liquid-liquid dispersions in a baffled mechanically agitated vessel. The results indicated that the axial impellers are more suitable for energy efficient macro-mixing of gas-liquid-liquid systems than radial impellers. For systems both with and without aeration, the results exhibited that the power consumption decreased with increase in dispersed oil phase volume fraction and decreased further with increase in flow rate of air.
Song et al. (2012) developed a planar optode system based on oxygen quenchable luminophore platinum (II) octaethyporphrin bound with thin polystyrene film and ultra violet light emitting diodes to measure the dissolved oxygen concentration field in micro scale water flows. From the results, it was observed that the dissolved oxygen concentration increased with increase in Reynolds number and the peak value of dissolved oxygen was found at two nozzle diameters away from the impinging point.

Agrawal (2013) presented literature survey on bubble dynamics and interface phenomenon. The review results showed that the addition of electrolyte to water decreased the bubble diameter 10 times, increased the interfacial area, increased the residence time of each bubble and increased the mass transfer coefficient. The results also showed that the size of the bubble decreased with increase in density of the gas.

Achouri et al. (2013) determined the oxygenation capacity of a holed hollow cinder self-inducing turbine with six holes of 0.5 cm diameter each. The results showed that the aeration capacity increased with increase in agitation speed of the impeller and decreased with increase in impeller submergence depth.

Wang et al. (2013) 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.

Sanza et al. (2014) evaluated the effects of presence of ethanol, sugar and phenols on dissolved oxygen measurements in a model and real
wine. The results suggested that significant errors were made for all the systems studied and responses were different for each system and hence a compensation value was developed to take into account the composition of the sample.

Hong et al. (2014) 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. The results also revealed that the rate limiting step in yeast fermentation was the transient local distribution of the rate of oxygen variation.

Yang et al. (2015) compared the flow pattern, gas holdup, dissolved oxygen and power consumption for standard Rushton turbine and dislocated-blade Rushton impellers. From the results, it was noticed that 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.

Ye et al. (2015) described the principles, design and characteristics of self-inducing reactors and the applications in the field of biotechnology. The results 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.
Zhang et al. (2015) studied the effects of five triple-impeller combinations on the gassed power consumption and volumetric mass transfer coefficient in a baffled agitated vessel using six types of impellers, viz., (i) six-half-elliptical-blade disk turbine, (ii) four-wide-blade hydrofoil impeller pumping down, (iii) four-wide-blade hydrofoil impeller pumping up (iv) parabolic-blade disk turbine and (v) CBY narrow blade and (vi) CBY wide blade. The results described that the power consumption for six-half-elliptical-blade disk turbine + 2 four-wide-blade hydrofoil impeller pumping up combination was higher than that of other four combinations of impellers for all the operating conditions taken for the study. From the results, it was noticed that the impeller combination had no effect at lower superficial gas velocities but at higher velocities parabolic-blade disk turbine + 2 four-wide-blade hydrofoil impeller pumping down showed the highest mass transfer performance and the six-half-elliptical-blade disk turbine + 2 four-wide-blade hydrofoil impeller pumping up showed the lowest mass transfer performance for all the operating conditions.

Tang et al. (2015) 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. From the results, it was observed 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 (2016) studied the interaction between the vortex core of swirling water flows and rising air bubbles in a cylindrical tank. The results indicated 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.
2.1 CONCLUSIONS FROM THE LITERATURE REVIEW

The following are the major conclusions made from the review of literature:

- Aeration is one of the indispensable processes that entails more power consumption and hence it is essential to make necessary attempts to minimize the power consumption for the aeration process without compromising the objectives of aeration process.

- When the per-pass conversion of a gas in a mechanically agitated contactor is low, recirculation of the gas is required to ensure the effective utilization of the gas. In this regard, the use of self-inducing reactor is a better alternative for both increasing the utilization of the gas and minimizing the power required for distribution of gas into the liquid.

- Though the self-inducing reactors are of many types, they can be grouped into two categories viz., stator-rotor type or draft-tube type and hollow impeller type. However, the inherent complications in the fabrication of self-inducing impellers must be addressed to.

- The air inducing impellers that are easy to fabricate are more attractive when compared with the impellers that involve complications in design and fabrication. Moreover no self-inducing impeller found in the literature cannot convert an existing agitated vessel into self-inducing reactor.

- It is important to find a technique that when adopted can convert the existing conventional agitated vessels into self-inducing reactors without any considerable major modifications.
• Very few authors investigated the suspension of solid particles using self-inducing impellers (Saravanan et al, 1994; Aldrich & Deventer, 1994; Conway et al, 2002; Ruthiya et al, 2003; Murthy et al, 2008).

• Water is the working fluid used for studying the performance of self-inducing impeller and only few investigators studied the effects of properties of working fluid on hydrodynamic characteristics of (Albal, 1983; Sedahmed et al, 1998; Jin et al, 2006; Rapala et al, 2011; Cheng et al, 2012) self-inducing impellers.

• Only few investigators studied the effect of density of the working fluid on gas induction performance of the self-inducing reactors (Sawant & Joshi, 1979; Lemoine et al, 2003). Hence the hydrodynamic performance of self-inducing impeller must be studied for a wide range of liquid phase density.

The problem definition, objectives and salient features of the present work are presented in the next chapter (Chapter 3).