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Optimisation of electrode dimensions of ERT for non-invasive measurement applied for static liquid–gas regime identification

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ABSTRACT

The non-invasive technique is one of the favourite methods applied in process plants, compared to other sensing techniques. Due to certain advantages, this technique is also implemented in process tomography such as in non-invasive ERT systems for multiphase mixtures. The purpose of this paper is to investigate the optimum size of the area of the electrode in terms of the width and height for the non-invasive ERT system that can be applied for a static liquid-gas regime. Based on a quasi-static electric field, a 2D simulation using finite element model software (COMSOL Multiphysics) was used to analyse the simulation results. As a result, by applying several widths and heights to the system, 18.5° and 200 mm in width and height, respectively, were chosen as the optimum dimensions to be applied for a 100 mm outer diameter and 2 mm thick acrylic pipe for the non-invasive ERT electrode. Later, experiments were conducted to obtain the tomogram for image verification. Thus, it is believed that the implementation of the optimised area of the electrode can allow the electricity to be emitted and significantly detected. The non-invasive ERT system will also give an alternative way for industry to monitor the performance of process plants.

1. Introduction

Mixtures such as liquid–liquid, liquid–solid and liquid–gas two-phase flow regimes are the main concern in industry applications. Visualization of the mixtures at an early stage in an industry application, such as in a vertical or horizontal pipeline, promises good performance and prevents any unwanted conditions in the process plant. One of the methods that can be implemented in industry applications is process tomography.

The implementation of process tomography in industry serves to reconstruct the cross-sectional image of the medium of interest. Process tomography is also known as Industrial Process Tomography (IPT) [1]. Due to its main advantage of being non-destructive to the process or object being measured, process tomography has become of widespread interest to researchers investigating its industrial applications. There are four types of sensing techniques for tomography: intrusive, non-intrusive, invasive, and non-invasive. The word intrusive relates to how the sensor protrudes into the medium of interest and invasive means that the sensor is applied to the inner surface of the wall of the pipeline. Additionally, the sensing techniques can be combined so that they can be intrusive and invasive, intrusive and non-invasive, non-intrusive and invasive, and non-intrusive and non-invasive, as in [2–3]. However, the non-intrusive and non-invasive approach

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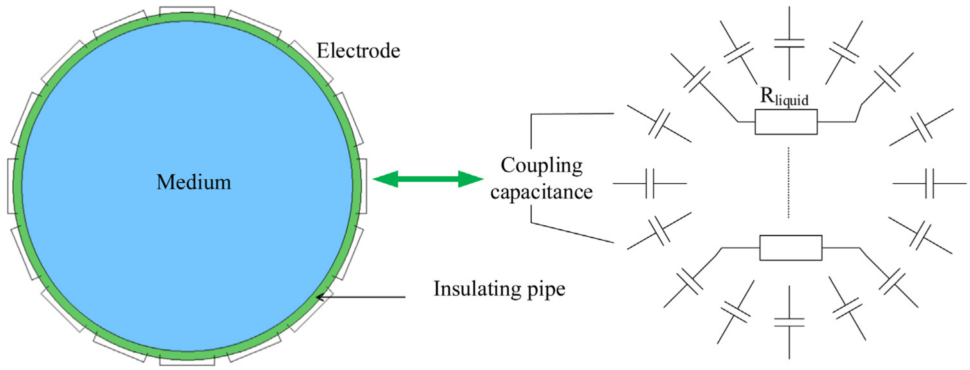

Fig. 1. Non-invasive ERT sensor and its equivalent circuit.

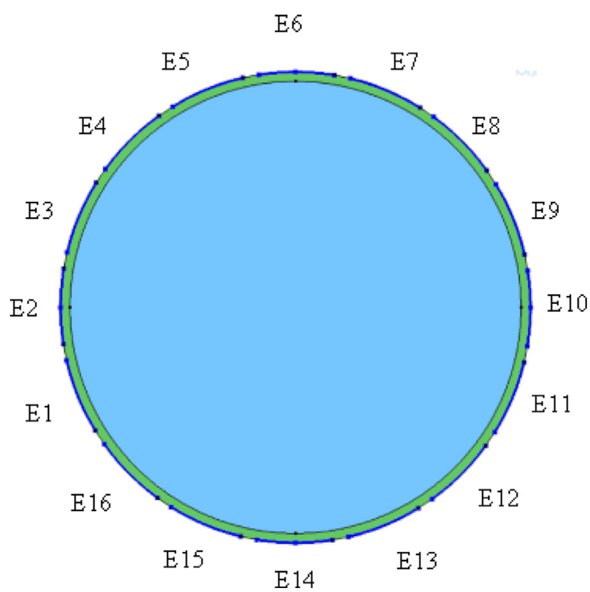

Fig. 2. 2D geometry of non-invasive ERT.

is a well-known method applied in industry due to its several advantages. As an example, it can avoid contamination of pure or sterile materials, minimising the hazards of working with poisonous, radioactive, explosive, flammable or corrosive materials and decreasing the safety and accountancy difficulties with valuable process materials. In particular, electrical capacitance tomography, ultrasonic tomography, X-ray computed tomography, optical tomography, and non-invasive electrical resistance tomography are the types of non-invasive process tomography applied for multiphase mixtures [4]. However, every type of process tomography has its advantages and disadvantages.

In this paper, the authors focus on electrical resistance tomography (ERT) research. The ERT reconstructs the image based on the conductivity distribution of the medium of interest. The conventional technique implemented for ERT is invasive but still non-intrusive to the system, such as in [5–12]. The main reason for applying the system invasively is to make sure that there is continuous contact between the electrodes and main fluids, so that the current signal can be conducted through the medium of interest [13]. The way to measure the current signal is to use either the adjacent method, the opposite method, boundary method, or a diagonal method [14].

However, the conventional technique for the ERT system has a direct contact to the conductive liquid. Consequently, this will cause corrosion to the ERT sensor, an unpredictable measurement error to the system and will of course limit the applications. Significantly, Cau et al. and B. Wang et al. [15–19] highlighted this issue and proposed a non-invasive ERT system for industry mixtures. The non-invasive ERT means that the electrodes are mounted on the vessel periphery. However, no discussion on the optimization of the electrode dimensions has been highlighted by other researchers for the non-invasive ERT system. Using this particular research as a springboard, the purpose of this paper is to investigate the optimium sensor dimensions in terms of the width and height of the electrode that can be used for the non-invasive ERT system. Also, the concern of this paper is only with a static liquid–gas regime. Water–air is assumed to be the liquid–gas regime. The 2D simulation of the optimization of the electrode uses the finite element model software, COMSOL Multiphysics. Later, based on the modelling size of the electrode in the simulation, the sensor performance is then verified using experimental testing of several images for the reconstruction of the static liquid–gas regime.

2. Basic principles of non-invasive ERT

2.1. Resistance and conductivity

Electrical resistance tomography is used to reconstruct the image based on the resistance distribution or conductivity distribution of the medium of interest. Thus, it is important to know the relationship between resistance and conductivity. In process tomography applications, the resistance can be measured by exciting voltage (or current) and detecting current (or voltage) via sensors mounted on the circumference of the pipe walls [20].

In addition, the conductivity of the medium is a measurement of the electron flow in a medium under the influence of an external electric field. The electrical conductivity, σ can be described based on Eq. (1) [21–23].

$$\sigma = \frac{L}{RA}\,(S/m) \tag{1}$$

For a non-invasive ERT system, R is the resistance of the medium of interest, L is the outer diameter of the pipe, and A is the area of the electrode. It is observed that σ is inversely proportional to R. Thus, the conductance, G, can be defined as Eq. (2).

$$G = \frac{\sigma A}{L} = \frac{I}{V} = \frac{1}{R} \tag{2}$$

However, most researchers use an insulating pipe as a vessel, with the non-invasive ERT sensor mounted on the pipe wall of the insulating pipe; hence, the current signal cannot be applied as a source because it will prevent the electricity from penetrating through the insulating pipe. Thus, the non-invasive ERT system applies a voltage as a source, and measures the current as a received signal. Also, the dimensions of the electrode of the non-invasive ERT are very important, to ensure that the signal can be transmitted and