Image Fusion of ECT/ERT for Oil-Gas-Water Three-Phase Flow

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ABSTRACT

The tomographic imaging of process parameters for oil-gas-water three-phase flow can be obtained through different sensing modalities, such as electrical resistance tomography (ERT) and electrical capacitance tomography (ECT), both of which are sensitive to specific properties of the objects to be imaged. However, it is hard to discriminate oil, gas and water phases merely from reconstructed images of ERT or ECT. In this paper, the feasibility of image fusion based on ERT and ECT reconstructed images was investigated for oil-gas-water three-phase flow. Two cases were discussed and pixel-based image fusion method was presented. Simulation results showed that the cross-sectional reconstruction images of oil-gas-water three-phase flow can be obtained using the presented methods.

Keywords: Electrical Capacitance Tomography, Electrical Resistance Tomography, Image Fusion, Oil-Gas-Water Three-Phase Flow, Process Parameters

1. INTRODUCTION

The application of both electrical resistance tomography (ERT) and electrical capacitance tomography (ECT) techniques for the monitoring of industrial processes has been the subject of extensive research (Xie, Huang, & Hoyle, 1992; Dyakowski, 1996; Warsito & Fan, 2001; Jeanmeure, Dyakowski, Zimmerman, & Clark, 2002). Many of the contributions so far have been limited to image two-phase material distributions. Usually, ERT is used when the continuous phase is conductive in multiphase flows, such as gas-water two-phase flow in vertical pipe. On the contrary, ECT is used when the continuous phase is nonconductive in multiphase flows, such as oil-gas two-phase flow. When it comes to oil-gas-water three-phase flow, it is hard for ERT or ECT to obtain good cross-sectional reconstructed images, from which oil, gas and water can be discerned clearly.

In order to obtain tomograms of oil-gas-water three-phase flow, an image fusion method was presented in this paper. The conductivity of oil, gas and water is different and that is the case for the permittivity. Based on the fact that ERT is sensitive to the conductivity of objects and ECT is sensitive to the permittivity of objects, it is feasible to obtain the tomogram of oil-gas-water three-phase flow by image fusion based on the reconstructed images of ERT and ECT.

The following section describes the feasibility of the image fusion of ERT and ECT for oil-gas-water three-phase flow. After that, the reconstruction algorithms for image generation and the employed image fusion method are described briefly. Finally, simulation results were presented and discussed in detail.
2. ERT AND ECT SENSORS

2.1. The Structure of Sensors

The 16-electrode ERT and ECT sensors are depicted in Figures 1(a) and (b).

In ERT, the electrodes are mounted equally on the interior of pipe. The measured objects in pipe must be conductive and the electrodes must contact with them. While in ECT, the electrodes are mounted equally on the exterior of pipe. The measured objects in pipe must be nonconductive or most of the mixture of the multi-phase material is nonconductive.

2.2. Image Reconstruction Algorithms

There are many different image reconstruction methods for ERT and ECT, which can be mainly classified into two categories, direct methods (linear back projection, Tikhonov regularization and truncated singular value decomposition) and iterative methods (Conjugate Gradient and Landweber) (Yang & Peng, 2003; Marashdeh, Warsito, Fan, & Teixeira, 2006; Wang, Tang, & Cao, 2007). In our study, Landweber iterative algorithm with optimal step length was adopted which is defined as (Liu, Fu, & Yang, 1999):

\[ G_{k+1} = G_k + \eta_k S^T (\lambda - SG_k) \]  
\[ G_0 = S^T \lambda \]  
\[ \eta_k = \frac{\|S^T e_k\|^2}{\|SS^T e_k\|^2} \]

where \( e_k = \lambda - SG_k \), \( \lambda \) is the measurements, \( \eta_k \) is the step length and \( G_k \) is the normalized image grey in the \( k \)th iteration, respectively.

3. IMAGE FUSION OF ERT AND ECT

For oil-gas-water three-phase flow, the conductivity (\( \sigma \)) and relative permittivity (\( \varepsilon_r \)) of oil, gas and water are given in Table 1 (Hjertaker, Tjugum, Hammer, & Johansen, 2005).

Two cases (named case I and case II) were investigated in this paper. The process of image fusion for the first case can be depicted in Figure 2. In this case, water is the continuous phase, while oil and gas are dispersed phases. Only bubbly flow with clearly discriminated oil and gas bubbles was considered.

It can be seen from the reconstructed image of ERT in Figure 2, conductive (water) and nonconductive (oil and gas) objects can be clearly separated. Oil and gas bubbles have the same area and are on the same radial locations. The reconstructed images of oil and gas bubbles after threshold filter are the same. The quality of the reconstruction image will not be affected by the permittivities of oil and gas. The result is that oil and gas bubbles cannot be discerned.

From the principle of ECT, objects with different permittivities can be reflected by the reconstructed images of ECT. It can be found from the reconstructed image of ECT in Figure 2 that the oil and gas bubbles can be...
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