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Void fraction of supersonic steam jet in subcooled water

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ABSTRACT

For most operations in process, petroleum and power industries gas-liquid two phase flows occurs, so an accurate estimation of void fraction is vital because it affects the calculations of heat and mass transfer as well as hydrodynamics. Any inaccuracy in estimation may lead to drastic incidents along with heavy monetary loss. An effort has been made here to estimate the approximate void fraction of supersonic steam jet into the sub-cooled water. Electrical Resistance Tomography (ERT) has been used for the purpose along with the Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software (EIDORS) to generate the conductivity scans obtained by ERT setup. Before the experimentation, for further assurance on our void fraction estimations, the measurement system has been calibrated by securing scans of heated Teflon rod of diameter 6 mm, which is approximately having the same cross-sectional surface area as the steam jet have and reported in previous studies at the same hydrodynamic conditions. Images of supersonic steam jet in subcooled water have been processed by the help of EIDORS and image processing technique. The over estimation in void fraction of Teflon rod is ranging from 46.17 to 83.44% and when it is subtracted from the total void fraction of supersonic steam jet (46.51–83.79%) at steam inlet pressure of 1.5–3.0 bar and surrounding water temperature 30–60 °C respectively, the actual void fraction of Teflon rod comes out to be ranging from 0.34% to 0.35% of the total cross-sectional area of vessel. When these results are compared with the previous studies, a close agreement has been observed between these two sets of results.

1. Introduction

An insight into a process reactor to yield accurate measurement of what is occurring in a vessel is vital for process intensification. The journey of mind storming and intense experimentation for around three and half decades has given birth to a relatively new class of non-invasive measurement technique that is called tomography. It has got birth some 35 years ago but for the level of maturity that it attains now, it has gone through rigorous tests and measurements since then. Yet obviously as its name implies i.e. "tomo" means slice and "graph" means image, its name is the true reflector of the way that it is functioning. This technique finds its use in the application areas wherever two or more phases interact with each other. These types of interactions mostly prevail in the process, nuclear and petroleum industries but with a fact that these industries do not cover the whole canvas, there are myriad other industries that have encountered or have to deal with these interactions. Out of these, the two phase flows that involve conversion of one phase into the other phase via mass, energy and momentum transfer are such that prevail mostly in the steam driven power industries. It is important to have in depth knowledge of the salient process parameters, which influence strongly on various operations such as transportation of the liquids or gases or mixtures of both of them in the pipelines, estimation of the storage capacity in the tanks during filling or evacuation, calibration of the meters or controlled transfer of fluids etc., All these need the accurate knowledge of the insight of the vessels where two-phase phenomena takes place and a single most important

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Nomenclature

Abbreviation Definition

EIDORS: Electrical Impedance Tomography Reconstruction Software (EIDORS) is an open-source software tool box written mainly in MATLAB/GNU Octave designed primarily for image reconstruction from electrical impedance tomography (EIT) data, in a biomedical, industrial or geophysical setting. While the name reflects the original intention to cover image reconstruction of data from the mathematically similar near infra-red diffuse optical imaging. It is available freely online at the address: http://eidors3d.sourceforge.net/

Electric Resistance Tomography: Electrical resistivity tomography (ERT) or electrical resistivity imaging (ERI) is a technique for imaging sub-surface structures from electrical resistivity measurements made at the surface, or by electrodes in one or more boreholes. If the electrodes are suspended in the boreholes, deeper sections can be investigated. It is closely related to the medical imaging technique electrical impedance tomography (EIT), and mathematically is the same inverse problem. ERT is essentially a direct current method.

P2000 ERT system The P2000 ERT system has been manufactured by ITOMS® (http://www.itoms.com/) which is a British based company.

Void fraction In gas–liquid two-phase flow, the void fraction is defined as the fraction of the flow-channel volume that is occupied by the gas phase as the fraction of the cross-sectional area of the channel that is occupied by the liquid phase. Here it is a ratio between the numbers of white to number of black pixels.

"imread" function "Imread" function is used in Matlab and its main use is for calculating the number of pixels in the grey scale i.e. white and black.

Approximate void fraction Approximate void fraction has been calculated for the supersonic steam jet and it has been termed as approximated due to the very fluctuating nature of interface and the ill-posed nature of the problem of ERT. So due to these two reasons as exact void fraction cannot be calculated by the present arrangements so we calculate approximate void fraction.

Conductivity scans A distribution of the electrical conductivity in a cross-section of the vessel based on the voltage measurements from electrodes is called conductivity scan.

Governing equation for ERT The mathematical equations that govern the working principles of ERT is given by Kirchhoff's law, as the total electric current in a closed volume is zero, so; $\nabla.(\sigma.\nabla u)=0$; where σ is conductivity (Siemens-S) and u is electric potential (Volts-V). So by expanding the gradients, we get, $\frac{\partial}{\partial x_1}\left(\sigma\frac{\partial u}{\partial x_1}\right)+\frac{\partial}{\partial x_2}\left(\sigma\frac{\partial u}{\partial x_2}\right)+\frac{\partial}{\partial x_3}\left(\sigma\frac{\partial u}{\partial x_3}\right)=0$

Total void fraction In case of calibration tests: void fraction of Teflon rod (actual)+void fraction measured from ERT (over-estimated); in case of experimental tests: void fraction of supersonic steam jet (actual)+void fraction measured from ERT (over-estimated)

Actual void fraction The void fraction of supersonic steam jet or Teflon rod without over estimation.

parameter that furnishes the information up to the level of satisfaction to all the hands and minds in action at the site is the "Void Fraction". It is worthy to mention that any inaccuracy in the measurement may lead to the devastating consequences along with the loss of revenue but we should not keep our sight apart from this very fact that where accurate measurement saves our valuable revenue, the establishment of such a setup and its maintenance also demands sacks of coins. In addition to it for the accurate measurements if we totally rely on the invasive techniques, then we have to have born to the disturbances in the flow regimes caused by the usage of these techniques. Despite the usefulness of the void fraction as being a major influential parameter, it also its self depends on a number of parameters that include flow rates of interacting fluids, thermodynamics, pressure and geometry of the confinement etc. We are fully aware of the fact that as the title claims, the present manuscript will acquaint the readers with one of the effort in which a parameter i.e. void fraction has been estimated, but its estimation could only be possible after certain compromises has been made during the study.

The present study focuses on the estimation of the void fraction of supersonic steam jet in subcooled water in which we only consider the aspect of variation of the electrical conductivity due to the change in the temperature. Yet as the word "subcooled" emphasis, a very serious effort has been made to keep the temperature uniform inside the vessel at least for the interval of time during which the industrial tomography system has been used to capture the scan of the fluids inside the vessel at the height of the electrode enclosure. For this a temperature controlling system is developed which is comprised of an 89C51 micro-controller [1] which has been used along with three LM35 temperature sensors [2] mounted at the inside of the walls of the vessel at three different positions i.e. top, middle and bottom of the wall. All these three LM35 temperature sensors have been triggered at the rate of 1 second and then the temperature measured from them has been feed into the micro-controller which (on the basis of pre-coded command) compares the average value of these three temperature sensors with the one the user feed manually through user interface. If the average value is higher than the value feed by the user, the micro-controller start injecting the water inside the vessel but as soon as the average value of temperature measured through these three temperature sensors goes below the user feed value, it will stop injecting water inside it. The other factors like mass transfer or momentum transfer have yet been intrinsically incorporated into the phenomenon but here only the change in electrical conductivity due to variation in temperature of surrounding water has been considered. The use of the electric resistance tomography is evident in some recent studies that include its use in the managed pressure drilling applications [3] and slug flow characterization in gas liquid flows [4]. Electric Resistance Tomography (ERT) is a kind of technique in which information regarding the flow regimes inside multiphase flow reactors is captured by using the in-situ gradient of the electric conductivities [5]. So far as its capability is concerned regarding its use as a technique for multiphase flow diagnostics, this technique is suited well for the cases where the continuous phase is conductive or in general there is a gradient of conductivities exists between the interacting fluids that exist in different phases. In the cases where the continuous phase exists in the liquid form and the dispersed phase exists in the vapor form, the void fraction is a quantity that