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Invited review paper

Application of electrical capacitance tomography in particulate process measurement – A review

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ABSTRACT

Particulate process measurement presents challenges because it often involves multiphase flow. Due to its advantages over other tomography modalities, electrical capacitance tomography (ECT) is widely applied in monitoring and measuring particulate processes. This paper presents a review on the application of ECT in particulate process measurement, including the monitoring of flow regime and solids distribution, solids flow velocity measurement, and fluidized bed dryers. The electrostatic phenomenon and the effect of electrostatics on the performance of ECT systems are also addressed. Finally, the challenges to ECT for particulate process measurement are given.

Contents

1. Introduction

Electrical capacitance tomography (ECT) is one of the industrial tomography modalities. It is based on measuring the change in capacitance of a multi-electrode ECT sensor due to the variation in concentration and/or distribution of dielectric materials. Using the capacitance data, a cross-sectional image of the material distribution in a pipeline or vessel can be reconstructed [1,2]. Compared with other tomography modalities, the advantages of ECT can be briefly summarized: (i) fast imaging speed (typically 100 frames/s), (ii) no radiation, (iii) robust, (iv) low cost, (v) non-intrusive and non-invasive, and (vi) withstand high pressure (up to 150 bar) and high temperature (up to 300 °C).

The first ECT system was developed in the end of 1980s [3]. In the past 20 years, a lot of work has been done in the development of ECT systems and a few review papers were published on the hardware, sensor design, image reconstruction algorithms and

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applications of ECT [4–12]. Yang presented a review on the hardware design of ECT system [4]. The advantages and disadvantages of two capacitance measuring circuits, which are charge/discharge circuit and AC based circuit, were compared. At present, there are several commercial ECT products available, such as the charge/discharge ECT system (from Process Tomography Ltd.) and the AC-ECT system (from ECT Instruments Ltd.). During an image reconstruction process, the capacitance measurements from an ECT sensor are used to obtain the material distribution in a cross-section. Due to the "soft-field" effect of ECT, and the limited number of independent measurements, image reconstruction for ECT is an ill-posed and ill-conditioned problem, making the reconstructed image be sensitive to errors and noises of capacitance measurements. Image reconstruction algorithms can be divided into two types: single step algorithms (such as linear back projection, singular value decomposition and Tikhonov regularisation) and iterative algorithms (such as Newton–Raphson, Landweber iteration and algebraic reconstruction technique). The algorithms for ECT were reviewed by Yang and Peng [10]. Some of the algorithms were investigated under typical distributions using both simulation and experimental data. Future developments in the field of the ECT image reconstruction were discussed [10]. The structure of an ECT sensor can significantly affect the performance of an ECT system. Recently, a review paper regarding the ECT sensor design was published [11]. The sensor diameter, the length and the number of electrodes as well as the size of earthed screens were discussed extensively.

Electrical tomography can be applied to monitor different processes. Dyakowski et al. reviewed the use of electrical tomography method to monitor and investigate the gas–solids and liquid–solids flows [8]. It was concluded that ECT systems were suitable for monitoring dry particulate flows, while ERT systems were recommended to monitor wet particulate flows. Although there are many review papers available, no paper has been published, systematically summarizing the application of ECT in the particulate processes, including gas–solids pneumatic conveying [13–32], gravity flows [33–41], fluidized beds [42–69] and fluidized bed dryers [70–75]. In these processes, some important parameters have to be measured, such as the solids distribution, solids flow velocity and moisture content, which greatly influence the performance and efficiency of the processes. Besides, electrostatic phenomenon is common in pneumatic conveying and fluidized bed processes. It results in inaccurate measurement and even malfunction of some ECT system. The structure of this paper is arranged as follows. At first, the monitoring of flow regime and solids distribution using ECT is provided. Then the methods of solids velocity measurement using ECT are introduced, followed by the applications of ECT in fluidized bed dryers. Finally, electrostatic phenomenon and the effect of electrostatics on the performance of ECT are discussed. The named particulate process measurements are summarized in Fig. 1.

2. Measurement of flow regime and solids distribution using ECT

There are many types of flow regimes in the particulate processes. Fig. 2 shows the flow regimes for a vertical pneumatic conveying and fluidized bed system [76]. In general, there are two categories: dilute flow and dense flow. In a dilute flow in a pipeline,

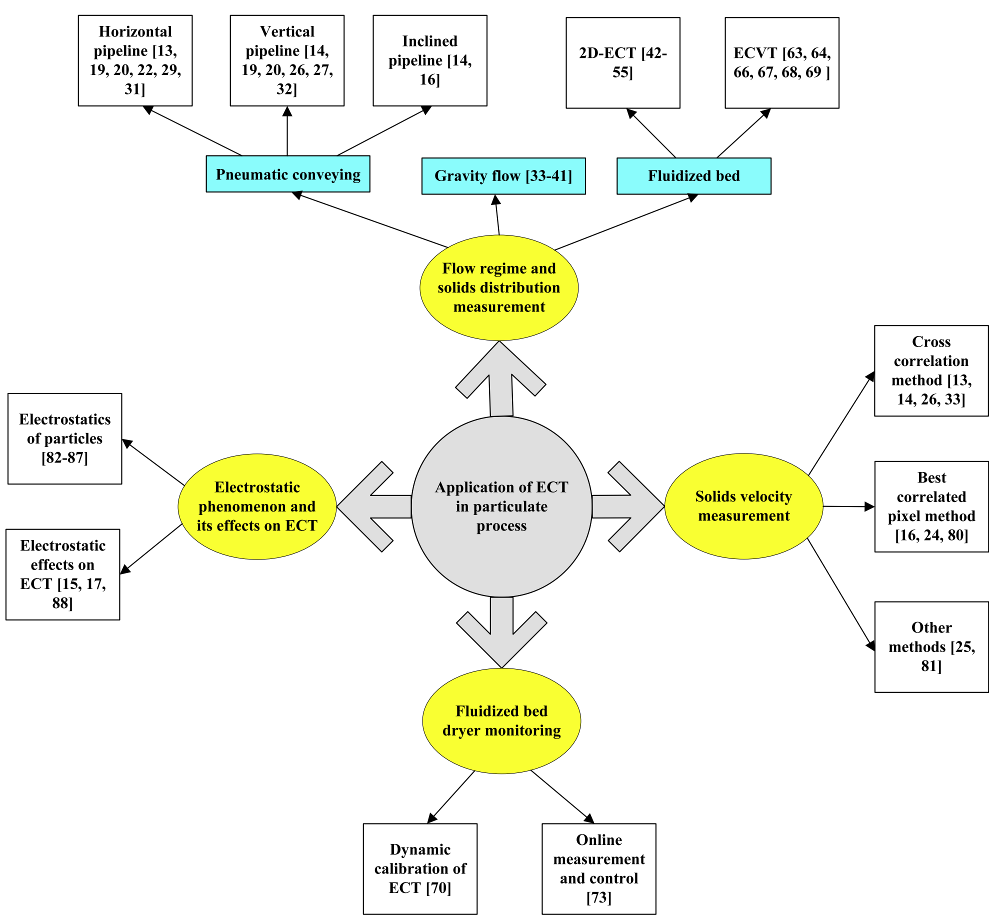

Fig. 1. ECT for particulate flow measurements – fundamentals and applications.