Current Signal versus Voltage Signal Excitation Source in Wire Mesh Tomography: A Simulation Study

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Available online 29 December 202

ABSTRACT

Wire mesh tomography (WMT) is widely used to investigate liquid-gas two-phase flow and single-phase mixing processing. A common approach in wire mesh tomography is to apply a voltage as a source and measure the current at the receivers. However, it is believed that by exciting a current signal at the transmitter, it will increase the signal distribution because of the positioning of the wire mesh itself. Thus, the objective of this paper is to propose the current excitation source at the transmitter and measure the voltage at the receivers. Based on AC/DC physics studies, a 3D simulation using finite element model software (COMSOL Multiphysics) was used to draw a 3D wire mesh sensor and get the sensor readings. A MATLAB software was used to reconstruct the tomograms of WMT. Besides, the wire mesh sensor was tested in a vertical liquid/gas two-phase flow process column with a nominal diameter of 30 mm. A single wire-mesh sensor with 8 x 8 electrode wires was used with a temporal and spatial resolution of 10 kHz, 5V voltage, and 4 mA current. Different bubble conditions of liquid-gas in the pipe were tested. Hence, the sensor reading performance and tomogram of the region of interest were obtained and analyzed. The image became more visible for the bubble with a radius of 19 mm by exciting the voltage at the transmitter. It can be proven that the gas phase cross sectional area, AG, for a bubble with a radius of 19 mm is higher than 10 mm and 4 mm, which is 2120.575 mm^2 or 75%. Besides that, by exciting the current, the gas phase cross-sectional area, AG, for a bubble with a radius of 19 mm was 989.6 mm^2, or 35%. However, when using current excitation as a source to detect tomograms in two-phase flow, more research is required.

Keywords: wire mesh tomography, current signal, liquid-gas

1. Introduction

Process tomography techniques are used to visualise the cross-section images of the substances in the horizontal or vertical pipes in our industries. This technique has generally been used to investigate two-phase flow behaviour in the oil and gas industry [1], the chemical industry [2] and biotechnology [2] as well. Process tomography has become of widespread interest in research due to its advantage of being non-destructive to the process or object being measured. There are four types of sensing techniques for tomography, which are intrusive, non-intrusive, invasive, and non-invasive [3]. The word "intrusive" is linked to how the sensor protrudes into the medium of interest and "invasive" is related to how the sensor is applied to the inner surface of the wall of the pipeline [3]. However, this technique can be combined so that it can be intrusive and invasive, intrusive and non-invasive, non-intrusive and invasive, and non-intrusive and non-invasive. Non-intrusive and non-invasive methods are commonly used in industry because they can minimise the hazards of working with poisonous, radioactive, explosive, flammable or corrosive materials and decrease the safety and accountancy difficulties associated with valuable process materials [3]. However, this technique 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. One of the intrusive and invasive processes in tomography is wire mesh tomography (WMT), which will be our concern in this paper.

Wire-mesh tomography (WMT) is widely used to characterise liquid-gas two-phase flow. The function of WMS is to detect the electrical conductivity value of the crossing point and allow high speed cross-sectional phase distribution visualisation [4]. A wire-mesh sensor is basically built with two layers perpendicularly across at an angle of 90° [2]. Both layers are installed orthogonal to each other without any physical contact. The first wire-mesh type tomography sensor was introduced by *Prasser* et al. [1] *at* the Research Centre Rossendorf (FZR*)*. It was experimented to measure fluid conductivity. On the other hand, wire-mesh tomography (WMT) is capable of measuring the instantaneous interfacial phase fraction as well as the bubble's size and velocity passing through the WMT. The WMT is used to generate high spatial resolution and temporal resolution, which is based on the size of the grid of the WMT-designed [2]. It is preferable over many other tomography devices in terms of low cost, high accuracy, and non-hazardous compared to others. Moreover, if the WMT is used for multiphase flow applications, the constituent fluids are required. It is needed to distinguish between the values of the measured property. Besides, the conductivity of the medium tested using the WMT requires at least one of the constituent fluids to have a relatively large value of electrical conductivity, for example, greater than 5 S/mm.

Basically, the common wire mesh tomography uses a tinned copper wire as the sensor. A common practice is applying a voltage excitation at each of the transmitter and obtain current measurement at the receivers. The current approach state that-the potential field was limited within a certain space by these zero potential wires and the received current has a strong relationship with the local fluid conductivity [5]. However, according to the potential simulation results, the uniform sensitive volume assumption is not accurate enough. As a conductive sensor, it is expected that by exciting a current distribution at the transmitter, the signal projection is more accurate compared to the voltage excitation and hence can get more accurate data of the sensor readings performance. Consequently, this technique is investigated and compared to the common approach in WMT

2. Basic Working Principle of WMT

The author in Ref. [6] used the wire-mesh sensor to measure the electrical conductivity of the air-water regime. Air is considered electrically insulating, while pure water is a conducting fluid. The wire-mesh sensor, which is based on a matrix arrangement of electrode wires with 16 x 16 electrode wires that are installed in a rectangular transparent channel, was used with a temporal and spatial resolution of 10 kHz and 3.1 mm. The first layer is a current transmitter, while the second one is a current receiver. According to Prasser in Ref. [2], [6]- [7], the transmitter wires are activated by a multiplex circuit successively. When one of the switches is connected, the receiver wires scan the received current individually. In that way, the current flows to the receiver wire through a control volume of a two-phase mixture around the crossing point of the two wires. Then, the currents are converted into voltages by operational amplifiers and sampled by individual sample circuits. Lastly, the analogue-to-digital conversion signals are stored for each wire. After the activation of the last transmitter, a two-dimensional matrix containing the conductivity values of all crossing points is obtained. Figure 1 below shows the simplified electrical scheme for an example of 4 x 4 wire mesh.

The measurement of the WMT is based on the sequence selection of transmitter channels. The electrodes are labelled from Tx1 until Tx8 and have a completed circuit linked to their voltage source or current source, and Rx1 until Rx8 as receiver electrodes. Firstly, when Tx1 is activated, Tx2 until Tx8 will be grounded, and then the value of the current or voltage signal of each crossing point between Tx1 and the receiver electrodes R1 until Rx8 as a single loop will be obtained. After that, Tx2 is activated, Tx1, Tx3, until Tx8 is grounded, and then the signal at each of the receivers will be measured as another loop. This process is repeated until all the transmitter channels have been set as transmitter, Tx, and all signals have been received at the receivers. Here, in this project the focus is to use the current as the excitation source and measure the voltage at the receivers.

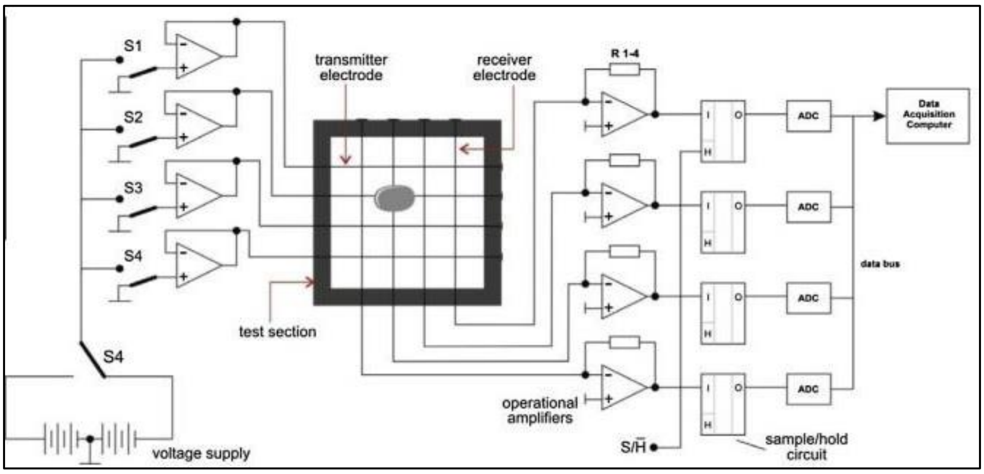

Figure 1. Simplified electrical scheme for example of 4×4 wire mesh sensor [13]

3. Methodology

3.1 Simulation WMT model using COMSOL Multiphysics

The Comsol Multiphysics software was used for designing, analyzing, and stimulating wire mesh electrodes in the application of liquid-gas identification. Figure 2 shows a basic flow process for WMT model where the WMT sensor consists of an 8 x 8-electrode wire in a 30 mm inner diameter vertical pipe. The transmitter electrodes are labelled from Tx1 to Tx8, while the receiver electrodes are labelled from Rx1 to Rx8. The AC/DC module of COMSOL Multipyhsics with electric current (ec) physics study was used in this study.

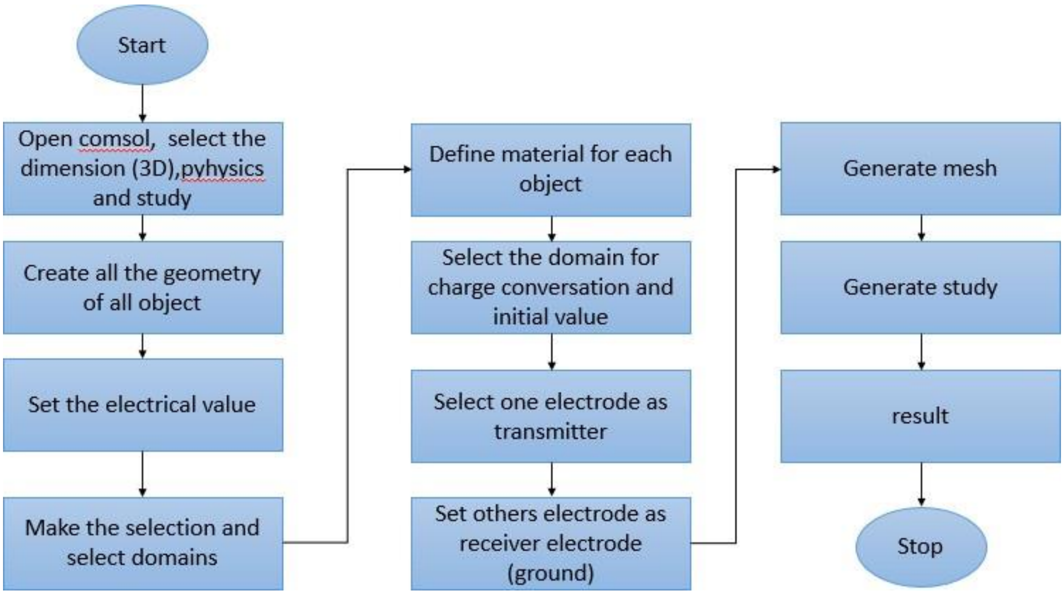

Figure 2. Basic flow process in COMSOL Multiphysics

In order to model the WMT electrode in COMSOL Multiphysics, the cylinder geometry was used to model the pipe and the wire electrodes, while the sphere was used as the air bubbles. For this case, the parameters such as diameter of the pipe, number of electrodes, and size of the electrode are based on the literature review. After the physical model is built, each domain needs to be defined based on its material to ensure the simulation same as a real application. Basically, the material of the electrodes must have high electrical conductivity and with that, copper will be the best material to be used as electrodes. For this project, the parameters used in WMT model were set as shown in Table 1.

Table 1. Parameters of WMT model

Item	Parameter
Number of electrodes	8×8
Diameter of electrode	0.2 mm
Gap between transmitter to transmitter	7.5 mm
Distance between transmitter and receiver	3.901 mm
Inner diameter of pipe	30 mm
Type of electrode	Copper (σ=5.998e7, ε= 1)
Excitation voltage	5 V
Excitation current	4 mA
Tested medium	Water (σ=9.13e-3, ε= 81) Air (σ=10e-15, ε= 1)

All the parameters were set up in COMSOL and the 3D design of 8×8 WMT electrode with 8 transmitter and 8 receiver was shown in Figure 3. The 3D model is chosen because the 2D model cannot show the gap of the wire plane axial distance between each of the transmitter and receiver.

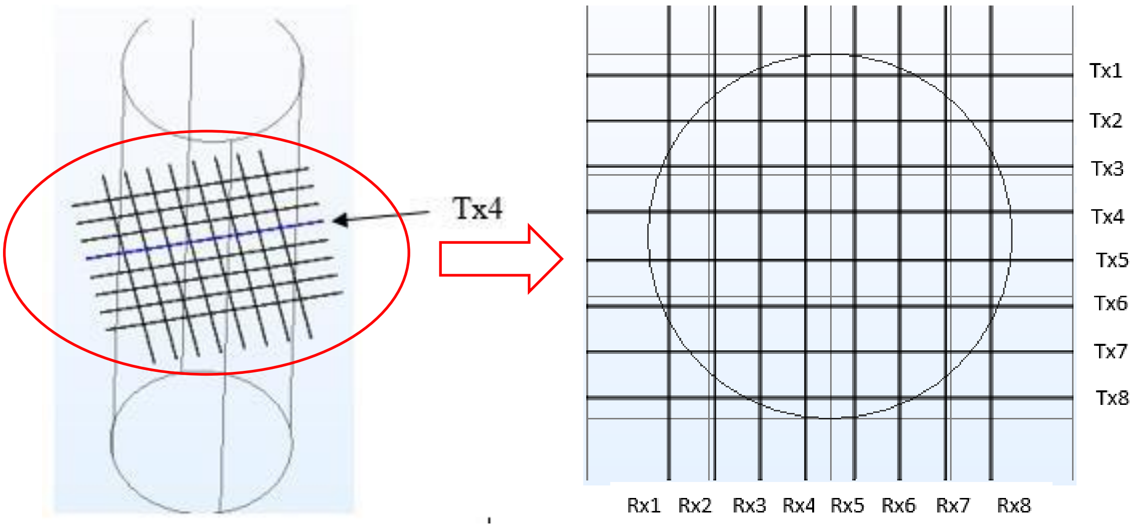

Figure 3. 3-Dimensional of WMT model with label of each channel in 2-dimensional

The measurement of electrical potential distribution is performed between each of the crossing point of transmitter and receiver. A matrix of 8 × 8 (64 measured value) is measured after exciting the last transmitter electrode, whereby only 40 points of the crossing point is useful. Figure 4 shows 40 crossing point is useful in this simulation. Domain point probes are used to measure the sensor reading at the receiver. At the same time, the measurement of electrical potential was taken between useful crossing point at Rx1 till Rx8 and the other 7 electrodes will be grounded.

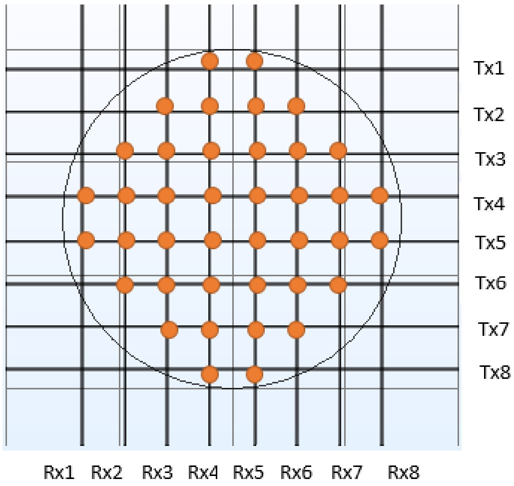

Figure 4. 40 crossing point used in the simulation

3.2 Image Reconstruction using MATLAB

In obtaining the tomogram for every tested medium, MATLAB simulation software was applied in this paper. The sensor loss and flow process are shown in Figure 5. Each of the sensor reading form the COMSOL Multiphysics software was obtained and export into MATLAB. Then, the sensor loss reading and tomogram coding were determined in MATLAB as illustrated in Figure 6. Later, the cross-sectional area, A as in equation 1 was obtained for the analysis purpose.

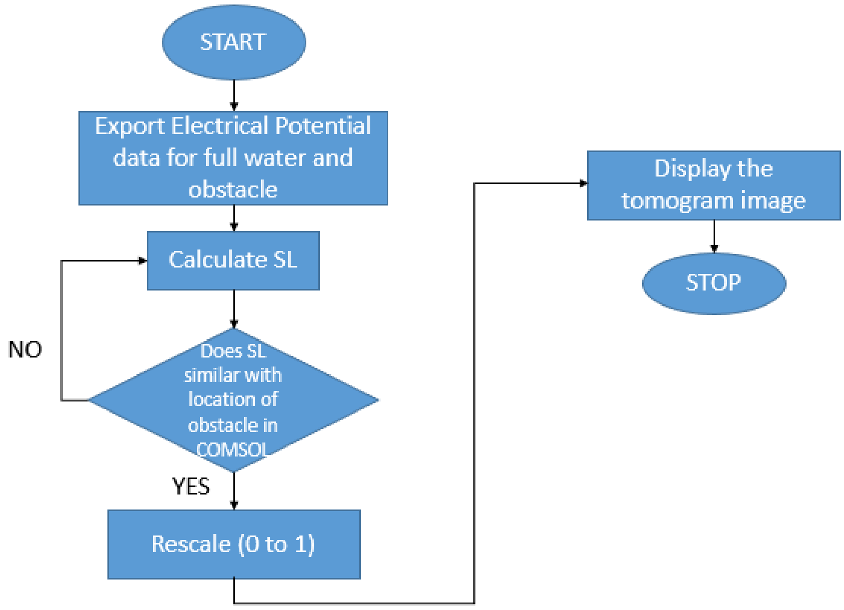

Figure 5. Basic flow process of image reconstruction in MATLAB

$$cross - sectional\ area, A \ = \pi r^2 \quad (1)$$

Where, r is the radius of vertical pipe and π equals to 3.1416. By using this formula, the total cross-sectional area for this system is 2827.433 mm^2. Since only 40 crossing is useful, each crossing point representing an area of 70.68583 mm^2 or 2.5 %.

```
%%Clear work space
clear all;
%%Load the sensor reading for full water(Homo) and with obstacle(Non_Homo)
%%Make sure the sensor reading value are electrical potential
%%If have N electrodes make sure the table are NxN for both


load fullwater.txt;
load obstacle.txt;

%%Make a repsentation for fullwater and obstacle
A=fullwater;
B=obstacle;
%%Calculate sensor loss
SL=(A-B)./A;
```

```
load SL;

DispMap= zeros(8);

NormDispMap=SL; % rename display image
a = min(NormDispMap(:));
b = max(NormDispMap(:));

for Tx = 1:8;
 for Rx = 1:8;
 NormDispMap(Tx,Rx) = ((NormDispMap(Tx,Rx)-a)./ (b-a))*1;
%%Eliminate NaN value at norm DispMap ; if not matlab cant plot img

 e=NormDispMap(Tx,Rx);
 d=isnan(e);
 e(d)=NaN;
 NormDispMap(Tx,Rx)=e;
 end
end

%Displaying map
%subplot(1,1,1);
pcolor(NormDispMap(1:8,1:8))
imageCenter=[64,64]; %Pixel/2
title('reconstructed image(rescaled 0-1)');
shading interp; % To hide the grid line from pcolor
colormap (jet) % Change color map to jet colour
colorbar % Display colorbar at RHS
%subplot(1,1,1);
%imagesc(NormDispMap(1:pixel,1:pixel))
%set(gca, 'YDir', 'normal'
```

Figure 6. Coding for calculating sensor loss and obtaining tomogram in MATLAB

4. Results and Discussion

The simulations for electrical field distributions was divided into two parts which are the homogenous and non-homogenous conditions for voltage excitation and current excitation. The plain water was used as the tested medium for getting the result. Thus, when one of the transmitter wire electrodes was activated, the potential field within the electrodes were produced. Noted that only 40 crossing points are used to measure the sensor reading and the unused points will be replaced by Not a Number, NaN.

Three different sizes of air as a bubble were tested in observing the result of voltage signal as the excitation source and current signal as the excitation source (see Figure 7). Based on Figure 7, it showed that the electrical potential for position at (x=1, y=32, z=100) for voltage excitation had less electrical potential value compared to the position at (x=1, y=62, z=100) and for current excitation, the value of electrical potential is slightly same which is 8e+05 V. Based on the comparison between each of the line graph conditions with the homogenous, there were always appear the decrement of electrical potential value at the receiver for both methods approaches. This effect was due to the air bubble was blocking the path of electrical field distribution at the transmitter.

After the simulation of three conditions had been done in COMSOL Multiphysics, it was time to proceed to the final process, which is the image reconstruction part. By using MATLAB simulation, the sensor loss reading was implemented to generate the tomograms of the different conditions of the obstacles. The voltage source and current source were compared to observe the results under different conditions. Figure 8 shows the tomograms of the different bubble sizes, which were 4 mm, 10 mm, and 19 mm. Then, the calculation of the gas phase cross sectional area, AG, and liquid phase cross sectional area, AL, were determined from equation 1. The calculations were made based on the concentration of colour in the tomogram.

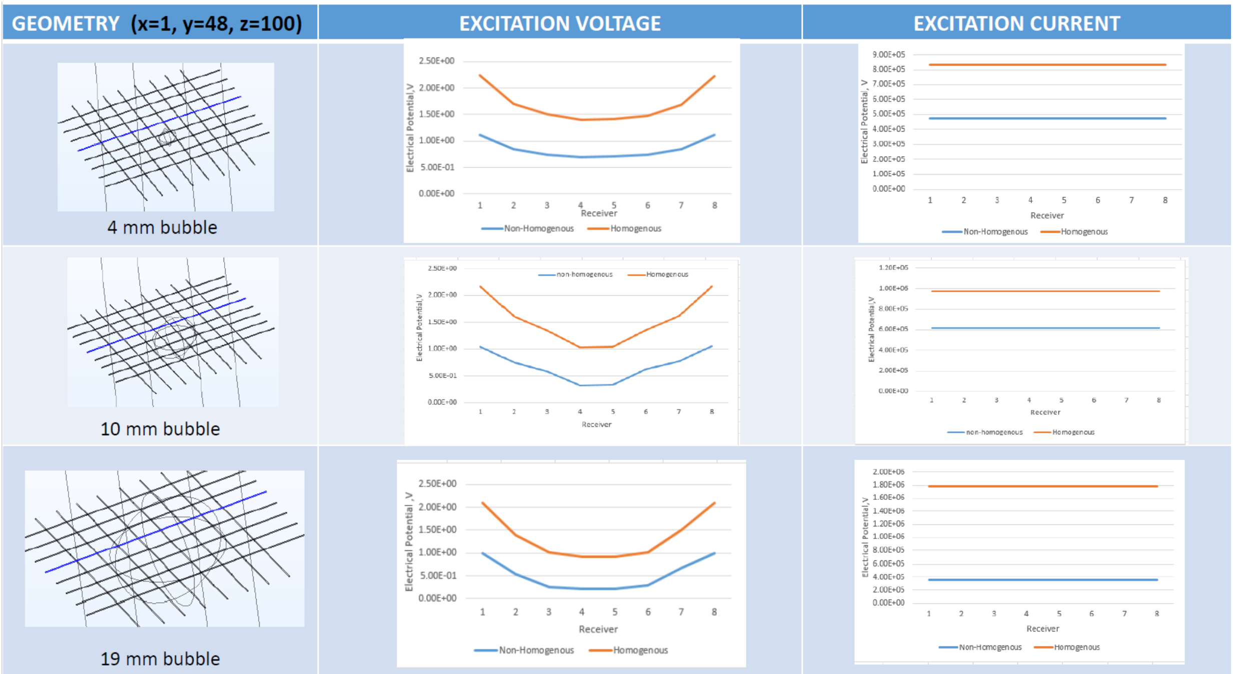

Figure 7. The line graphs comparison of electrical potential value for both technique

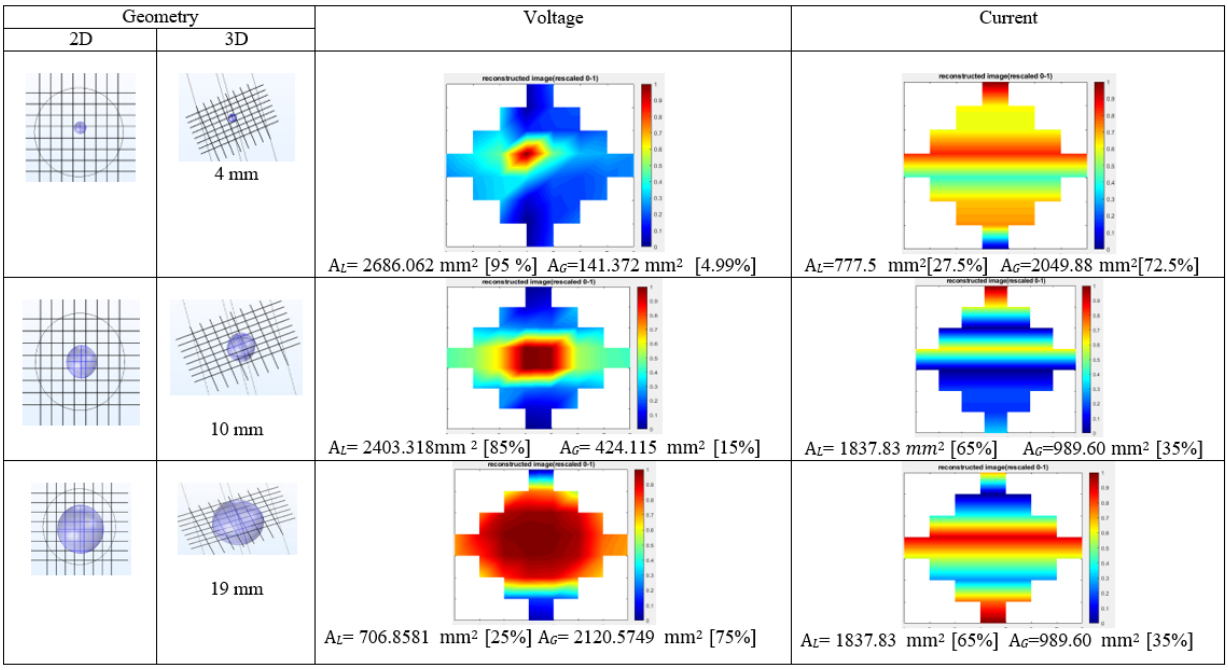

Figure 8. Image reconstruction for different size of obstacle at the same position (x=1, y=48, z=100)

Furthermore, by exciting the voltage at the transmitter, the image became more visible for the bubble with radius 19 mm. It can be proved that the gas phases cross sectional area, A_G, for bubble with radius 19 mm is higher than 10 mm and 4mm which is 2120.572 mm^2 or 75% as shown in Figure 8. Besides that, by exciting the current signal at the excitation channel, the gas phase cross sectional area, A_G, for bubble with radius 19 mm is 989.6 mm^2 or 35%.

5. Conclusion

In short, the objectives of this paper were generally have been achieved. Based on the simulation results obtained, the WMT has been modeled using 3D geometry in COMSOL Multiphysics software to be applied in liquid/gas identification in two phase flow. In order to develop this system, 8×8 electrodes were used with 0.2 mm diameter of wire. Usually, the common approach in WMT is based on the voltage excitation at the transmitter and measure current at the receiver. Hence, as a conductive sensor, it is expected that by exciting a current distribution at the transmitter, whereby the signal projection is more accurate compared to the voltage excitation. Consequently, this technique is investigated and compared to the common approach in WMT. In addition, the wire mesh tomography provides reliable measurements of liquid-gas two phase flows interface and its void fraction. However, based on the simulation results, it is recommended that more effort should be invested into estimating the gas-liquid phase interface using the WMT technique for current signal excitation because the results were not good as those achieved using the voltage excitation technique.

Acknowledgment

The authors would like to thank the Collaboration Research Grant (CRG-UTM) RDU182304 and CRG 05G04 for support the research.

5. References

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