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Review

Electrical resistance tomography: A review of the application of conducting vessel walls

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ABSTRACT

Despite decades of research, the study on tomography continues to be a subject of great scientific interest. Amongst all the kinds of tomography available, electrical resistance tomography (ERT) has been chosen as the field of study because of its advantages of being low cost, suitable for various kinds and sizes of pipes and vessels, having no radiation hazard, and being non-intrusive. In the development of ERT systems for conducting vessel walls, prior knowledge of the fundamental process of the ERT system whilst improving the design and operation of the process equipment is essential. In this paper, a review of the application of ERT for the conducting vessel wall is presented, providing information about its evolution over the years. The limitations and advantages of different strategies of ERT are also presented besides an overview of the system. Electrode fabrication on the conducting vessel wall is addressed.

Contents

1. Introduction

The word 'tomography' comes originally from the Greek 'tomos' which means to slice and 'graph' meaning image. In other words, tomography can be defined as a process of making a cross-sectional image of an object. A cross section of the object is called a tomogram, whilst the equipment that generates the image is called a tomographic system [1,2]. Tomography offers a unique opportunity to reveal the complexities of the internal structure of an object without the need to invade it. The concept of tomography was first published by a Norwegian physicist, Abel, for an object with axisymmetrical geometry. Nearly 100 years later, an Austrian mathematician, Radon, extended Abel's idea for objects with arbitrary shapes. Advances in the use of the tomography technique, namely computerized tomography (CT)

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and computerized axial tomography (CAT), were presented by Godfrey Hounsfield of Great Britain and Allen Cormack of the United States during the 1970s. Since then, tomography has become widely used as a medical diagnostic technique. It has been developed over the last decade into a reliable tool for imaging in numerous industrial applications [3].

One of the most extensive modalities of tomography, which has greatly evolved since it was invented in the 1980s, is electrical resistance tomography (ERT), a particular case of electrical impedance tomography (EIT). ERT has become a promising technique in monitoring and analysing various industrial flows due to its diverse advantages, such as high speed, low cost, suitability for various sizes of pipes and vessels, having no radiation hazard, and being non-intrusive [4–10]. It has the potential of providing both qualitative analysis by providing the data required for measurement of some flow parameters, such as velocity distribution, and flow regime identification [11]. As a non-intrusive, fast visualization tool, close attention has been paid to ERT in multiphase flow research. Compared with conventional measurements, ERT can provide real-time cross-sectional images of conductivity distribution within its sensing region. Other parameters, for example local and global gas hold-ups and radial velocity maps, can be extracted from the reconstructed images [12].

ERT has gained acceptance as a useful means of rapidly delineating the resistivity distribution of materials inside a process vessel or pipeline [13]. Most of the primary sensor geometries for the process equipment of ERT concentrated on embedding invasive but non-intrusive electrodes into a wall vessel/pipe section composed of an electrically non-conductive material, such as acrylic, perspex or polyvinylchloride. Conversely, the majority of industrial pipelines and process vessels are constructed from conducting metallic composites. Thereby, the development and improvement of ERT measurement methods to accommodate this environment are proposed in this research.

In this paper, a review of the application of ERT on conducting vessel walls for process monitoring and industry is presented. Information regarding the evolution of this topic over the years, besides the advantages and limitations are also given. Recent research on ERT and its developments in conducting boundaries are presented and an overview of the system, measurement strategies and electrode fabrication is addressed.

2. Recent research and applications employing ERT

Since its exposure in the 1980s, many attractive and inspirational works and research have been presented by researchers around the world. In 2012, Zhang and Chen [14,15] presented a new flow pattern identification algorithm for common two-phase flows based on electrical resistance system measurement, principal component analysis–general regression neural network (PCA–GRNN) and principal component analysis–support vector machine (PCA–SVM). Yang et al. [12] introduced a dual-plane ERT technique to provide a real-time measurement of air volume fraction distribution within its sensing region. The system could generate cross-sectional images as well as flow velocity maps. Sharifi and Young [11,16] presented a study on the flow and velocity profile of various milk solutions in horizontal and vertical pipes as well as spatial 3-dimensional (3D) monitoring using ERT. Gas hold-up in a multi-stage bubble column has been investigated by Jin et al. [17].

In measuring the multiphase flow, Dong et al., Tan et al. and Zhang et al. [18–20] presented a new ERT system employing a fully programmable and reconfigurable FPGA- (field programmable gate array) based Compact PCI (peripheral component interconnect) bus. They are from the same research group in Tianjin University. The experiments are differing in object of interest and the results consequently. The research by [18] visualize the oil/gas/water meanwhile [19] investigate the water flow through the gas dynamics simulations and experiments by [20] have been performed in tap water. FPGA is adopted in the research since it produces significantly more computation power, through parallel implementation, compared with the traditional instruction-driven digital signal processors. This advance in technology brings improvements in performance such as high bandwidth and good precision when applied to ERT systems. Moreover, the use of digital components (FPGA chips) makes upgrading and debugging easier. The FPGA chips are used in the new data acquisition system for implementing the functions of digital filters, digital demodulations, injecting strategy change and data transportation based CompactPCI bus, etc.

Yenjaichon et al. [21] applied ERT to evaluate the mixing quality of an industrial pulp mixer. Xu et al. [22] described a parallel ERT system based on Compact PCI for multiphase flow measurement. Tahvildarian et al. [23] employed ERT in investigating the mixing of micron-sized polymeric particles in a slurry reactor. Kourunen et al. [24] applied a 3D ERT to characterize gas hold-up distribution in a laboratory flotation cell. Other researchers [6,12,17,25–29] have analysed gas hold-up using ERT in a bubble column.

Meng et al. [30,31] combined the ERT sensor with a Venturi meter to measure the mass flowrate of an air–water two-phase flow. A feasibility study has been undertaken by Kowalski et al. [32] to explore the use of ERT for detecting the early onset of ageing in formulated products. Karhunen et al. and Seppanen et al. [33–37] have published a number of research papers on the ERT imaging of concrete. In a study by Jin et al. [38], the mean phase hold-up and radial gas hold-up distributions are discussed using ERT together with the differential pressure method with two axial locations in a gas–liquid–solid of a bubble column. Hosseini et al. [39] used ERT to investigate the solid–liquid mixing in an agitated tank equipped with a top-entering axial-flow impeller. Cui et al. [40] proposed a twin plane ERT system on gas/liquid two-phase flow in a vertical pipe which helps to realize the online monitoring of flow regime classification and gas hold-up computation. Chao et al. [41] obtained cross correlation velocity of oil–water two-phase flow in a horizontal pipe by a dual-plane ERT. In reconstructing the conductivity distribution of ERT, Cao et al. [42] applied electrical capacitance tomography (ECT).

Experiments on gas–water two-phase flows have been conducted by Tan and Dong [43] in a horizontal pipe using the ERT system and a V-cone meter. Xu et al. [7] applied ERT for slug flow measurement of gas/liquid flow in horizontal pipes. Razzak et al. [44] investigated liquid–solid two-phase systems in a liquid–solid circulating fluidized bed (LSCFB) for flow characteristics. Beforehand, Razzak et al. [45,46] successfully implemented ERT in a gas–liquid–solid circulating fluidized bed (GLSCFB) system, where the local and average phase hold-ups and propagation velocities were determined using cross correlation and compared it to optical fibre probe measurements. Park et al. [47] adopted ERT in monitoring a radioactive waste separation process. Pakzad et al. [48] used ERT to measure the mixing time of the xanthan gum solution with the yield stress stirred in a baffled tank. In this case, the xanthan gum solution is a pseudo-plastic fluids possessing yield stress.

Tan et al. [49] proposed a multi-plane ERT system based on a parallel data-acquisition system for gas/liquid two-phase flow. By applying ERT, Lee and Bennington [50] measured the flow velocity and uniformity also in a model batch digester. Ruzinsky and Bennington [51] applied ERT to measure the liquor flow through a model chip digester. Kim et al. [52] introduced ERT for the interfacial boundary recovery in stratified flows of two immiscible liquids. A numerical procedure for tackling shape varying bodies in ERT based on the mesh less method was discussed by Cutrupi et al. [53]. Chen et al. [54] identified the flow regime of oil/gas two-phase flow using ERT. Wang et al. [55] presented a study on the velocity distribution and air volume fraction of gas–liquid in a swirling flow using ERT. Earlier, Kim et al. [56] applied ERT to visualize and analyse the mixing of two miscible liquids with distinct conductivities in a stirred vessel. Jin et al. [57] studied the effect of sparger geometry on gas bubble hold-up distribution using ERT. In a study by