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Initial Study of a Wire Mesh Tomography Sensor for Liquid/Gas Component Investigation

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Abstract - Experimental studies have been carried out to study the principle operation of the conductive type wire-mesh tomography sensor and analyse the wire-mesh tomography sensor for the liquid/gas two-phase flow interface and void fraction distribution in a process column. The measurement of the two-phase flows in the process column is based on the cross-sectional local instantaneous conductivity. The sensor consists of two planes of parallel electrode wires with 16 electrodes each and was placed orthogonally with each plane. The sensor electrode wires were made of tinned copper wire with an outer diameter of 0.91 mm which stretched over the sensor fixture. Therefore, this result in the mesh grid size with $5.53 \times 5.53 mm^2$. The wire-mesh sensor was tested in a horizontal liquid/gas two-phase flows process column with nominal diameter of 95.6 mm and the sampling frequency of 5882.3529 Hz. The tomogram results show that the wire-mesh tomography provides significant results to represent the void fraction distribution in the process column and estimation error was found in the liquid/gas interface level.

Keywords: Process tomography, Wire-mesh sensor, Wire-mesh tomography

1. Introduction

Process tomography techniques are used to visualize the cross-section images of the mixtures of substances flowing in the process column. Process tomography produces cross-section images related to the phase fraction in the process column. Process tomography technique has widely used to investigate multiphase flow behaviour in oil and gas industries, chemical industries and also biotechnology industries [1]. An intrusive wire-mesh conductive tomography sensor is an alternative technique which was designed by H. M. Prasser in 1998 [2]. This sensor can use to gain void fraction distribution in multiphase flow process visualization. Multiphase flow describes the two or more physically distinct simultaneous flow mixtures in a process column. The mixtures can be the combination of one or more components of gaseous, liquid, or solid.

By using tomography techniques, several measurements like velocity or phase fraction boundaries can be determined and analysed. Thus, various tomography sensors used for the purpose of obtaining information such as phases flow patterns, phases flow velocity and phases boundaries investigation. Then, sensors' output data is then used to generate desire dimensional images to monitoring or analysis the process system involved. Therefore, tomography techniques can help to provide problems' solutions and improve process performance of system [3].

Process Tomography is very efficient to be used to visualize the cross-section images of mixtures of substances flowing in the process column. Among the sensing methods of process tomography, electrical process tomography including electrical capacitance tomography (ECT) based on permittivity value measurement and electrical impedance tomography (EIT) is more popular in recent years. This is because of electrical process tomography is convenient, low cost and safe compared with other methods based on nuclear magnetic resonance (NMR), X-ray or y-ray and ultrasound etc. [4]. The main disadvantages of electrical process tomography are the sensitivity problem, inverse problem [5] and fast forward problem [6]. Therefore, an intrusive wire-mesh sensor, namely, wire-mesh conductive tomography, is applied to overcome the shortcomings of electrical process tomography as stated above.

Wire-mesh sensor (WMS) is an alternative technique and is absolutely new to the tomography systems. A wire-mesh sensor is basically built with two layers perpendicularly located which were stretched over the process column as the transmitter layer and the receiver layer. The both layers of wires were installed orthogonal to each other without any physical contact. The first wire-mesh type tomography sensor introduced by Prasser *et al.* [2] at the Research Centre Rossendorf (FZR) was experimented to measure fluid conductivity.

On the other hand, a WMS is capable to measure the instantaneous interfacial phase fraction as well as the

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bubble's size and velocity passing through the WMS [2, 7, 8]. WMS is used to produce high spatial and temporal resolution, which is depending on the grid size of the designed WMS. Wire mesh tomography is function to detect the crossing point's electrical conductivity value and allow high speed cross-sectional phase distribution visualization. It is advantageous over many other tomographic devices in terms of low cost and non-hazardous compared to radiation tomographic methods.

Multiphase flow describes the two or more physically distinct simultaneous flow mixtures in a process column. The mixtures can be the combination of one or more components of gaseous, liquid, or solid. Basically, there are four types of multiphase mixtures can be identified [1], which are the liquid-gas flow, liquid-solid flow, gas-solid flow, and an immiscible liquid-liquid flow. Multiphase flow is not only important for engineering disciplines, but also for the industrial applications and others scientific fields like chemistry, physics, biology and meteorology.

2. Types of Process Tomography Techniques

The process tomography basic principle for multiphase flow investigation is to evaluate physical properties of phases flow a process column. Sensors were placed around the cross-section of a process column with an equal distance arrangement between each of it, then, the independent measurement data taken from sensors are used to reconstruct a two-dimensional image representing the interfacial distribution. Researchers as Ismail *et al.* [9] had concluded that an electrical capacitance tomography technique is very helpful in solving multi-phase flow meter and oil separator problems in the oil industry. While, Patel *et al.* [10] had proposed an electrical resistance tomography technique used to investigate the efficiency of continuous- flow mixing system for biopolymer inside a stirred tank reactor.

There are various tomography systems with different kinds of sensing techniques like radiation, electrical, ultrasound, and an intrusive tomography technique which is the wire mesh. Tomography techniques as the X-ray, gamma-ray, magnetic resonant imaging (MRI), optical, electrical, and ultrasound are the most common used for multiphase flow measurements. Each of the tomography techniques has its own advantages and disadvantages in the context of multiphase flow investigation.

X-ray tomography is based on the radiation frequency signal attenuation, which is because of the presence and influence of a subject. Gas and water in the two-phase flow process column are consisting of distinct attenuation characteristics of the X-ray radiation. Therefore, cross-sectional void fraction images can be obtained by using a rotating source-detector system. Besides, gamma-ray tomography is a non-intrusive method and its sensing principle is same as X-ray tomography as measuring the attenuation of ionising radiation [11].

Magnetic resonant imaging (MRI) is a famous tomography technique used in medical diagnostics, which is related to the evaluation on nuclear magnetic resonance due to the hydrogen nuclei when Larmor frequency is transmitted in the investigation area.

Optical tomography uses the projection light like infrared, visible or ultraviolet radiation as information carrier. The light is emitted and received by a well-designed source-detector system, and process images are then can be reconstructed by measured data of light intensity changes. Recently, a new approach to optical tomography system had designed by Yan and Liao [12].

Electrical tomography techniques can be divided into several branches as the normally invasive type electrical resistance tomography (ERT), the electrical impedance tomography (EIT) which is used to measure resistance and capacitance and the non-invasive type electrical capacitance tomography (ECT). These tomography systems had received significant attention from industry in recent years, this may be because of their low cost, convenient, and safe to use compared to others radiation tomography techniques. Electrical process tomography produces low resolution cross-sectional images, based on the measured data of permittivity and conductivity. A detail study on electrical tomography has been reported by Xie *et al.* [13], York [14], Tapp *et al.* [15], Marashdeh *et al.* [16], Cao *et al.* [17], and Mohamad *et al.* [18]. Among the sensing methods of process tomography, electrical process tomography including EIT and ECT is more popular in recent years. This is because of electrical process tomography is convenient, low cost and safe compared with other methods based on nuclear magnetic resonance (NMR), X-ray or y-ray and ultrasound etc. [4]. But, electrical process tomography had faced on the disadvantages of sensitivity problem, inverse problem [5] and fast forward problem [6].

Ultrasound tomography is a technique, where detectors were received the presence of acoustic waves transmitted from a source, which had travelled through a investigate area, and so the acoustic impedance properties are measured. At this moment, ultrasonic tomography measurements can be measured by applying the reflection mode [19] and the transmission mode [20, 21]. Both modes can successfully be employed for investigating multiphase flow with the assist of the most suitable image reconstruction algorithm.

3. Wire-mesh Sensor

Wire-mesh sensor (WMS) is an alternative technique and is absolutely new to the tomography systems [2]. A wire-mesh sensor is basically built with two layers and each layer is perpendicular to each other and stretched over the process column as the transmitter layer and the receiver layer. The both layers of wires were installed orthogonal to each other without any physical contact. WMS is a mesh of

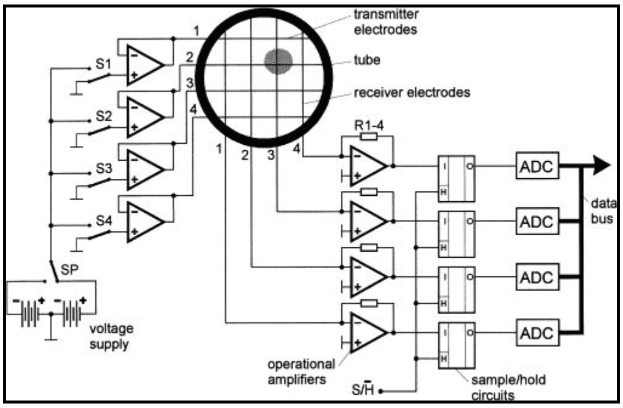


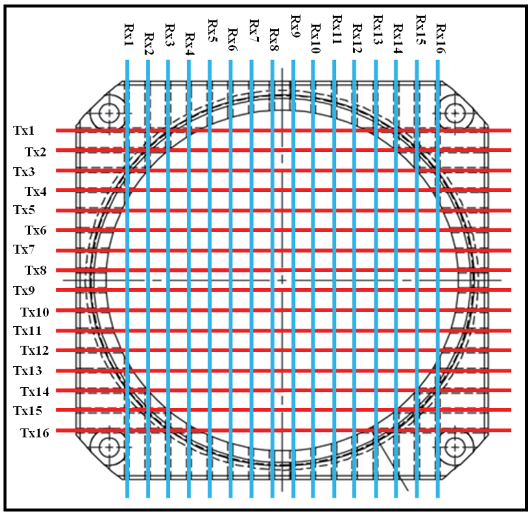
Fig. 1. Simplified scheme of the electrode-mesh device [2].

wire or bar electrodes, which separated into two planes, one as the transmitter electrodes and another plane arranged 90° to the transmitter plane is the receiver electrodes. Each of the electrodes is arranged with a desire pitch distance and there is also a small distance between the transmitter and receiver plane where the output value is measured at the crossing points of the electrodes. Wire-mesh sensor is capable to produce high spatial and temporal resolution investigated images. Wire-mesh sensor has two types of operating principle, which are based on the measurement of conductivity, or permittivity value in the investigation area. A WMS can be applied to overcome the shortcomings of electrical process tomography, and it also has an advantage of low cost compare to radiation based tomography.

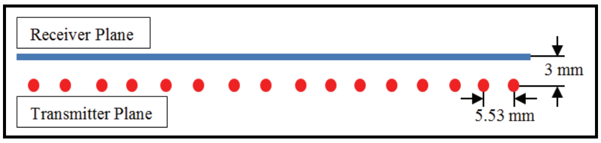
Fig. 1 is the illustration of a 4x4 wire-mesh sensor, the transmitter electrodes as Tx1, Tx2, Tx3 and Tx4 have a completed circuit linked to its voltage supply terminal and the receiver electrodes as Rx1, Rx2, Rx3 and Rx4 is linked to its signal processing circuit. At the beginning, Tx1 is activated and Tx2, Tx3, and Tx4 is grounded, and then measuring the value of conductivity of each crossing point between Tx1 and the receiver electrodes Rx1, Rx2, Rx3, Rx4 as a single loop. After that, Tx2 is activated, Tx1, Tx3 and Tx4 is grounded, and then measuring the value of conductivity of each crossing point between Tx2 and the receiver electrodes Rx1, Rx2, Rx3, Rx4 as another loop. Continue to do the measuring loops for Tx3 and Tx4, then, a complete 4x4 matrix of measurement data is obtained.

3.1 Design of the wire-mesh sensor

The sensor is designed to have two layers of tinned copper electrodes, which is perpendicular between each layer. There is a 2×16 wires with wire diameter, D = 0.91 mm, pitch distance between each of the electrodes, P = 5.53 mm, plane distance between transmitter plane and receiver plane, H= 3 mm. This WMS will stretch over a Perspex process column, which the column inner diameter, D_{in} = 95.6 mm, outer diameter is 101.6 mm. A matrix of 16×16 (256 measured values) is measured after exciting



(a)



(b)

Fig. 2. (a) Top-view of WMS Fixture; (b) Front-view of WMS Fixture.

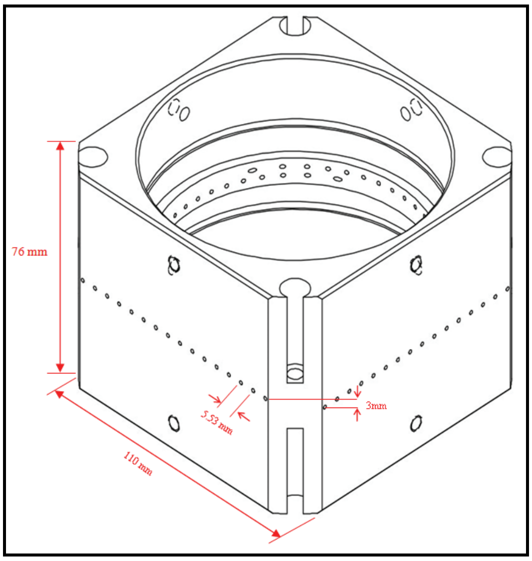


Fig. 3. Wire-mesh tomography sensor's Fixture.

the last transmitter electrode, only 216 of the crossing point is useful. Fig. 2 (a) and (b) shows the top view of initial designed wire-mesh sensor, where Tx1 to Tx16 is the electrodes of transmitter plane (horizontal red line) and the Rx1 to Rx16 is the receiver electrodes (vertical cyan line).

The sensor fixture shows in Fig. 3 does have a height of 76 mm and its width is just 110 mm that installed between two process columns. An O-ring is placed 10 mm above and below of the electrodes planes to prevent any leakage from the process column.

Each electrode plane allows 16 parallel wires to stretch over to both ends and all of the electrodes were crimped with screw connector as refer to Fig. 4, and the electrode was made of tinned copper wire with the diameter of 0.91 mm. The transmitter and receiver plane were distributed orthogonal to each other in the cross-section of the process column, which form a grid that has a pitch value of 5.53 mm. A distance equals to 3 mm was separating the transmitter and receiver plane. Therefore, the designed wire-mesh tomography sensor geometry provides a spatial resolution of 30.58 mm^2 in a process column with a cross-sectional area of 7178.04 mm^2.

The wire-mesh sensor manufactured as shown in Fig. 4 is used to investigate the liquid/gas flow interface and the phases void fraction visualization. Fig. 5 illustrates a complete structure of wire-mesh tomography sensor system design. It consists of components such as a wire-mesh sensor, transmitter electronic circuit, ADC module, unit of micro-controller, data transfer unit, and a functional computer. This wire-mesh tomography sensor system design is based on the advantages of two samples of wire-mesh sensor signal acquisition and processing method in [22] and [23].

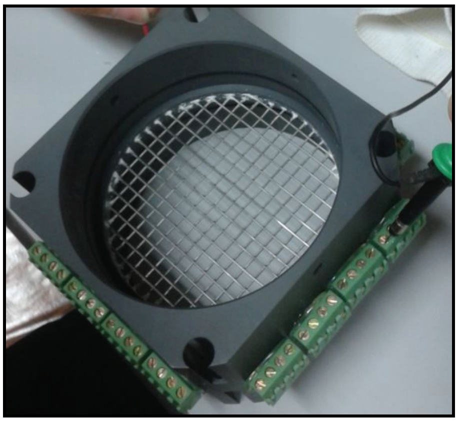


Fig. 4. Illustrations of manufactured wire-mesh sensor.

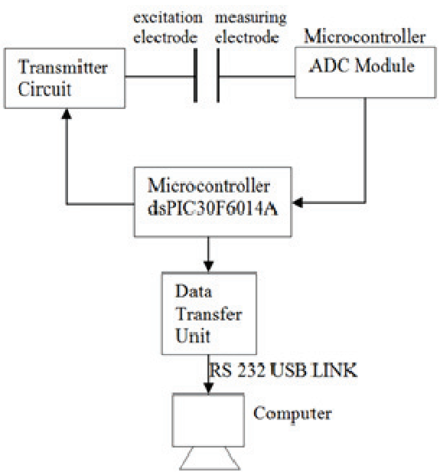


Fig. 5. Block diagram of wire-mesh sensor tomography system.

The micro-controller unit was used to control the excitation of the transmitter electrodes. A 5V rectangular pulse was generated for only 0.165 ms as the excitation period of a transmitter electrode by the micro-controller. The transmitter electrode was activated sequentially. The data acquisition (DAQ) strategy used in the conductive wire-mesh tomography sensor system is to design a simple approach to investigate the cross section phase information by using the wire-mesh tomography technique. Therefore, a micro-controller, dsPIC30F6014A, with built-in ADC module was used to process the receiver signal from each receiving electrode simultaneously for each excitation period. An USB to UART converter was used as the data transfer unit, that allows serial communication with the computer.

4. Results and Discussions

The liquid/gas interface visualization can be achieved by using the colour scale technique to distinguish the phases

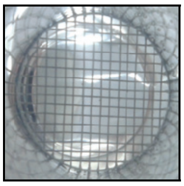
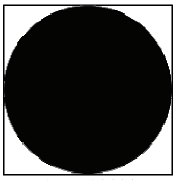
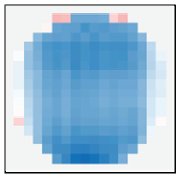
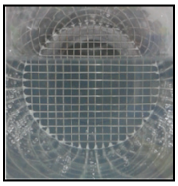
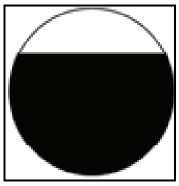
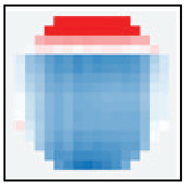
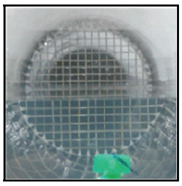
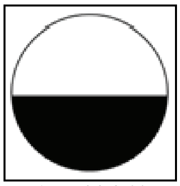
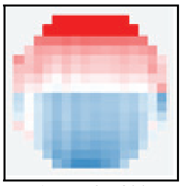
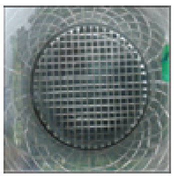
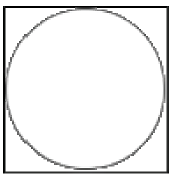
	Void Fraction	Phantom	Tomogram
A		 A_L = 100%	 A_L = 96.76%
B		 A_L = 74.23%	 A_L = 77.88%
C		 A_L = 46.67%	 A_L = 52.78%
D		 A_L = 0%	 A_L = 0%

Fig. 6. Illustrations of the void fraction, phantom and the tomogram results.

in the process column, then, plotting them in their node position formed by the orthogonal parallel wires. Each node represents the centre of grid size of 5.53×5.53 mm^2. The phantom image was used to clearly describe the experimental situation and the liquid/gas interface level. The results are shown in Fig. 6 where AL denotes the liquid area (in percentage).

The error of the tomogram result for phantom A may lead to misinterpreting the instantaneous flow situation as bubbly flow located at the top and east area of the result image, even though the actual measurement volume is completely filled with liquid in the process column. A careful observation of the result of the experimental data shows those crossing point values near to the sensor's wall were relatively lower than the others crossing point values that not at the periphery of the wire-mesh sensor. Therefore, the liquid/gas distributions at the periphery of the wire-mesh sensor need to be determined by a calculation method that is different to the central crossing point measuring method.

Two distinct regions of the liquid/gas two phase flows in the process column were well depicted in the tomogram result image B. But, an observation of the liquid/gas interface level shows that there is an overestimation of the level of liquid/gas region's interface with the calculated error was about 3.65%. The tomogram result image of C is still consists of the periphery crossing point error as discussed in tomogram result image B, but the few centre crossing points above the liquid/gas interface is the major of the sensing error. Those crossing points should not be indicated as liquid phase, but the sensing values of those crossing points are mostly near to interface value.

The tomogram results B and C from the wire-mesh sensor shown that an overestimation occurred slightly in the determination of phases interface compared to its phantom. However the discrepencies are small and acceptable in this experiment.

5. Conclusion

The liquid/gas two-phase flow interface and its void fraction were experimentally investigated using conductive type wire-mesh tomography sensor. The circular type wire-mesh sensor was designed for a circular cross-sectional area test section of 7178.0366 mm^2. Wire-mesh tomography technique provides reliable measurement of liquid/gas two-phase flow interface and its void fraction, as a maximum error for liquid/gas two-phase flow is recorded in the phantom C with 6.11%. Besides, full liquid flow phantom A has achieved a accuracy of 0.9676, while the full gas flow accuracy of phantom D is 1. In order to improve the estimation of the gas-liquid interface using the wire-mesh tomography technique, a suitable image reconstruction algorithm needs to be studied in the future.

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