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New Concept of ECT/ERT/GRT Tomography for Multiphase Flow Measurements

1. Introduction

The multi phase flow measurements are very important tasks in many areas of industrial processes applications. One of them is undersea exploration of oil in the petroleum industry.

ATKINSON I., THEUVENY B., *et al*. (2004) present review of current and possible future technologies in multiphase flow measurements. There were around 1300 such installations in 2004. Currently there are in use mixed flow measurement systems based on separation and independent measurements of component flow.

After separation of the components fluid flow are measured by mechanical meters, gas flow is measured by an orifice meter. Cost of single separator installation comes to about 500 000 US$. Therefore there is a great demand for installation of low cost multiphase meters to avoid use of costly separators. Another type of three phase meter uses Venturi equipped with absolute end differential pressure sensor and dual energy gamma ray detectors. This device measures total mass flow and fractions of gas, oil and water. Different aspects of application of gamma radiation in process tomography is presented by Holstad (2003, 2004), Tjugum *et al.* (2001, 2003)

One of the aims of the research performed within DENIDIA MC ToK project in cooperation of Computer Engineering Department of the Technical University of Lodz and Department of Physics and Technology of the University of Bergen was to design and test three phase flow meter based on combining three modalities: ECT, ERT and gamma ray radiation. Compact three phase flowmeters have existed for more than 30 years but they are only working for well-mixed flows in vertical pipes. There is a demand for multiphase flowmeters down holes, in the oil production industry, where the pipes are inclined or horizontally positioned.

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2. Description of the System

The system is built on 90 mm diameter PVC pipe and consist of 8 stainless steel pin shaped resistance electrodes and 8 copper capacitance electrodes with dimensions 100×25 mm placed outside the pipe. The system uses ECT measurements from copper electrodes when the mixture is oil or gas continuous and not conducting and ERT mode when the mixture is water continuous and conductive. ECT/ERT sensor is connected to the 16-channel electronic measurement unit, DENIDIA ECT designed and manufactured in the Technical University of Lodz. In addition to this, a vertical and a horizontal directed narrow gamma beam from two pin sources (AMC.P1, QSA Global) are placed in the radial mid plane of the EIT system. The two beams are detected by two CTZ – sensors (eValuator 1000) including all necessary electronics for giving out a TTS shaped signal equal to number of counts.

Sensor (7 on Fig. 1) is built as 50 cm pipe segment with flanges for ease of replacement within the flow rig. The radioactive sources are inserted into protective lead holders. The construction is closed in 1.5 mm steel housing. The installation used for experiments is presented on Figure 1.

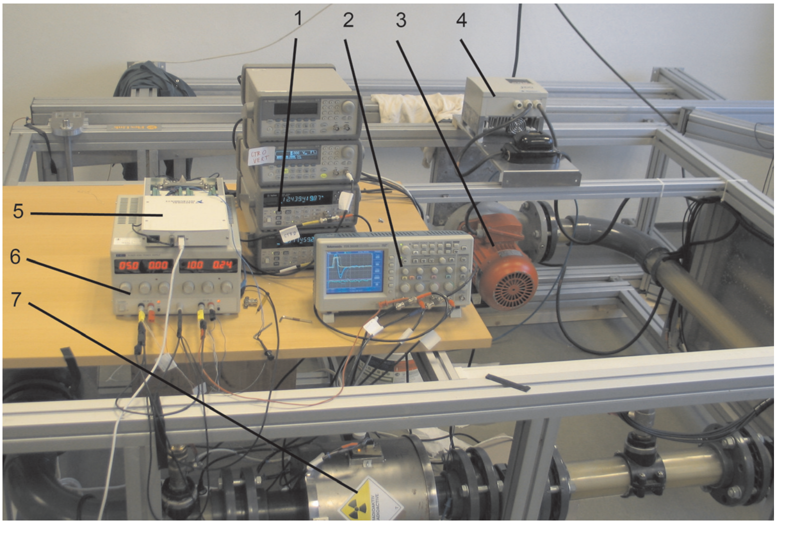

Fig. 1. Test stand. 1 – pulse counters, 2 – testing oscilloscope, 3 – Centrifugal pump drive, 4 – pump drive inverter, 5 – National Instruments DAQ card, 6 – Power supply for eV1000, 7 – Tomographic multi modality sensor

3. Calibration of The EIT System

Prior to performing measurements in an installation the system has to be calibrated. Calibration of EIT system is performed in few steps.

3.1. The ECT-system

The ECT-system must be calibrated at empty pipe and the pipe filled with oil, and the calibration data stored in the flow computer. It can also be calibrated at distilled water to control the validity of the calibration equations.

1) Pipe filled with gas:

$$C_i^{gas} = K_i^{gas} \varepsilon_0 \varepsilon_{gas} \tag{1}$$

2) Pipe filled with oil:

$$C_i^{oil} = K_i^{oil} \varepsilon_0 \varepsilon_{oil} \tag{2}$$

3) Pipe filled with distilled water:

$$C_i^{w_d} = K_i^{w_d} \varepsilon_0 \varepsilon_{w_d} \tag{3}$$

where i = 1–2, 1–3, …, 1–N, 2–3, 2–4 ….. 2–N …… N = total numbers of electrodes, $\varepsilon_0\varepsilon_{gas}$, $\varepsilon_0\varepsilon_{gas}$, $\varepsilon_0\varepsilon_{w_d}$ are dielectric constant and relative permittivity of gas, oil and distilled water respectively.

$$K_i^{gas} = \frac{C_i^{gas}}{\varepsilon_0 \varepsilon_{gas}} \tag{4}$$

Thus all the K_i^{oil}, $K_i^{w_d}$, K_i^{gas} can be derived from equations corresponding to water and gas.

3.2. The ERT-system

The ERT-system can only be calibrated at salt water. Since this tomograph is mainly intended for use in the North Sea, sea water or water at same conductivity (5 S/m) should be used.

1) Pipe filled with saline water:

$$R_i^{w_s} = K_i^{w_s} \frac{1}{\sigma_{w_s}} \tag{5}$$

where values for i are the same for all electrode pairs, as for ECT system, Thus

$$K_i^{w} = R_i^{w} \sigma_{w_s} \tag{6}$$

3.3. The GRT-system

The used system consists of two perpendicular narrow beams. It is therefore not a full tomography system but never the less of necessity it helps in a three-component flow specially designed for horizontal pipes. Calibration procedure of the GRT-system is performed in a similar way, sensor is filled with all flow components: gas, oil and water.

1) Pipe filled with gas:

$$I_{gas} = I_0 e^{-\mu_{gas} D - 2\mu_d d} \tag{7}$$

2) Pipe filled with oil:

$$I_{oil} = I_0 e^{-\mu_{oil} D - 2\mu_d d} \tag{8}$$

3) Pipe filled with water:

$$I_w = I_0 e^{-\mu_w D - 2\mu_d d} \tag{9}$$

Where I_{gas}, I_{oil}, I_w are number of counts elapsed for sensor filled with gas, oil and water respectively, I_0 is the initial count elapsed with empty gamma sensor.

Using ECT it is often difficult to determine the border between gas and oil. It is usually easier to determine the interphase between water and oil where the difference in electrical permittivities are large (71/2.3). This inter phase border can be applied to increase the accuracy of determining the border between oil and gas using the GRT. If the sensor is filled with a mixture of the components: gas, oil and process water, the linear absorption coefficient along the gamma ray beam in an oil/gas/water- mixture can be presented in the following form:

$$\mu_{mix} = \mu_{gas}\alpha_{gas} + \mu_{oil}\alpha_{oil} + \mu_w\alpha_w \tag{10}$$

$$\alpha_{gas} + \alpha_{oil} + \alpha_w = 1, \quad \alpha_{oil} = 1 - \alpha_{gas} - \alpha_w \tag{11}$$

This gives:

$$\mu_{mix} = \alpha_{gas}(\mu_{gas} - \mu_{oil}) + \alpha_w(\mu_w - \mu_{oil}) + \mu_{oil} \tag{12}$$

where α_{gas}, α_{oil} and α_w are the fraction of the components in the gamma beam and μ_{mix}, μ_{mix}, μ_{mix} are linear absorption coefficients of gas, oil and water respectively.

Elapsed number of counts for the multi phase mixture can be described by the following formula.

$$\begin{aligned} I_{mix} &= I_0 e^{-\mu_{mix} D - 2\mu_d d} = I_0 e^{-\alpha_{gas}(\mu_{gas}-\mu_{oil})D - \alpha_w(\mu_w - \mu_{oil})D - \mu_{oil} D - 2\mu_d d} \\ \frac{I_{mix}}{I_{gas}} &= e^{-\alpha_{gas}(\mu_{gas}-\mu_{oil})D - \alpha_w(\mu_w-\mu_{oil})D - (\mu_{oil}-\mu_g)D} \end{aligned} \tag{13}$$

Since α_w is known from the EIT image we can find α_{gas} from gamma measurements. After some calculations the fractions of different phases can be derived from the following formulae:

$$\alpha_{gas} = \frac{\ln \frac{I_{mix}}{I_{oil}} - \alpha_w \ln \frac{I_w}{I_{oil}}}{\ln \frac{I_{gas}}{I_{oil}}} \tag{14}$$

$$\alpha_{oil} = \frac{\ln \frac{I_{mix}}{I_w} - \alpha_{gas} \ln \frac{I_{gas}}{I_w}}{\ln \frac{I_{oil}}{I_w}} \tag{15}$$

4. Experimental Results

The experiments on multi modality sensor were performed in University of Bergen using flow rig with capacity of 35.6 l. For experiments North Sea water and diesel petrol was used. Experimental setup of the installation is presented in Figure 1. After calibrating of the system (ECT, ERT, GRT) the flow measurements were performed for series of two phase and three phase flow compositions.

The graphs (Fig. 2 and 3) present measurements performed for liquid mixture containing 50% of sea water and 50% of Diesel oil. In a steady state the flow is stratified, so lower part of the sensor is filled with water. The graphs show flow measurements captured while start of the pump and volume fraction oscillations leading to water/oil emulsion. The graphs of ECT and ERT show relative values of capacitances and resistances. The negative values of capacitances are caused by salt water and noise component of the signal. GRT graph shows oscillations of counts acquired by vertical and horizontal gamma sensor. Horizontal axis corresponds to gamma counting periods.

Measurement data obtained from different modalities confirmed flow composition oscillations, easily visible in a transparent rig segment. It appeared, that combining measurement data acquired from different modalities enables on-line calculations of a flow composition.

5. Conclusions

The experiments with newly designed multi modality sensor performed on a multi phase flow rig in Bergen showed, that combined mode tomograph (ECT/ERT) with added gamma sensors (horizontal and vertical strongly helps to determine flow composition of a mixed flow. Different experiments showed, that accuracy of measurement of water or oil cut varies from 3% to 12%. The construction of the sensor enables robust measurements. Some efforts have to be made according to the electronic ECT/ERT measurement unit to protect the system against noise, mainly originating from pump power inverter.

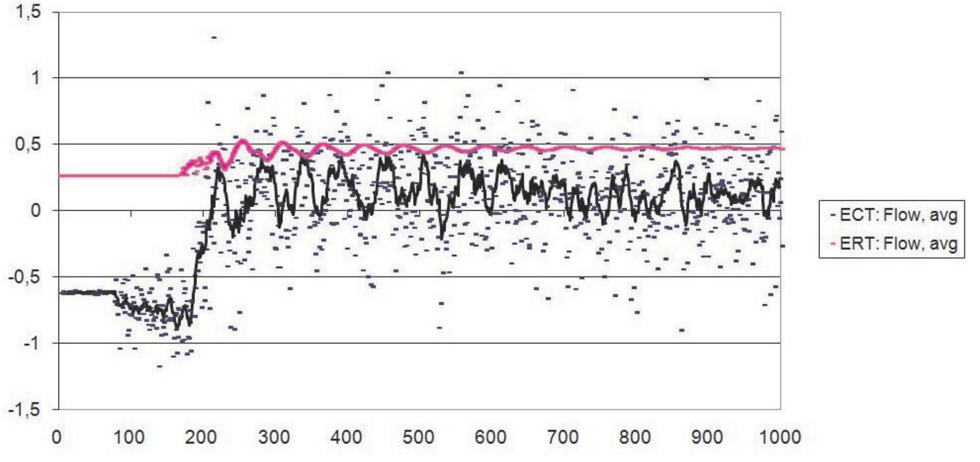

Fig. 2. Measurements of relative values of capacitances and resistances while pump start in a flow rig. Rig filling: 50% sea water, 50% Diesel oil. Horizontal axis: measurement frames

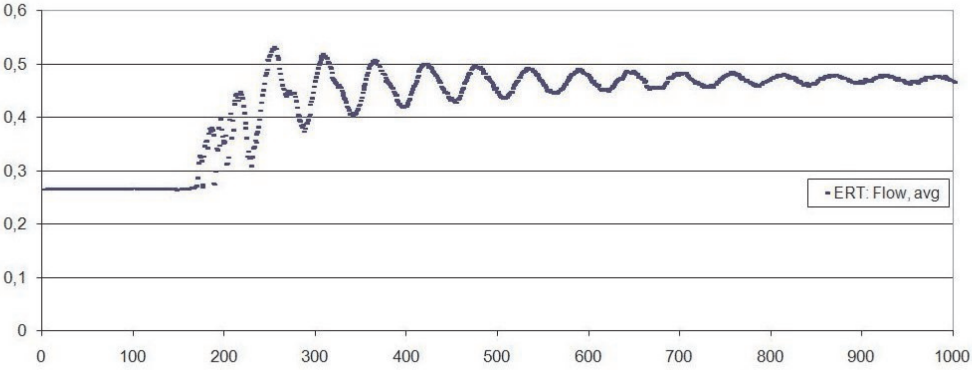

Fig. 3. Measurements of relative values of resistances while pump start in a flow rig. Rig filling: 50% sea water, 50% Diesel oil. Horizontal axis: measurement frames

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