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Application of Electrical Capacitance Tomography System for Non-Invasive Phases Distribution Detection in Gas-Liquid Mixtures

1. Introduction

The qualitative and quantitative estimation of the distribution of phases in gas-liquid or gas-solid particles mixtures is necessary to describe the flow or mixing processes of this type of mixture. It also gives a possibility to understand the relations describing heat and mass transfer in two-phase mixtures. Knowledge of the distribution parameters such as volume fractions of particular phases and the structure of each phase (image of the structure and flow character) allows for an appropriate construction of industrial installations. It is also of some assistance to choose the optimal parameters for conducting the processes in which we deal with the two-phase flow. The possibility of pinpointing the exact numerical value of these parameters during the process would make it possible to regulate it as it happens. This, in turn, would make the process most efficient and free of risk caused by exceeding the acceptable parameters.

Describing the distribution of the phases is, in many cases, impeded and a number of measurement methods which deliver error-prone results are used. These methods do not allow for modelling of the phenomenon in 3-D.

The aim of this paper is to show the capabilities of the Electrical Capacitance Tomography (ECT) system as a technique for real-time three-dimensional examination of the parameters of the two phase flow structure. The main advantages of the ECT method over other techniques is a fact that this is a non-invasive, non-intrusive and, in addition, a very fast technique for investigation of the distribution of any dielectric materials. The ECT image provides the information about the flow fraction profile. Due to the high speed of ECT measurements it is possible to find out flow velocity and the phase distribution of the flow.

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Some preliminary experiments were carried out. For this propose a half-industrial two-phase flow experimental set-up was build. This set-up consists of three different diameters of the pipes laid horizontally and vertically as well. Nowadays the ECT system was applied only for one section.

2. The gas-liquid flows

The quantities which determine the phenomena occurring in the course of two-phase flow of gas-liquid mixtures are connected with the parameters characterizing the distribution of both phases. It is essential to mention here the degree of gas hold-up and also the parameters characterizing the repeatability of formation of the defined structures of two-phase flow to which one may account, for instance, the length or volumes of selected gas bubbles or liquid slugs in a slug flow.

The estimation of the quantities characterising two-phase flow is possible only on the basis of the measurements performed which will allow to determine the parameters with the accuracy required. The difficulty in measurements of two-phase flow parameters stems from the stochastic character of this phenomenon. In the course of two-phase gas-liquid mixture flow one may observe a number of flow types. Some of them are of the character established from the point of view of the location of the interface (e.g. the layer flow in a horizontal tube). It must be added that there occur such types of flow which display certain stability and repeatability of generated structures (slug or annular flow). Nevertheless, this stability may be disturbed randomly. On the other hand, other types of flow are characterized by an incessant variability of shapes forming the gaseous structures (froth flow).

In the vast majority of cases the presence of each phase in a chosen cross-section or in a chosen unit volume is prone to incessant changes. The quantity and shape of the interface alters incessantly thereby impeding the measurements of a number of parameters, Additionally, each interference originating from the application of measurement probes located inside the flowing mixture evokes disturbances which may contribute to significant errors.

Those phenomena bring about the fact that the best methods for measurements of two--phase mixture flow parameters are non-invasive methods. It must be mentioned that a number of methods (Ulbrich, 11 ASME) [10] based on photographing or filming of the chosen area and, next, analyzing the pictures obtained by means of the specialist computer programmers is widely applied. The insufficiency of those methods is the lack of possibility to obtain the information concerning the whole visualized area of the flowing mixture – in the case where some objects cover the other ones. What is more, the electrical methods which serve for the application of probes functioning on the basis of resistance measurement or the electrical capacity are also applied. In both cases it is feasible to construct such measurement probes so that they do not disturb the flow. Nonetheless, the application of point probes acting in accordance with that principle does not give the possibility of the analysis of the whole elementary volume in which the measurements are performed. On the other hand, the application of volume probes of this type gives only the averaged result. The same drawbacks may be ascribed to the radiation methods which are used in the course of two-phase flows. Those methods are based on the measurement of suppression of radiation permeating through the two-phase mixture.

The best tools to evaluate the parameters of two-phase flow seems to be the non-invasive methods acting in a dynamic way which allow the assessment of the shapes generated and susceptible to rapid changes of the flow structures. Among such methods the application of process tomography seems to be the most useful.

The applied modules of analysis and processing of the measured data allow to obtain the information concerning the state of the process which are, subsequently, conveyed in the form of the entry parameters to the automatic systems controlling the functioning and efficiency of the industrial process. The development of this type of the systems aimed at the automatic control is the object of the research of the team of scientists from the Computer Engineering Department, Technical University of Lodz who investigate the process tomography and who cooperate with the Chemical Engineering Department, Technical University of Lodz.

3. The research facility

The research facility of the semi-industrial character (see Fig. 1) aimed at the measurement of two-phase flow of gas-liquid mixtures has been designed and constructed. This installation allows to carry out the measurements both in the horizontal and the vertical geometry. The operation of this installation is controlled by the computer system.

a) b)

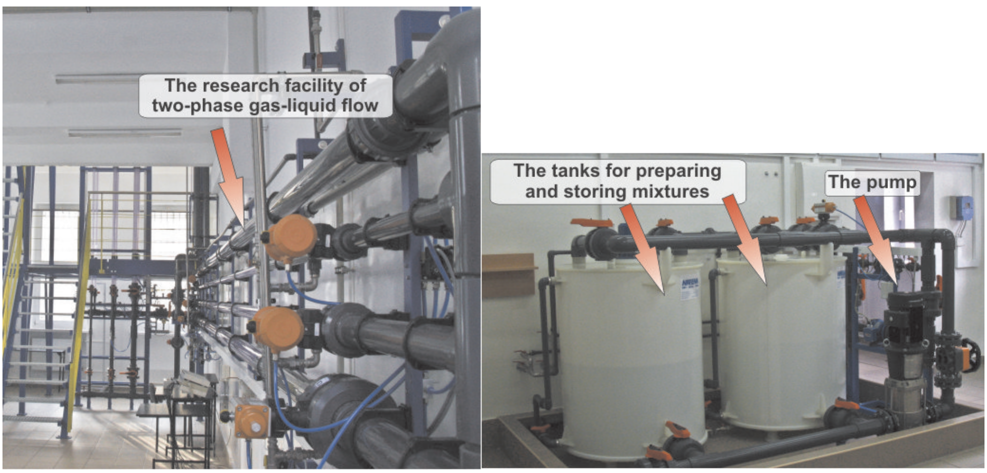

Fig. 1. The general view of the measurement part of the research facility (a); Set of tanks with a pump which supplies liquid to the installation (b)

Both horizontal and vertical part of the installation are equipped with the measurement pipeline of three different internal parameters – 34, 53.6 and 81.4 mm which enables to carry out the process of two-phase flow in a different scale. The lengths of the measurement section segments of the horizontal pipelines are equal to 7.5 mm whereas the lengths of the measurement sections segments of the vertical pipelines are composed of transparent segments. This fact allows to observe visually the structures of flow forming inside which enables their photographing or filming. The latter option is very relevant from the point of view of further research connected with the application of CCD cameras. The pipelines are constructed from pipes made of polyvinyl chloride and are equipped with fittings made of the same material.

The fact that the pipelines are supplied with the investigated liquid ensures the system of devices which are composed of storage tanks and a multi-stage impeller pump. In one of the tanks a propeller mixer is installed. This enables to prepare the investigated liquids which may constitute water solutions of substances. The accurate determination of the volumetric flowrate of the liquid pumped into the pipelines under scrutiny is made possible by the electromagnetic flowmeters. The impeller pump allows to supply the liquid with the volumetric flux equal to 50 m^3/h to the installation. The application of a screw compressor allows to obtain the volumetric stream of the air of pressure 7 bar, equal to 1000 l/min. Obtaining the aforementioned volumetric gas and liquid stream enables to observe all types of two-phase flow occurring under the industrial conditions – starting with bubble flow and ending with annular flow. In the Figure 2 the front and top schematic views of the facility are shown.

The measurement segments of pipelines are equipped with rapid, pneumatic valves electrically controlled and installed at the beginning and at the end of each of those segments. Those valves closing simultaneously allow to close the portion of the two-phase mixture in the test section of the pipeline. This in turn enables to estimate the shares of the selected components (phase shares). The volumetric share of the selected phases may be evaluated measuring the volume of the liquid phase in the closed measurement section of the vertical pipeline or determining the volume of the liquid indispensable to force out the gas phase from the measurement section of the horizontal pipeline. Pressure losses in the course of two-phase mixture flow are measured using the electronic manometers installed.

4. The ECT system

The electrical capacitance tomography (ECT) became a very useful technique for any industrial and biomedical applications as a non-invasive tool for monitoring the dynamic processes. The aim of this technique is to visualize the phase distribution of the dielectric materials. The concept of ECT involves mounting a number of electrodes around the object to be measured. Then, in the first step, the electrical capacitances between various pairs of electrodes are measured. Thus, a set of independent integral measurement values is obtained. In the second step the distribution of the electrical permittivity is mathematically reconstructed from the capacitance measurements.

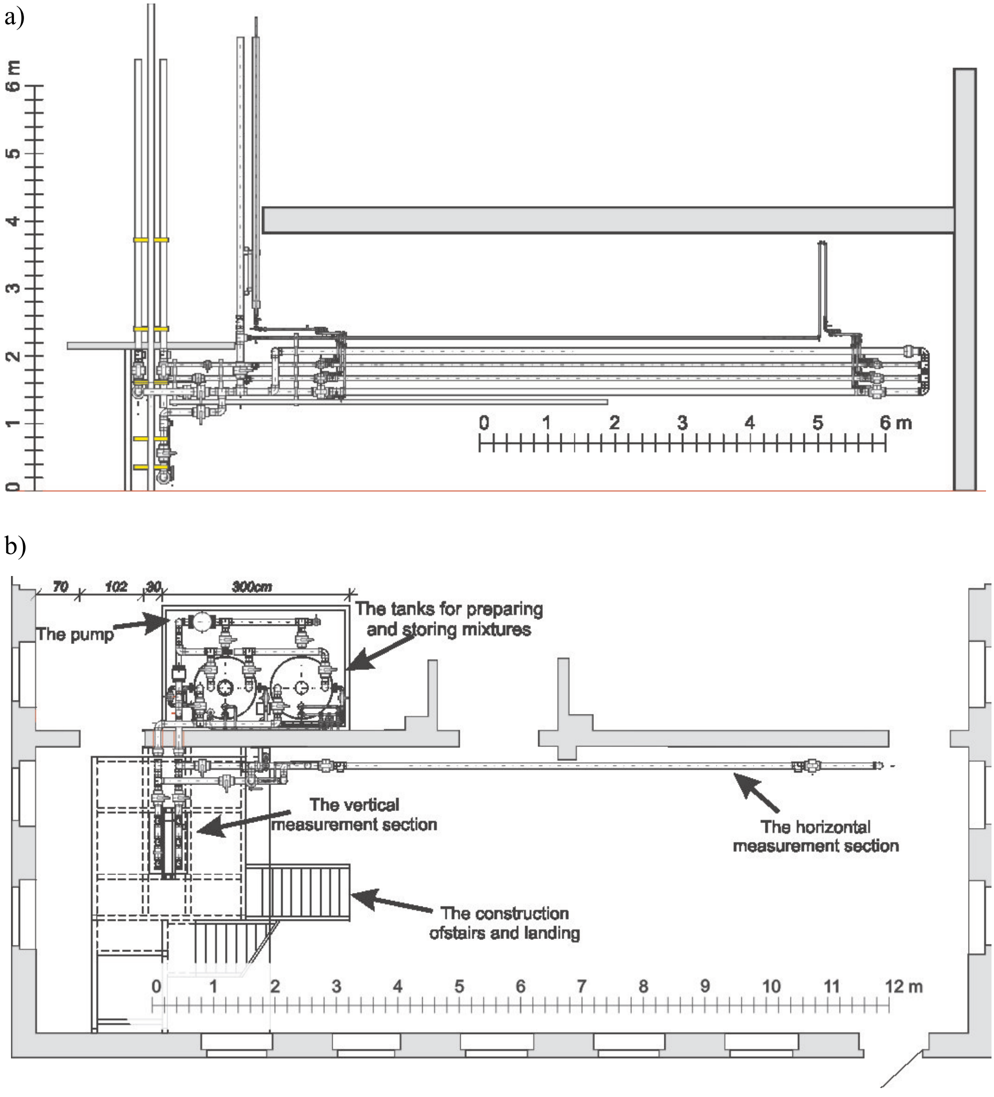

Fig. 2. The schematic view of the research facility for gas-liquid flow investigation: a) the side view; b) the top view

The hardware of capacitance tomography for flows applications consists of one or two sensors with usually 8, 12 or 16 electrodes, one or more electronic devices for the measurement of capacitances and a computer which controls the measurement, stores the acquired data and reconstructs images from the integral measurements. The sensor consists of copper electrodes, which are mounted around the circumference of a PVC (polyvinyl chloride) tube. The PVC tube is arranged between the electrodes and the measurement area.

Thus a real non-invasive measurement is ensured, because there is no mechanical interaction between the fluid in the measurement plane and the electrodes. In Figure 3 the picture of the ECT sensor with the view on its electrodes layout and the ECT measuring unit are shown.

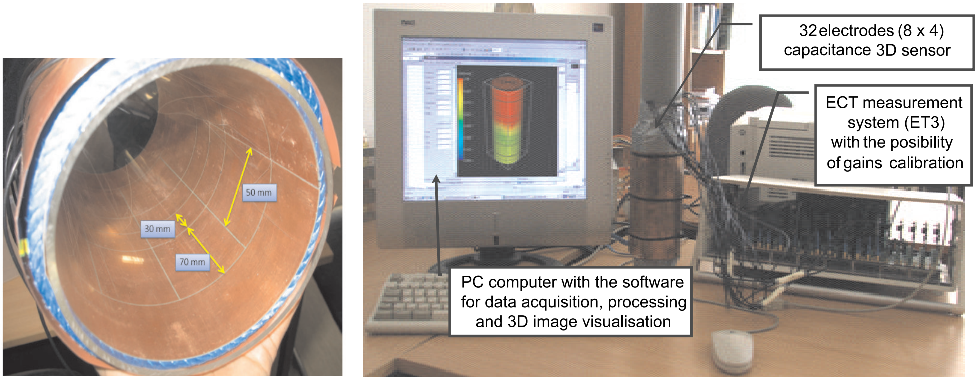

Fig. 3. The picture of 3D ECT sensor with the view on its electrodes layout and the ECT system

The measurement concept of capacitance tomography is as follows: One electrode is switched on as the sender or the source electrode and all the other electrodes are chosen to be the receivers electrodes. The receiver electrodes can be grounded or floated. This depends on the feature of the measuring unit.

After measuring all of the capacitances the field of permittivity inside the sensor has to be mathematically reconstructed. The reconstruction process has to invert the measurement one. This is not possible directly, due to the non-linearity of the Poisson equation for the electric field with respect to the permittivity. However, it is possible to mathematically describe the measurement.

Hence, a forward calculation from the permittivity to get the measurements is possible. Such a forward calculation can be used for an iterative reconstruction algorithm [8].

On Figure 4 the screen of application TomoKISStudio can be seen. This software is dedicated for tomographic data retrieving and processing as well as for 3D image reconstruction, processing and visualization. Thanks to this it is possible to do the 3D ECT data analysis in the real time.

5. The ECT data analysis

The application of ECT system for non-invasive phases distribution detection in gas-liquid mixtures will meet the following requirements:

– the quantitative measurement of characteristic parameters of the process like flow velocity or phase distribution,

– the on-line monitoring of the flow regime behavior for avoiding any critical events,
– the on-line control of the process as a feedback according to the measurement data.

The tomographic data analysis methods applied to ECT can be developed in three categories [1, 5, 7, 9]:

– raw measurement data or processing of tomographic image sequence in order to gather information about the examined process;
– 2D or 3D visualization and image analysis.

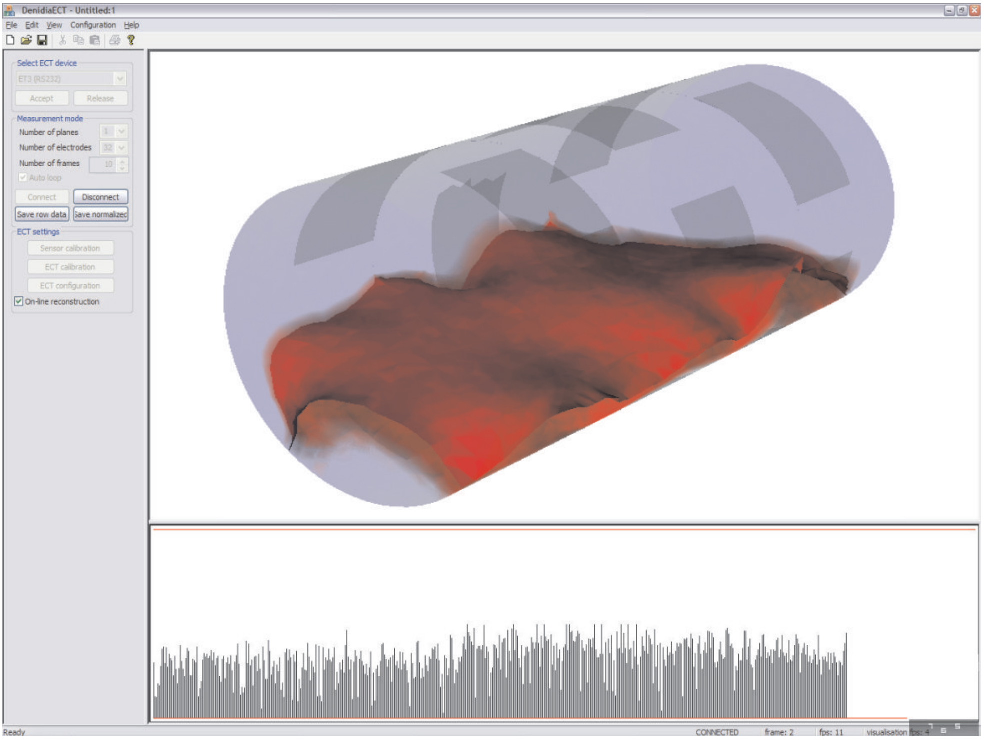

Fig. 4. The screen of the application with the reconstructed 3D image of the gas/liquid flow

Therefore, besides the 3D nonlinear image reconstruction method some algorithms have been developed and implemented as:

– noninvasive 3D inspection of dielectric permittivity for bubbles distribution determination (see Fig. 5a),
– level set reconstruction for shape detection from 3D capacitance data dedicated for calculation of the phase distribution (see Fig. 5b).

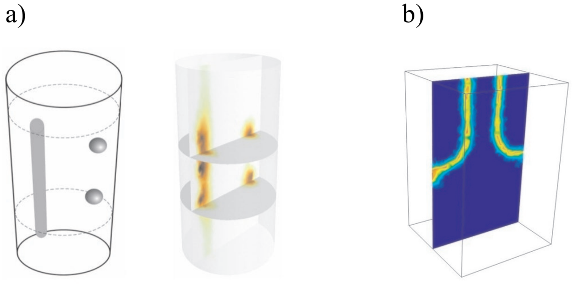

Fig. 5. Examples of working algorithms for 3D ECT data analysis:
a) noninvasive 3D dielectrics inspection; b) level set reconstruction

6. Automatic process control

The methods for monitoring and diagnosis of any industrial processes aim to determine the state of the process according to the diagnostic signals. After the comparison of the current state of the process with the pattern stored in the knowledge base it is possible to automatically decide about the change of the operation parameters for the flow forcing devices like pumps. This in turn significantly reduces the time for detection and localization of any undesirable breakdowns. The task for computer diagnostic systems in the case of closed pipelines is to detect any irregularities or failures, or even better to warn against such a situation (the prediction of the disturbing out of range process parameters) as well as to report and to register them or to support the technical stuff in critical moments. The future work related to this is to adapt the described methods of tomographic data analysis and to implement the module of the automatic flow process control. The hardware part of this module has to be divided into two parts:

- the measurement unit for collecting all of the information about the current state of the process;
- the control unit for setting the working parameters of the process.

There are the following measurement elements in the flow facility from which the data need to be collected:

- electrical capacitance tomography system for the non-invasive phase distribution and velocity profile measurement,
- the electromagnetic flowmeters the flow volumetric intensity measurement,
- two mass flowmeters with a high precision for gas stream measurement.

The aim of applying the last flowmeters is only to calibrate the ECT system. In the future work this equipment is planned to be ignored.

However, the fluidal flow facility has three elements for tuning the flow process. It is:

- multi-stage impeller pump with an engine of the regulated rotational speed,
- gas distributors with the system of regulation of the volumetric gas flow rate,
- pneumatic valves electrically controlled.

This step of research is still in the design and implementation phase.

7. Conclusions

The experimental installation aimed at the investigation of the characteristic parameters of two-phase flow of gas-liquid mixtures has been designed and constructed in Computer Engineering Department Laboratory. The installation controlled by the computer system allows to perform the measurements in the horizontal and vertical geometry. The installation is equipped with measurement probes and the analysis and measurement data modules which enable to obtain the information about the structures of two-phase flow. This results will allow to characterize the flow and constitute the basis for the mathematical description of the processes which occur.

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