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Measurement and analysis of water/oil multiphase flow using Electrical Capacitance Tomography sensor

E.J. Mohamad [a,*], R.A. Rahim [b], M.H.F. Rahiman [c], H.L.M. Ameran [a], S.Z.M. Muji [d], O.M.F. Marwah [e]

[a] Department of Mechatronic and Robotic, Faculty of Electrical & Electronics Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor 86400, Malaysia
[b] Process Tomography and Instrumentation Research Group, Infocomm Research Alliance, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Skudai 81310, Malaysia
[c] School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Pauh, Perlis, Malaysia
[d] Department of Computer Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor 86400, Malaysia
[e] Department of Manufacturing and Industrial, Faculty of Mechanical and Manufacturing Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor 86400, Malaysia

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ABSTRACT

The paper investigates the capability of using a portable 16-segmented Electrical Capacitance Tomography (ECT) sensor and a new excitation technique to measure the concentration profile of water/oil multiphase flow. The concentration profile obtained from the capacitance measurements is capable of providing images of the water and oil flow in the pipeline. The visualization results deliver information regarding the flow regime and concentration distribution of the multiphase flow. The information is able to help in designing process equipment and verifying the existing computational modeling and simulation techniques.

1. Introduction

An Electrical Capacitance Tomography (ECT) system is able to obtain information about the contents of vessels, based on measuring variations in the dielectric properties of the flowing material inside the vessel [1]. ECT can be used with vessels of any cross section, but most work to date has used circular geometries [2]. A typical ECT system consists of a sensor built up from 8, 12 or 16 electrodes, capacitance measurement circuit, central control unit and control PC [3]. The electrode, which is normally built from conductive plate, acts as the sensing surface that directly contains the measuring volume. The capacitance measuring circuit detects permittivity variations and the signal conditioning circuit converts the analog measurement readings to digital format. A central control unit is designed to synchronize all the operations and to transfer the data to a control PC. The control PC receives the measurements, stores the acquired data, reconstructs images from the integral measurements and takes feedback action to control the flow [4]. In this work, a sixteen segmented electrodes sensor was developed and mounted symmetrically on the outer surface of an insulating horizontal pipeline.

An ideal capacitance measuring system will have a very low noise level, a wide dynamic measurement range and a high immunity to stray capacitance. Stray capacitance is a type of noise where the leakage capacitance is due to connection between the circuit and the cable to the electrode [2]. In a practical ECT system, there are three main sources of stray capacitance which affect the capacitance measurement: screened cable, CMOS switches and sensor screen. A 1 m long screened cable connecting the sensing electrode to the measuring circuit introduces about 100 pF of stray capacitance [5]. Additionally the stray capacitance may vary with cable movement, ambient temperature changes, component variation and external or internal electric field changes [6]. Typical measurement capacitance values are in a range between 0.01 and 0.5 pF. Consider that the measurement error should be better than 1% for all capacitance measurements [7].

* Corresponding author.
E-mail addresses: elmy@uthm.edu.my (E.J. Mohamad), ruzairi@fke.utm.my (R.A. Rahim), hafiz@unimap.edu.my (M.H.F. Rahiman), hanis.liyana@yahoo.com (H.L.M. Ameran), szarina@uthm.edu.my (S.Z.M. Muji), mdfaizan@uthm.edu.my (O.M.F. Marwah).

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In most of previous research regarding ECT, the signals from the sensor electrodes are usually connected to the signal conditioning circuit by using coaxial cable. The coaxial cable is able to shield disturbance or stray capacitance external to the system. However, the cable connecting the measuring electrode and signal conditioning circuit introduces most of the stray capacitance. Therefore, the connecting cables should be made as short as possible. In this project we propose a better solution by completely removing the use of cables to connect the electrode plates directly to the signal conditioning circuit. The signal conditioning circuit which is built on the electrode sensor becomes an ECT sensor module. This module not only reduces the noise, but can also work independently of other modules.

Furthermore, a known challenge in ECT systems which are categorized as soft field tomography is that the sensor is less sensitive at the center of the pipe [7]. This is due to the sensitivity of adjacent electrode pairs being much higher than the sensitivity of opposing electrode pairs, resulting in the higher measurement sensitivity near the wall as compared to the central area. The use of external sensors also produced nonlinear changes of capacitance measurements in function of material permittivity. Hence, a new method is developed to enhance the situation of nonlinear potential distribution and less sensitivity in the ECT measurement central area. A differential potential excitation scheme is used instead of the conventional single excitation technique.

2. Brief literature review of two phase flow visualization

Bolton [8], is among the pioneers in imaging liquid/liquid (water/oil) flow using ECT in two-phase flow systems. Their system consisted of a PTL-200 and 12 parallel capacitances that operated at a high frequency of 1.25 MHz. Moreover, they employed an LBP algorithm for image reconstruction. An alternative calibration procedure was applied with kerosene as the low permittivity fluid, whereas the higher permittivity fluid was emulsion of ~40% of water and with 60% of kerosene. They found that the ECT system distinguished hold-up images between 25% and 50% distribution with increasing water flow in the kerosene continuous phase.

Jaworski [9], who performed an experiment using external and internal electrodes that employed a commercially available PTL-300 ECT system, continued the study of Bolton et al. [8]. The imaging of uniform water/oil mixes with distilled water as a continuous phase. The internal electrode sensor tended to overestimate the amount of oil, whereas the external electrode sensor underestimated the amount of oil. Overall, the ECT sensor exhibited nonlinear behavior, particularly for high-permittivity media and a thick pipe wall.

Hasan and Azzopardi [10] have conducted an investigation on the imaging of stratified liquid/liquid flows in horizontal and inclined pipes using an ECT system. The calibration was applied with kerosene as the low permittivity medium and water as the high-permittivity medium. Their study claimed that in a liquid/liquid flow, the phases within the pipe are distributed in several fundamentally different flow patterns or flow regimes that primarily depend on the flow rates of the two phases and the angle of inclination as shown in Fig. 1.

The research development above indicates that the application of ECT for imaging a spatial distribution in a pipe cross-section is reliable and has great potential. Therefore, the present work aims to image the stratified liquid/liquid flows in a horizontal pipeline specifically for the two-phase flow of water/oil mixes. This analysis is intended to verify the flow patterns along the pipeline that could be recognized by the image of the proposed segmented ECT system.

3. ECT system development

This research aims to investigate the use of a portable sensor design in an ECT system. As shown in Fig. 2, the project can be divided into 3 stages, which are the portable sensor design, the central control unit design and software programming.

ECT systems are usually comprised of 8, 12 or 16 electrodes. The size of each electrode decreases relatively to the growing number of ECT sensor electrode [7]. The sensor provides excitation signals and converts the measured capacitances into voltage signals, which are conditioned and then digitized for data acquisition.

In this research, 16 segmented electrodes have been fabricated onto the 110 mm diameter pipeline. It is very important that the pipeline material must be pure insulator to minimize measurement error as the detected signals are received from the excited electrode, and not from the current that flows through the pipe. The thickness of the pipeline and the permittivity (ε) of the material will influence the measured value of standing capacitance. However, other factors, such as the requirements of corrosion, abrasion, temperature resistance, and the temperature stability, may limit the selection of the pipeline material [11]. Fig. 3 shows an arrangement of 16 electrodes sensor on pipelines that has been designed in this project to cover 110 mm acrylic pipe in diameter with wall thickness of 5 mm, R_1 is inner pipeline radius 50 mm, R_2 is outer pipeline radius, 55 mm and electrode stretch angle θ is 22.5°.

The smaller radius-electrode ratio, the more serious effect of pipeline thickness will arise. Pipelines thickness has significant influence not only on capacitance but also on image. The maximum capacitance change is at $\rho=0.85$, which is beneficial for

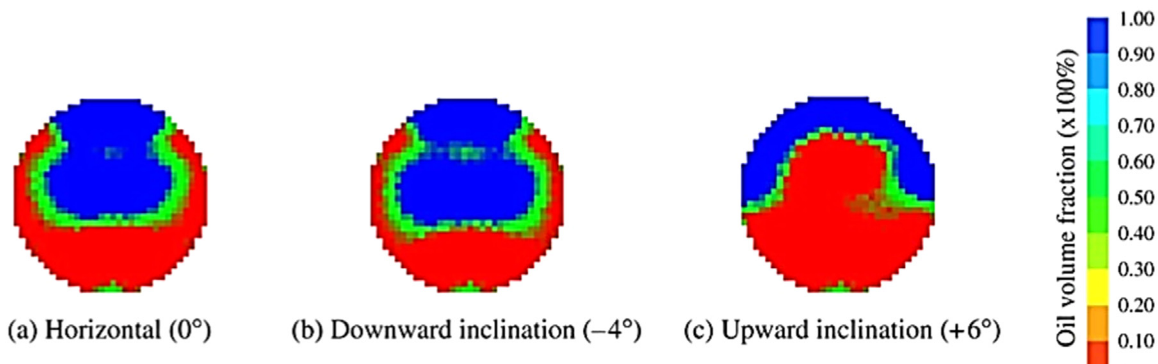

Fig. 1. Phase distribution in a pipe cross-section for mixture with input oil fraction 70% at different angles of inclination taken from Hasan et al. [10].