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Electrical resistance tomography for gas holdup in a gas-liquid stirred tank reactor

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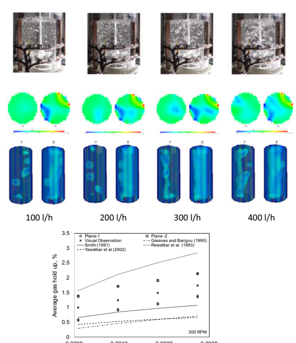
HIGHLIGHTS

- Objective of present work is to quantify the gas hold up using ERT.
- To establish operating protocols of ERT for gas-liquid stirred tank.
- Develop suitable data processing methodologies & establish guidelines of ERT.
- Quantitative analysis of ε & compare it with reported correlations.

GRAPHICAL ABSTRACT



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ABSTRACT

Gas-Liquid flows in stirred tank reactors (STR) are used in many significant industrial operations such as hydrogenation, absorption, stripping, oxidation, hydrogenation, ozonation, chlorination, fermentation, etc. Gas-Liquid STRs are expected to perform several functions such as mixing, dispersing gas into liquid, mass and heat transfer and reactions. Gas hold up distribution and various flow regimes are the key parameters affecting performance of gas-liquid STRs. Various techniques such as visual analysis, photography, light attenuation, optical probe method are used to understand gas hold-up distribution within stirred tanks. Most of these techniques have some limitations with respect to measurement of gas hold up distribution. Electrical Resistance Tomography (ERT) is an upcoming technique for obtaining both qualitative and quantitative data on multiphase process units non-invasively and non-intrusively. In this work, an attempt was made to establish and validate the ERT technique for characterizing gas-liquid flows in a laboratory scale STR using the Rushton turbine impeller. ERT was used to study gas holdup and to identify flow regimes. The results were compared with the visual measurements as well as previously published correlations. The effect of gas flow rate, impeller speed on the mean gas holdup is discussed. The methodology and results presented in this work will be useful to effectively apply ERT for characterizing gas-liquid flows in stirred tanks.

1. Introduction

Gas-Liquid flows in stirred tank reactors (STR) have many industrial applications such as absorption, stripping, oxidation, hydrogenation, ozonation, chlorination, and fermentation. STRs

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Nomenclature

A	cross sectional area of the tank (m^2)
D	impeller diameter (m)
D_P	6-pitched blade turbine diameter (m)
D_R	Rushton turbine diameter (m)
Fl	Flow number
Fr	Froude number
g	gravity of earth (9.8 m^2/s)
H	height of the liquid (m)
H_o	height of liquid when ungassed (m)
H'	is the test statistic
H_g	height of liquid when gassed (m)
N	impeller speed (rpm)
N_p	power number
N_{CD}	critical impeller speed for gas dispersion (rpm)
P	power (W)
Q	gas flowrate (LPH)
Re	Reynolds number
T	tank diameter (m)
V	volume of the tank (m^3)
vvm	volume of gas sparged per unit volume of the liquid per minute
Z	is the HIT statistic

Greek letters

ε_M	Maxwell's equation for gas holdup
ε_v	gas holdup value through volume expansion method
υ_s	superficial velocity (m/s)
μ	viscosity of fluid (Pa s)
ρ	density of the fluid (kg/m^3)
σ_{mc}	reconstructed measured conductivity from ERT (mS/m)
σ_1	conductivity of the continuous phase (mS/m)
σ_2	conductivity of the dispersed phase (mS/m)
r_j	is the rank of pixel j
K_i	is the *it* he zone,
n_i	is the number of pixels in the *i*th zone

are mostly used for mixing, effectively dispersing dispersed phase into continuous phase, realizing desired mass and heat transfer for carrying out various industrially relevant transformations. Despite the widespread use of stirred vessels, variations in design, operational protocols and complexities of multiphase system always pose challenges for improving reactor performance.

Gas holdup and flow regimes are key parameters for performance estimation and scaling up of reactors. Gas-Holdup or void fraction is defined as the volume occupied by gas bubbles as a fraction of the clear liquid volume and is one of the measures of the efficiency of gas-liquid contacting. It is one of the most important characteristics needed to understand; design and model gas-liquid flows for allowing rational design and scale up of the reactors (Dong et al., 2003, 2012; Paglianti et al., 2000). Therefore, it is an important parameter studied widely by many researchers (Dong et al., 2012; Dave et al., 2009; Jin et al., 2013; Karimi et al., 2013a,b) (see Tables 1a and 1b).

Concerning the measurement of gas-liquid flows in stirred tank reactor; various techniques have been used in the past (see Table 2) such as visual analysis, photography, light attenuation, and optical probe methods. However to understand the dynamics of the process it is very imperative to have the capacity to visualize inside the process. In process industries, most of the systems are opaque systems which eliminate the usefulness of many techniques in the real investigations. According to the industrial application, it is very important to have a measuring technique that can give the information of the process without disturbing the flow. Electrical resistance tomography (ERT) is one such technique gaining the popularity in this domain due to its unmatched potential of providing both qualitative and quantitative information on the internal investigated space and behavior of process flows without causing any disturbance.

Recently our group has demonstrated the applicability of ERT technique for liquid phase mixing in solid-liquid stirred tank

Table 1a
Literature review on gas holdup determination by different techniques.

Reference	Design conditions	Sparger and baffles	Impeller	Operating conditions	Technique	Studied parameters	Remarks
Mueller and Dudukovic (2010)	T – 0.20 m C/T – 0.33 D/T – 0.33 H/T – 1	Ring Baffles - 2	6RT	N- 350–750 rpm Q- 264–750 L/h Air-Water	Optical probe	Gas holdup	Lack of quantitative information/data
Lee and Dudukovic (2014b)	T – 0.20 m C/T – 0.33 D/T – 0.33 H/T – 1	Ring Baffles - 4	6RT	N- 126–830 rpm Q- 58–850 L/h Air-Water	Optical probe	Gas holdup & Bubble count at different locations	Identification of regimes
Saravanan et al. (2009)	T – 0.45 m C/T – 0.33 D/T – 0.33 H/T – 2	Ring Baffles - 4	PTD, PTU, DT	N- 150–1200 rpm Q- 2880–5760 L/h Air-Water	Visual method	Effect of C/T, inter-impeller clearance and surface tension on ε_g for the optimum C/T	Bottom clearance of T/3 gave the maximum gas holdup
Takriff et al. (2013)	T – 0.40 m C/T – 0.33 D/T – 0.33 H/T – 1.4	Nozzle Sparger Baffles - 4	RT, Lightnin A320	N- 0–400 rpm Q- 120–480 L/h Air-Water	ERT	Gas Holdup and Mass transfer coefficient were measured for different impellers	ERT used to determine the optimum conditions for gas-liquid mixing
Yawalkar et al. (2002)	T – 0.57 m C/T – 0.33 D/T – 0.33, 0.5H/T – 1	Perforated Pipe Baffles - 4	DT, PTD	N- 108–1080 rpm Air-Water	Visual method	Gas Holdup	ε_g depends on various correlations Difficult to predict