

**ANALYSIS OF THRESHOLDING TECHNIQUES FOR TWO-PHASE
IMAGE**

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Department of Electrical & Electronic Engineering
Universiti Teknologi PETRONAS
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Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Muhamad Suhaidi Bin Umar

INVOLVEMENT FROM THIS WORK

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ABSTRACT

This report presents the result of a study the behaviour of two-phase gas-liquid flow and two-phase liquid-wax waxy crude oil by using several thresholding techniques. The behaviour of gas-liquid is based on liquid film thickness and liquid holdup for gas-liquid flow and behaviour of liquid-wax is based on wax volume fraction. Several thresholding techniques are applied on the images which are captured by Electrical Capacitance Tomography (ECT). The results at the end of this report show which thresholding techniques are capable of yielding good threshold's images and which methods can be used for the two-phase images in ECT applications.

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LIST OF ABBREVIATION

ECT	Electrical Capacitance Tomography
MPF	Multiphase Flow
GUI	Graphical User Interface
LFT	Liquid Film Thickness
LHU	Liquid Holdup
WVF	Wax Volume Fraction
WAT	Wax Appearance Temperature

LIST OF NOMENCLATURE

Symbols

b	Binary Value	A	Area of pipe (m^2)
k	Bias Factor	D	Diameter of pipe (cm)
p	Probabilities	M_G	Gas flow rate (L/m)
q	Total probabilities at certain level	M_L	Liquid flow rate (L/m)
ν	Liquid viscosity (kg/ms)	N	Total pixels in image
w	Window size	I	Image Intensity
y	Threshold level for Otsu's method	R_{eL}	Reynolds's constant
		R	Maximum standard deviation
		T	Threshold Value

Greek Symbols

μ	Means	δ	Liquid film thickness (cm)
ρ_G	Density of gas (kg/m^3)	σ	Standard deviation
ρ_L	Density of liquid (kg/m^3)	σ^2	Variance

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In industrial process and petroleum industry, the mixture of two components (two-phase) regularly occurred where both phase will be transported together in the same pipeline. The two phase that be discussed in this report are gas-liquid flow and liquid-wax. One of the techniques in order to study the behaviour of two phase mixture is by using Electrical Capacitance Tomography (ECT). ECT is a simple, non-invasive and non-intrusive, flow regime independent and low cost method. ECT is a type of Multiphase Flow (MPF) Meter which is capable of providing the real time data to monitor the multiphase performance in pipeline. MPF meter already has been used in well-testing infrastructure in order to reduce the high cost of single phase techniques.

ECT can provide the cross-sectional image and important parameters such as liquid film thickness, liquid holdup, wax volume fraction and others. Some parameters are used for flow rate calculation such as prediction of wet gas flow rate in venturi tube. Besides that, we also can observe the formation of wax in crude oil at different temperature by using ECT.

Two-phase images must be distinct between two components to calculate those parameters by using thresholding techniques. There are a lot of thresholding techniques are needed to be analysed in order to determine which threshold's method are preferable in two-phase image of ECT applications. The threshold's methods will be compared with Otsu's method [1] (as benchmark) since this method was already proved by other researchers [2] which is this method can be used in two-phase image of ECT applications.

1.2 Problem Statement

1.2.1 Problem Identification

The ECT is capable of capturing the images of two-phase mixture such as gas-liquid and liquid-wax mixture. Those images contain the valuable information such as liquid film thickness, liquid holdup and wax volume fraction and others. In order to calculate those parameters, the image needs to separate between two components either gas-liquid or liquid-wax. For that purpose, threshold's technique needs to be applied on the image. After thresholding process, two-phase will be distinct to two different regions. But, there are many thresholds' methods that will result different threshold's images. Therefore, this project applies some threshold's methods in order to determine which methods are capable of solving and yielding the good threshold's images and capable of providing the important parameters from those images.

1.2.2 Significances of Project

By determining some threshold's methods that can be used in ECT application, it will help for the next research such as estimation of wet gas flow rate in venturi meter that was reported by Huang *et al.* [3]. They predicted the total mass flow rate in two-phase by calculating the gas void fraction in the pipeline. Therefore, when they try to apply different threshold's methods in their research, they will obtain different value of gas void fraction and different value of total mass flow rate. By comparing those data with their ground through, they will obtain the best methods for predicting the total mass flow rate in two-phase flow. It means, this report is an early step to provide several acceptable threshold's methods for the main parameter's calculation in oil and gas industry such as mass flow rate in two-phase flow.

1.3 Objective and Scope of the Project

1.3.1 Main Objective

The main objective in this project is to determine which threshold's methods are suitable and preferable to be used in two-phase image of ECT applications. In order to complete the main objective, the sub-objectives in this project must be achieved:

- i. Implement some threshold's methods including Otsu's [1], Niblack's [4], Sauvola's [5] and hybrid's method by Kuo [6] onto the asymmetrical annular two-phase gas-liquid images by using own MATLAB programming. The threshold's method that will produce the good threshold image will be used for next calculation.
- ii. Calculate liquid film thickness and liquid holdup from threshold's images by using the acceptable threshold's methods from the first objective. Then, to determine which threshold's methods will trend their results within $\pm 10\%$ of Otsu's results (benchmark).
- iii. Calculate the wax volume fraction from waxy crude oil images. It is to determine the behaviour of crude oil and formation of wax at the changing of temperature.

1.3.2 Scope of Project

In this report, we focus on ECT which is one of the best methods to measure two-phase flow. The project focuses on the measurement of annular two-phase gas-liquid flow in vertical upward flow and liquid-wax of waxy crude oil. Then, thresholding will be applied in this measurement process. Threshold's algorithm including Otsu's [1], Niblack's [4], Sauvola's [5] and hybrid's method by Kuo [6] will be studied and will be implemented to the images by using own programming in MATLAB. The MATLAB programming skill will be used in order to apply the threshold's algorithm into MATLAB.

1.4 Relevancy of Project

When the chosen and preferable threshold's algorithm is applied to the real industrial plant process, it will improve the process of visualization, monitoring, safety purpose, environmental protection, energy conservation, increase product quality, and possibly for intelligent control in future.

1.5 Feasibility of Project

Final year project will be done in two semester and about 8 months. The project is including research (literature review), MATLAB programming and data analysis. The scope of project only focuses on threshold's algorithm and applying it onto the asymmetrical annular two-phase gas-liquid vertical upward flow images and liquid-wax of waxy crude oil images. The asymmetrical annular gas-liquid images are gathered from previous project by Ismail *et al.* [7] and the waxy crude oil images are gathered from the experiment that was run in UTP by PhD student. Then, MATLAB will be used as software in order to apply own programming.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Study of two-phase mixture is applicable to wide range of applications such as in industrial plant, reactor and others. Two-phase flow in particular gas-liquid and liquid-wax are usually discussed because by controlling or monitoring two-phase mixture in pipelines will improve the online measurement, increase quality control and increase safety control. The discussion will follow the flow in figure 1.

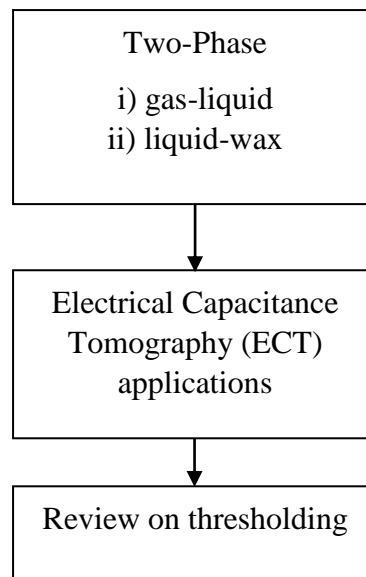


Figure 1 : Flow of literature review

2.2 Two-Phase Phenomena

2.2.1 Gas-Liquid

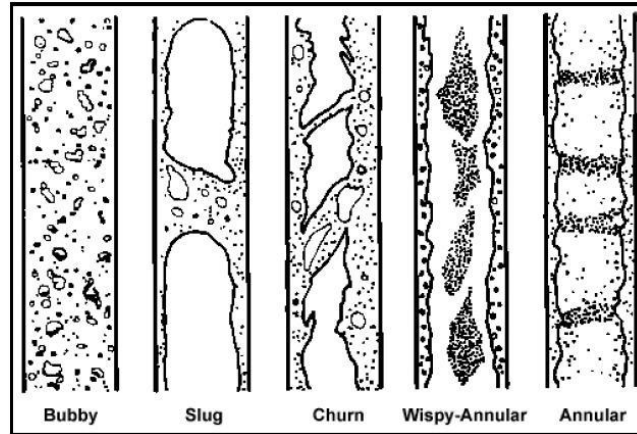


Figure 2 : Flow pattern in vertical upward two-phase gas-liquid flow

The flow patterns that can be occurred in vertical upward gas-liquid flow are bubble, slug, churn, wispy-annular and annular as shown in figure 2 [8]. One of the most common gas-liquid flow patterns is the annular flow [9-15]. It is characterized by a thin film of liquid around the channel wall and a gas core at the centre of channel. When high gas flow rate on the liquid film becomes dominant over gravity, the liquid will flows as a thin film on the wall after is expelled from the tube centre while gas continuous flow at the tube centre. Most of the time, the annular flow in a pipeline is asymmetrical which is the radius of thin film for every angle from the centre are not same as shown in figure 3 below.

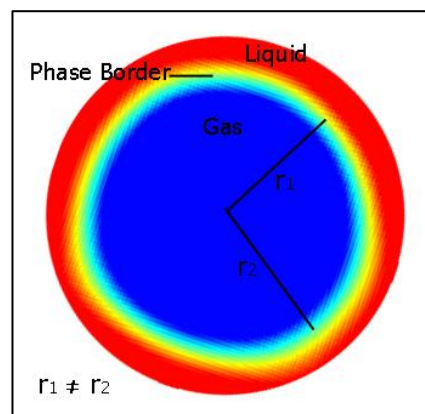


Figure 3 : The example of asymmetrical annular two-phase flow

2.2.2 Liquid-Wax

Liquid-wax is happened when the wax start to form in pipeline where contains the crude oil. It is happened when crude oil flows through a subsea pipeline on the ocean floor, the temperature of oil eventually decreases below its wax appearance temperature (WAT) because of the heat losses to the surroundings. Then, the wax starts to form in the pipeline [16-17].

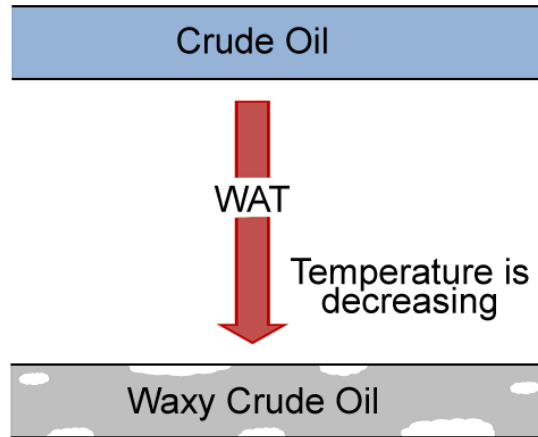


Figure 4 : Formation of wax in crude oil

2.3 Electrical Capacitance Tomography (ECT)

One of the technologies that are capable of examining the two-phase mixture is electrical capacitance tomography (ECT) [2,7,18-19]. ECT is a type of multiphase flow (MPF) meter which is based on non-invasive visualization technique which is capable of obtaining cross-sectional images from dynamic industrial process. Dyakowski *et al.* [18] and Ismail *et al.* [2] conclude that, ECT is preferred because it is flow regime independent, non-intrusive, low cost and minimal maintenance.

ECT is developed to reconstruct the dielectric properties after the measurement of electrical capacitance taken between all possible pairs of electrode are done [18] such shown in figure 5 below; electrode 1-2 as C1, electrode 1-3 as C2 until electrode 8-7. ϵ_1 and ϵ_2 are the measured characteristic of components in the pipeline.

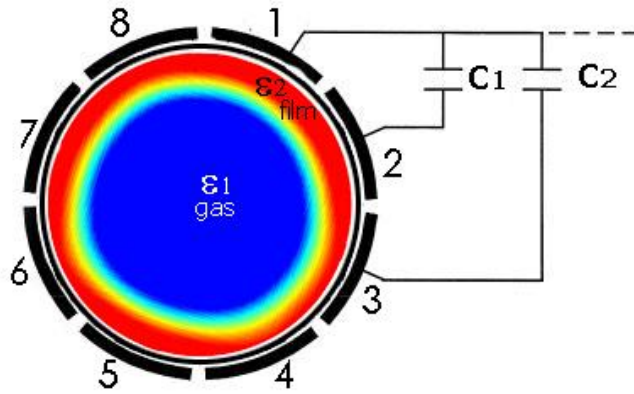


Figure 5 : Basic Configuration of Electrical Capacitance Tomography (ECT)

2.4 Review on Thresholding Techniques

In this experiment, thresholding technique is needed in order to separate between two components to two different phases. Thresholding algorithm will change the grey-scale of images which are taken by ECT to binary scale. In binary mode, two different components are separated at the phase border. The figure 6 below shows the images of two-phase before and after thresholding is done.

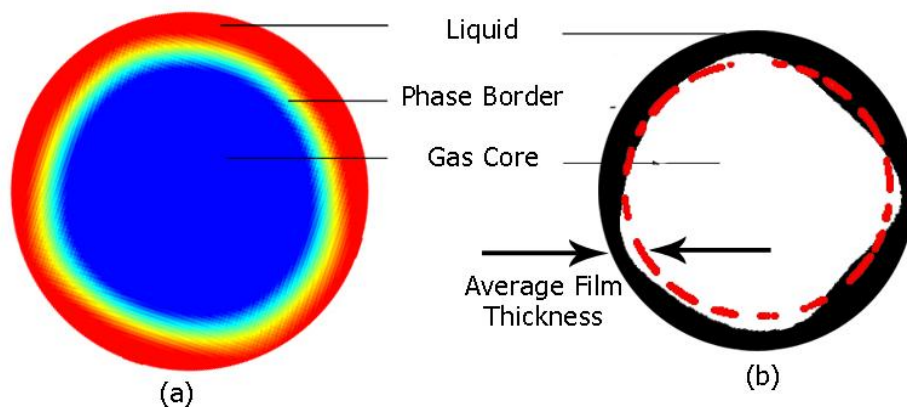


Figure 6 : The example of gas-liquid image (a) before and (b) after thresholding

Since the distribution of liquid around the pipe's wall is asymmetrical and always changes in real-time data, the calculation of liquid film thickness only takes the average of thickness on the image was taken.

2.4.1 Otsu's method algorithm

Otsu's method [1] is a global thresholding and histogram-based technique. Otsu chose the value of threshold by minimising the value of within-class variance, σ_B^2 of the whole image. Let, the level of image's gray-scale denoted by $[1, 2, \dots, L]$ and the number of pixels at the level i is represented by n_i . Therefore, the total pixels in the images will be equal to $N = n_1 + n_2 + \dots + n_L$.

The probabilities of histogram of the images will be:

$$p_i = n_i/N \quad (2)$$

where $p_i \geq 0$ and $\sum_{i=1}^L p_i = 1$

Now, the image is divided to two classes; object, X_1 and background, X_2 at the level, y . Therefore, X_1 are the pixels that have value of level $[1, \dots, y]$ and X_2 is the pixels that have value of level $[y + 1, \dots, L]$. The total probabilities for each class are represented in equation (3) and equation (4) below. Then, the class mean for both classes are represented in equation (5) and equation (6) below:

$$q_1 = \sum_{i=1}^y p_i \quad (3)$$

$$q_2 = \sum_{i=y+1}^L p_i \quad (4)$$

$$\mu_1 = \sum_{i=1}^y ip_i/q_1 \quad (5)$$

$$\mu_2 = \sum_{i=y+1}^L ip_i/q_2 \quad (6)$$

The classes' variances are given by:

$$\sigma_1^2 = \sum_{i=1}^y \frac{(i - \mu_1)^2 p_i}{q_1} \quad (7)$$

$$\sigma_2^2 = \sum_{i=y+1}^L \frac{(i - \mu_2)^2 p_i}{q_2} \quad (8)$$

The value of class probabilities, q , class mean, μ and class variance, σ^2 changed when the level y was changed. Therefore, Otsu find the level y that make the within-class variance, σ_B^2 is minimize by using equation (9) below:

$$\sigma_B^2(y) = q_1(y) \sigma_1^2(y) + q_2(y) \sigma_2^2(y) \quad (9)$$

2.4.2 Niblack's method algorithm

Niblack [4] is a local thresholding which is the image is divided to sub images within a window size $w \times w$. Each pixels will have own threshold's value, $T(x, y)$ by considering the neighbourhood pixels within window size. The value of threshold is denoted by:

$$T(x, y) = \mu(x, y) + k\sigma(x, y) \quad (10)$$

Where $\mu(x, y)$ and $\sigma(x, y)$ are the local mean and standard deviation of the pixels within window size and k is the bias factor between 0 and 1. Local mean and local standard deviation means the values that calculated for each sub-image by using the pixels intensity in that sub-image.

2.4.3 Sauvola's method algorithm

Sauvola's method [5] also one of the local thresholding and since Niblack's method produced some noise at the background, Sauvola's method suggested the Niblack's equation was modified by adding a factor R where R is maximum value of standard deviation, σ in the image. The equation is used in Sauvola's method is:

$$T(x, y) = \mu(x, y) \left[1 + k \left(\frac{\sigma(x, y)}{R} - 1 \right) \right] \quad (11)$$

where k is a bias factor between 0 and 1.

2.4.4 Hybrid algorithm

Hybrid's thresholding was proposed by Gorman [20] and Liu *et al.* [21] by combining the advantages of global and local thresholding. In 2010, Kuo *et al.* [6] combined Otsu's method which is global thresholding with Niblack and Sauvola's methods which are local thresholding. The objective of this algorithm is to retain the picture information after binarization.

Firstly, hybrid's method will obtain the threshold value from global thresholding or Otsu's method and is denoted by T_{global} . Then, value of T_{global} will be used in local thresholding. The image is divided to sub-images or window, W by using size $m \times n$. Then number of pixels that have grey value less than T_{global} in W is represented as N . Then, the method choose another value from image's histogram and denoted by S where value of S is less than T_{global} and the selection of S is to make the number of pixels falling between S and T_{global} be a quarter of N .

Thus, the target pixel, p in window W will be binarized by using equation (12) below:

$$b(p) = \begin{cases} 1 & , I(p) > T_{global} \\ Local\ Thresholding & , T_{global} \geq I(p) > S \\ 0 & , I(p) \leq S \end{cases} \quad (12)$$

Local thresholding in (12) is used when the grey level of the pixels, $I(p)$ within W is between T_{global} and S . Local thresholding algorithm in (13) will calculate T_{local} :

$$T_{local} = \begin{cases} \mu_{local} - \frac{\sigma}{T_{global}} & , |I(p) - \mu_{local}| \geq \frac{T_{global}}{16} \end{cases} \quad (13.1)$$

$$\left[\mu_{local} \times \left[1 + k \left(\frac{\sigma}{T_{global}} - 1 \right) \right] \right] , |I(p) - \mu_{local}| < \frac{T_{global}}{16} \quad (13.2)$$

Where k is a preset constant, μ_{local} is the average gray value of all pixels in window,

W and σ is local standard deviation of the gray value of pixels in window, W . Noted that, equation (13.1) and equation (13.2) are Niblack's and Sauvola's method respectively. The local standard deviation equation is calculated by using equation (14):

$$\sigma = \sqrt{\frac{\sum_{i=0}^{m-1} \sum_{j=0}^{n-1} (I[W(i,j)] - \mu_{local})^2}{m \times n}} \quad (14)$$

Once the value of local threshold, T_{local} is obtained, binarization will be using equation (15) below:

$$b(p) = \begin{cases} 1, & I(p) > T_{local} \\ 0, & I(p) \leq T_{local} \end{cases} \quad (15)$$

Table 1 : Summary of histogram thresholding techniques

Method	Otsu [1]	Niblack [4]	Sauvola [5]	Kuo (hybrid) [6]
Classification Techniques	histogram	histogram	histogram	histogram
Performance Quality	Global	Local	Local	Global + Local
Advantages	Faster algorithm	Improve Otsu's method	Improve Niblack's method	Improve Otsu's, Niblack's and Sauvola's methods
Drawbacks	Noise for complex background	Noise at the background	Lost some data	Slower algorithm
Complexity	Moderate	Moderate	Moderate	High

Table 1 is a summary of review on thresholding techniques including Otsu's, Niblack's, Sauvola's and Kuo's method.

CHAPTER 3

METHODOLOGY

The project was start with experiment setup, follow by ECT measurement and image reconstruction which are done by system. Then, the images were threshold by using selected techniques. After that, several parameters from the threshold's images were calculated and lastly, data gathering.

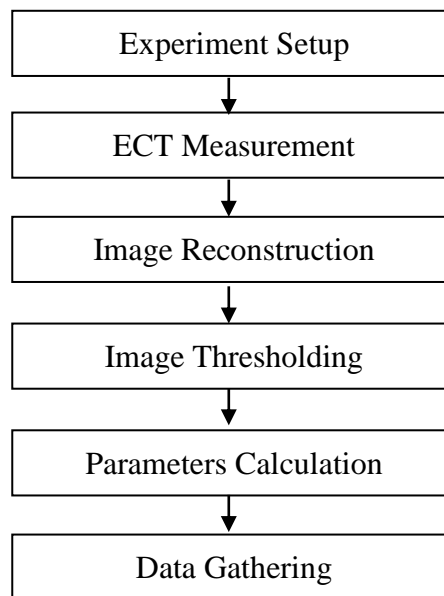


Figure 7 : Final Year Project Flow Chart

3.1 Experiment Setup

3.1.1 Gas-Liquid

In this experiment, a venturi meter is used in vertical orientation. Figure 8 below show a drawing of venturi meter with 4 main locations which are inlet, outlet, throat1 and throat2 where ECTs were placed. The diameter for inlet and outlet is 32 mm and the diameter for throat1 and throat2 is 16mm. Then, the experiment was done at 4 different gas flow rate and at 9 different liquid flow rate. In this experiment, we assume that no liquid droplets in the gas region and no liquid back flow.

Table 2 : Liquid and Gas volume flow rate

Gas Volume Flow Rate (L/m)	Liquid Volume Flow Rate (L/m)								
	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
550				X	X	X	X	X	X
600			X	X	X	X	X	X	X
650		X	X	X	X	X	X	X	X
700	X	X	X	X	X	X	X	X	X

Sign of “X” means, the images are captured at respective liquid and gas volume flow rate.

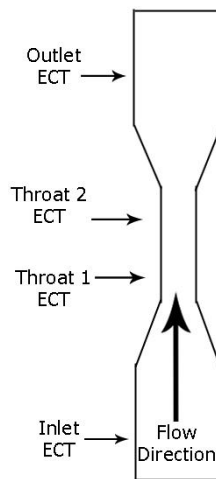


Figure 8 : 4 locations for annular flow capturing

3.1.2 Liquid-Wax

The experiment is run by using ECT sensor in order to capture the crude oil image in static mode. Figure 9 and 10 below illustrate how the experiment on crude oil is run. At first, crude oil was warmed by warm water to rise the temperature of crude oil. Once, the temperature of crude oil reach around 40°C, crude oil is transferred into ECT. Images start to be captured at several temperatures.



Figure 9 : Upper view of ECT that contains crude oil

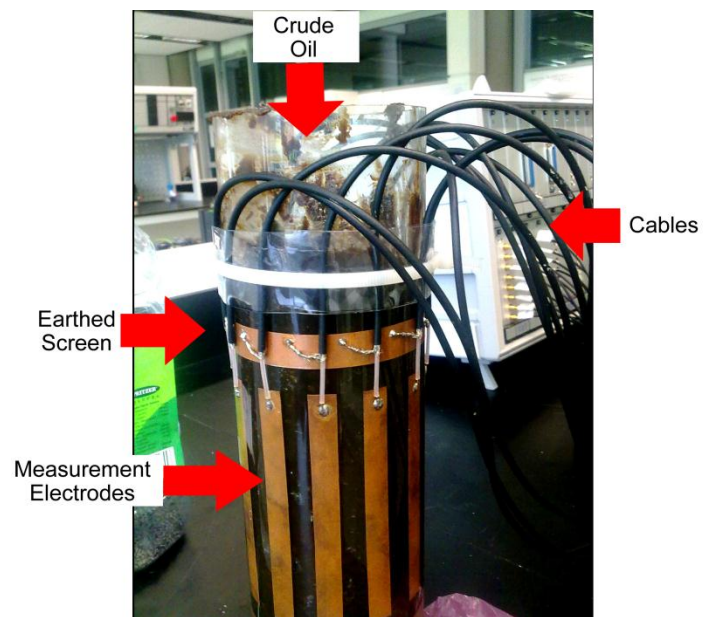


Figure 10 : Front view of ECT that contains crude oil

ECT sensor specifications:

- i. Number of Electrodes: 12
- ii. Electrodes length: 100mm
- iii. Electrodes width: 10mm
- iv. Distance between electrodes: 2mm
- v. Pipe diameter (Inner): 78mm
- vi. Pipe diameter (Outer): 80mm

3.2 Image Reconstruction

Image reconstruction can be categorised to two categories which are iterative and non-iterative techniques. The commonly used is non-iterative algorithm which is Linear Back Projection (LBP). The fraction of high permittivity material, $E(p)$ at pixels, p is shown in equation (16):

$$E(p) = \frac{\sum_{i=1}^{N-1} \sum_{j=1}^N \lambda_{ij} S_{ij}(p)}{\sum_{i=1}^{N-1} \sum_{j=1}^N S_{ij}(p)} \quad (16)$$

where S is the sensitivity map and the normalised changes in capacitance, λ is shown in equation (17):

$$\lambda_{ij} = \frac{C_{ij}^m - C_{ij}^l}{C_{ij}^h - C_{ij}^l} \quad (17)$$

where

C^m = Measure capacitance of the mixture flowing through pipe (F)

C^h = Measure capacitance when the sensor is full of high permittivity material (F)

C^l = Measure capacitance when the sensor is full of low permittivity material (F)

The examples of two-phase images that had been captured by ECT at different temperature for liquid-wax experiment are shown in figure 11.

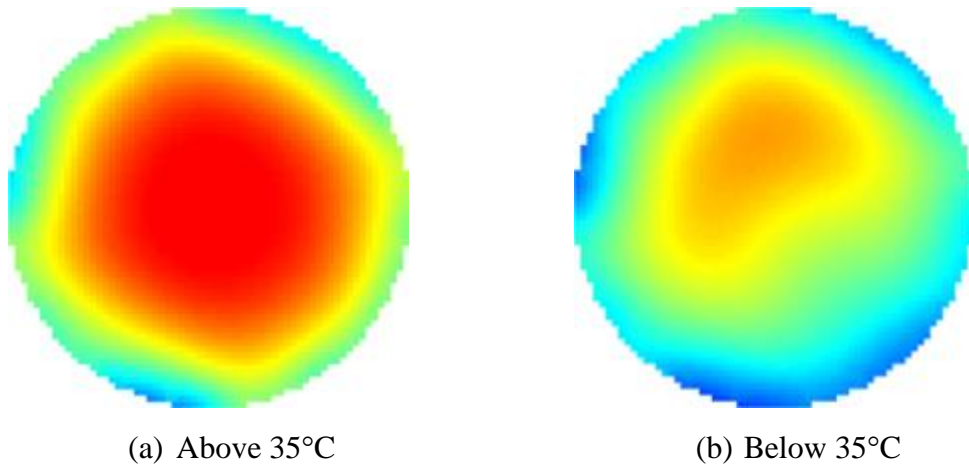


Figure 11 : Example of waxy crude oil image (a) above and (b) below WAT (35°C)

The examples of annular images that had been captured by ECT at different locations for gas-liquid experiment are shown in figure 12. Those images were captured at 550L/m of gas flow rate and 0.4L/m of liquid flow rate.

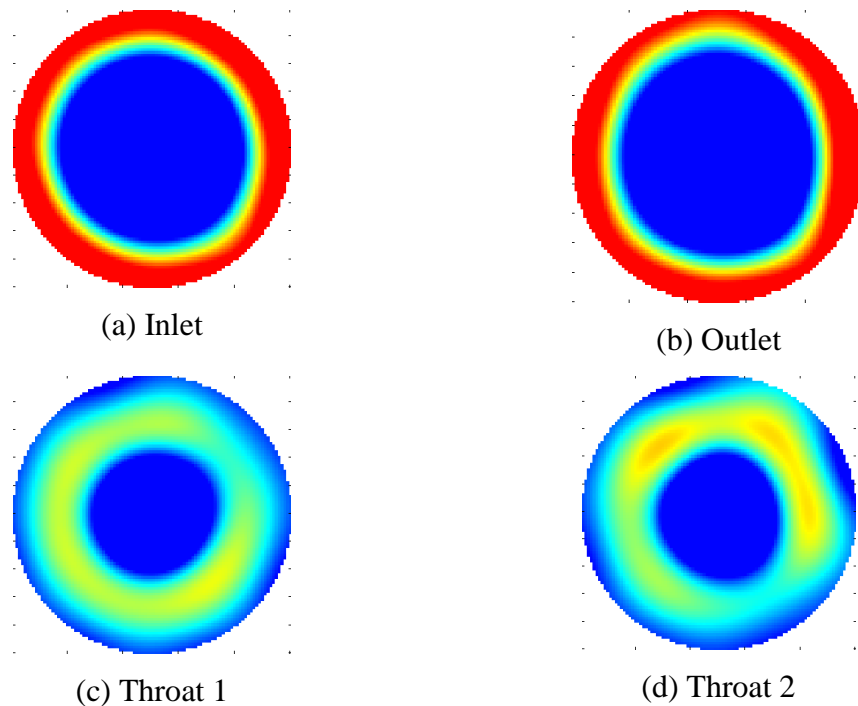


Figure 12 : Annular Images were taken at different locations

3.3 Image Thresholding

The thresholding techniques have been used in this experiment are Niblack's, Otsu's, Sauvola's, and Kuo's methods. Those algorithms are shown in this report (chapter 2.3). Those algorithms and equations are converted to MATLAB programming and test with some annular images. After going through the testing process, we found that Niblack's method unable to produce the good threshold's image. Therefore, the next procedures only use Otsu's, Sauvola's and Kuo's methods for comparative analysis. The basic algorithm Otsu's, Sauvola's and Kuo's methods are shown in figure 13, 14 and 15 respectively.

3.3.1 Otsu's Algorithm in MATLAB

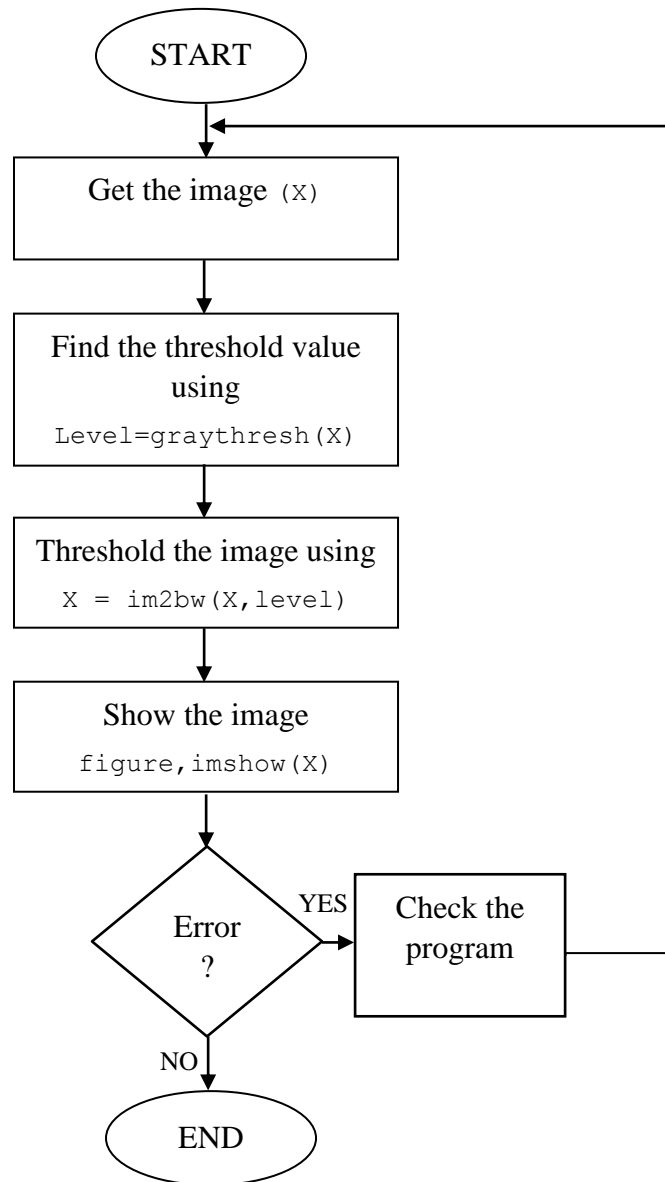


Figure 13 : Flow Chart for Otsu Algorithm

The whole programming for Otsu's algorithm is attached in Appendix A.2.

3.3.2 Sauvola's Algorithm in MATLAB

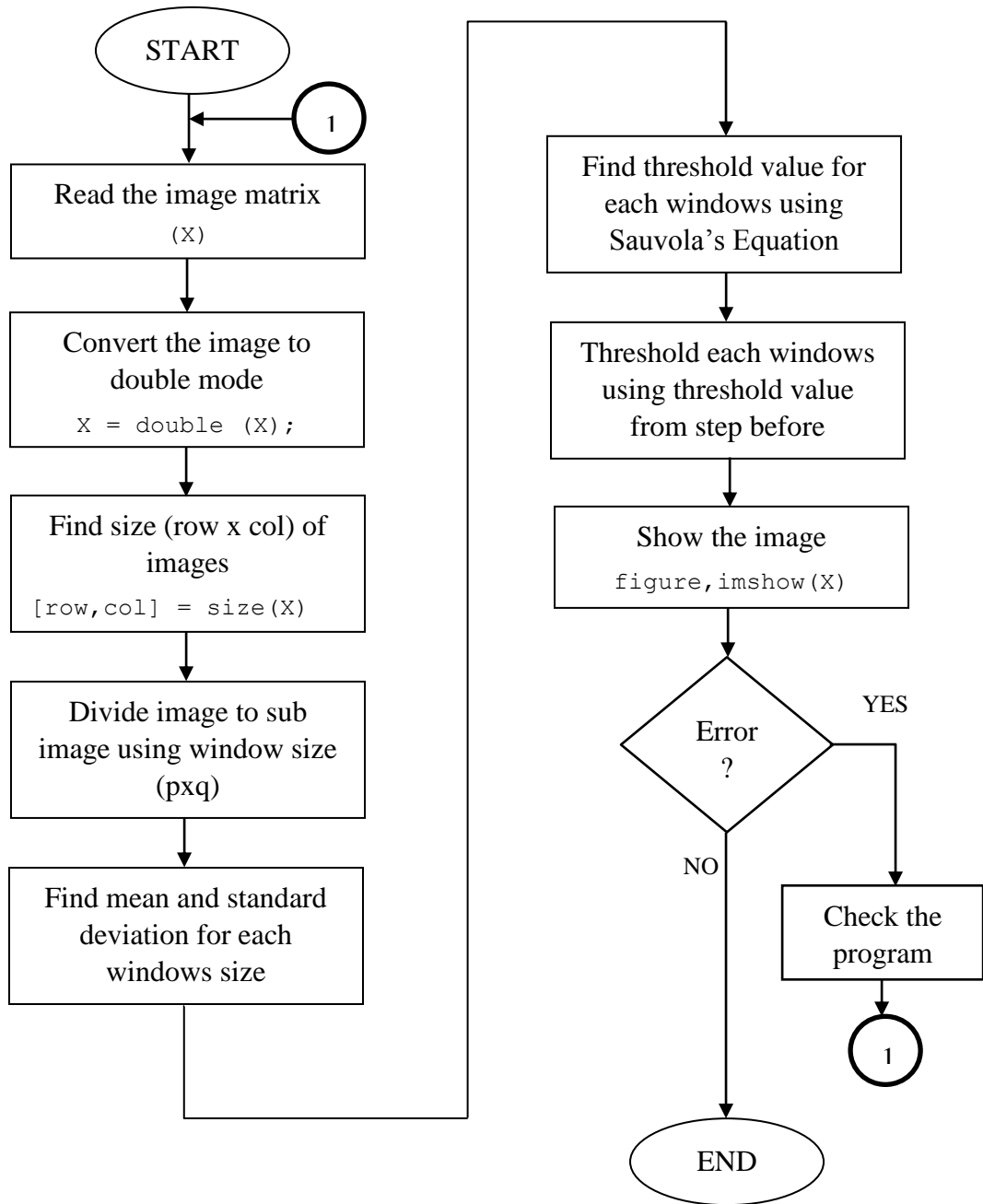


Figure 14 : Flow Chart for Sauvola's Algorithm

The whole programming for Sauvola's algorithm is shown in Appendix A.3.

3.3.3 Kuo's Algorithm in MATLAB

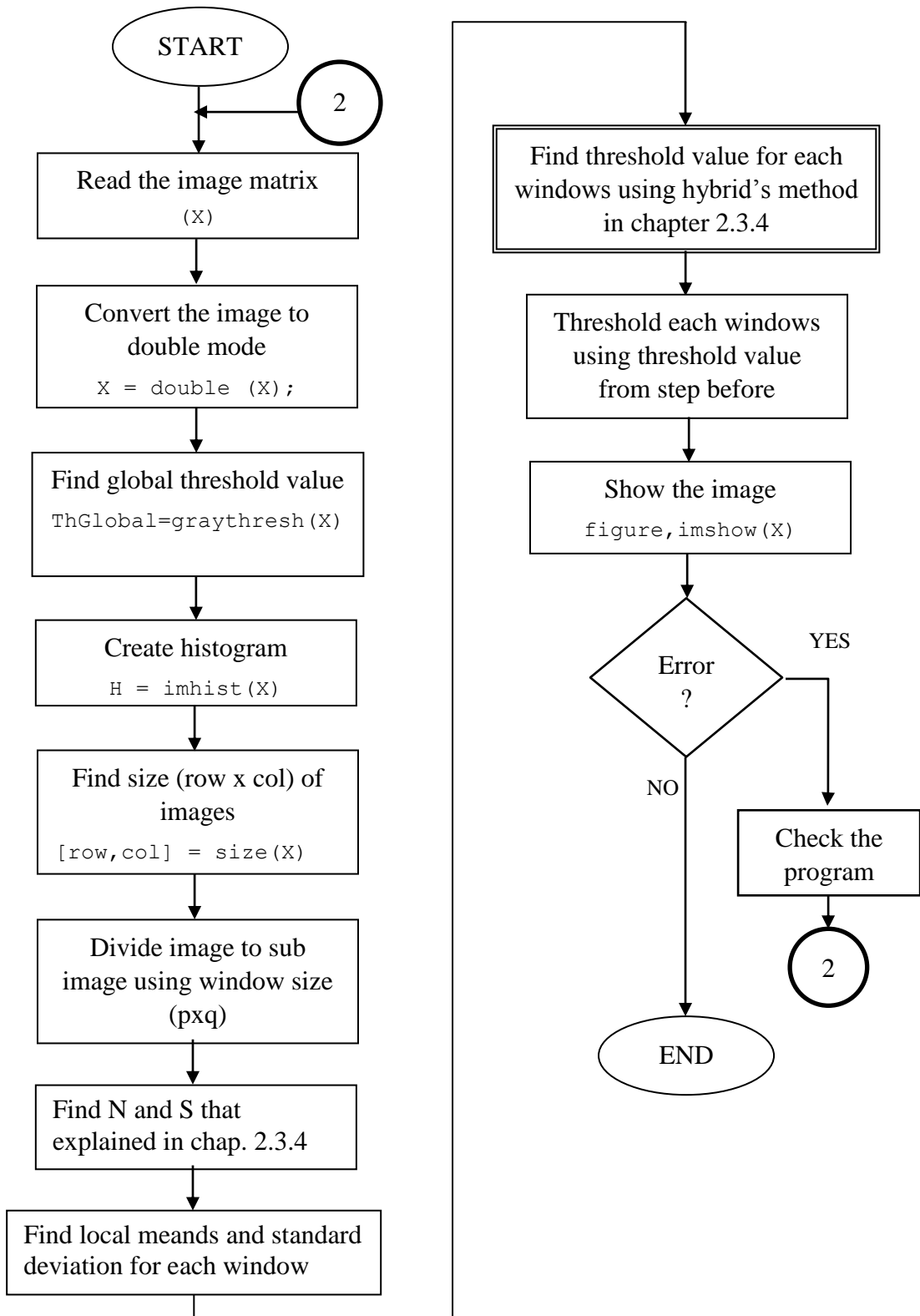


Figure 15 : Flow Chart for Kuo's Algorithm

The real programming for Kuo's or Hybrid's algorithm is shown in Appendix A.4.

3.4 Graphical User Interface (GUI)

The main parameters are liquid film thickness and liquid holdup from asymmetrical annular flow image. The parameters are calculated in MATLAB programming by using a Graphical User Interface that is totally created by me. The programming for the main GUI is shown in Appendix A.1.

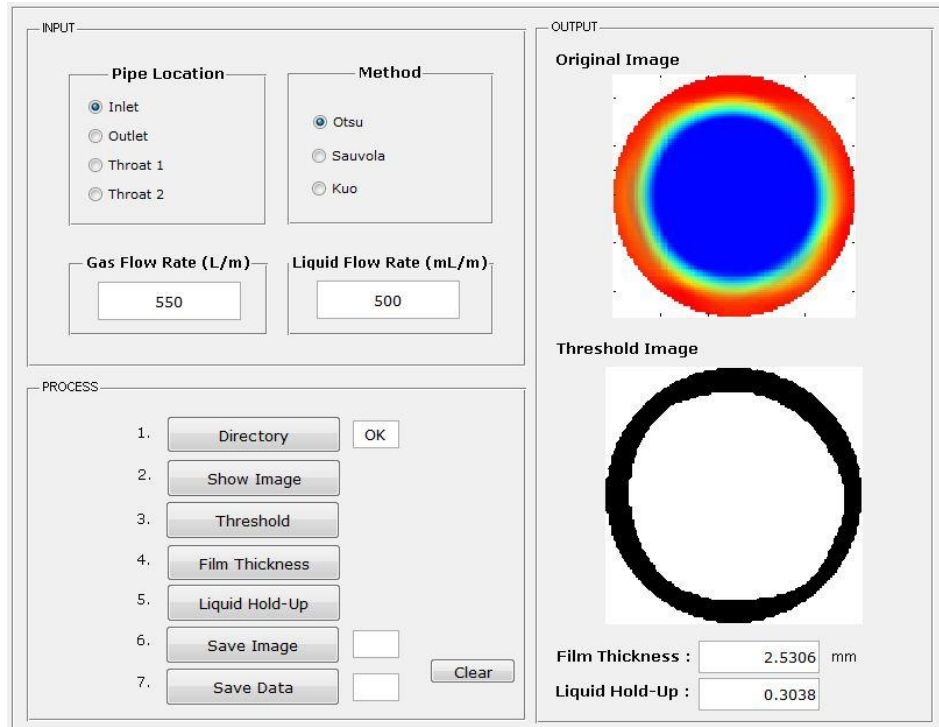


Figure 16 : Graphical User Interface (GUI)

Flow of GUI in figure 16:

1. Choose pipe location and threshold's method
2. Inset value of gas flow rate
3. Insert value of liquid flow rate
4. Search the image in Directory
5. Show the image (Image will be appeared at Original Image)
6. Threshold the image (Image will be appeared at Threshold Image)
7. Calculate Liquid Film Thickness
8. Calculate Liquid Holdup
9. Save the threshold's image in the same directory of original image
10. Save the data of liquid film thickness and liquid holdup in an excel file

3.5 Liquid Film Thickness

The images that were captured by ECT will be threshold by using three Otsu's, Sauvola's and Kuo's method. Then, liquid film thickness is calculated from threshold images by averaging the film thickness at eight different locations.

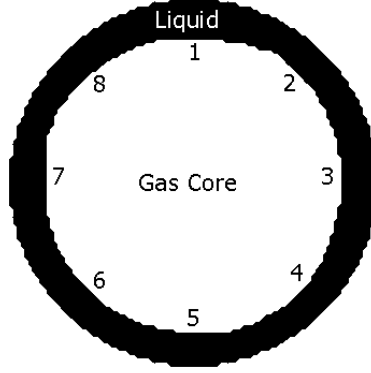


Figure 17 : Eight locations for averaging of film thickness

Liquid film thickness at an image is calculated by using equation (16).

$$\delta = \frac{\delta_1 + \delta_2 + \delta_3 + \delta_4 + \delta_5 + \delta_6 + \delta_7 + \delta_8}{8} \quad (16)$$

3.6 Liquid Holdup

Liquid holdup is the ratio of liquid components in the pipe. Therefore, the calculation for liquid holdup is sum of black pixels over the sum of pixels within the pipe.

$$LHU = \frac{\text{sum of black pixels}}{\text{sum of pixels within pipe}} \quad (17)$$

3.7 Wax Volume Fraction

Wax volume fraction is measure in the experiment of liquid-wax

$$LHU = \frac{\text{sum of black pixels}}{\text{sum of pixels within pipe} - \text{sum of black pixels}} \quad (18)$$

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Gas-Liquid

4.1.1 Threshold's Image

4 threshold's methods which are Niblack's, Sauvola's, Otsu's and Kuo's methods are applied on annular image in order to determine which method is capable of obtaining good threshold image. All those threshold's images were threshold by using annular images at 550 L/m gas flow rate and at 600 mL/m of liquid flow rate.

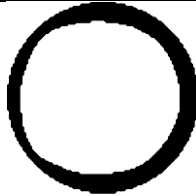
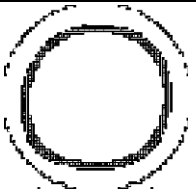

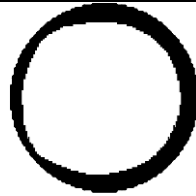
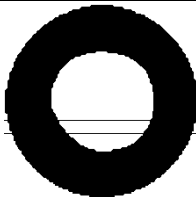

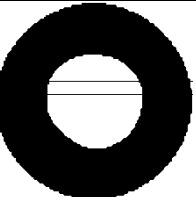
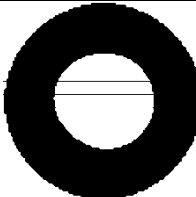
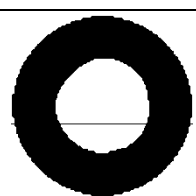
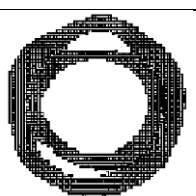
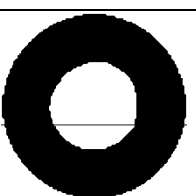
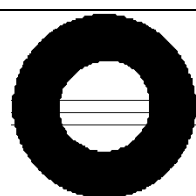
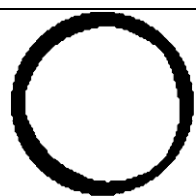
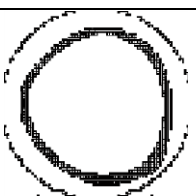
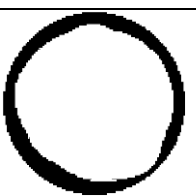
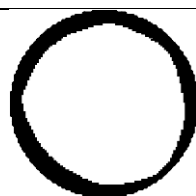
Pipe	Method			
	Otsu	Niblack	Sauvola	Kuo
Inlet				
Throat1				
Throat2				
Outlet				

Figure 18 : Sample of threshold's images for different threshold's methods

Based on figure 18, there are only three threshold's methods can yield good threshold's images which are Otsu's, Sauvola's and Kuo's method. Therefore, these three methods are used in this project in order to threshold the other images. Niblack's method is not acceptable and does not used in next thresholding since this method produces some noise after thresholding process.

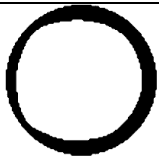
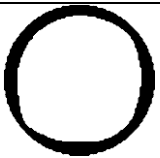
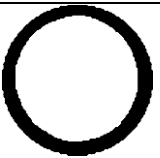






Method	Liquid Flow Rate (L/m)		
	0.6	0.8	1.0
Otsu			
Sauvola			
Kuo			

Figure 19 : Threshold's image at 550 L/m of gas flow rate in Inlet


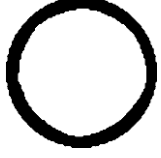

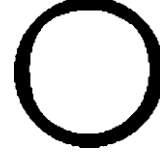




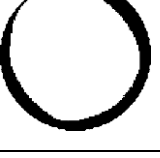
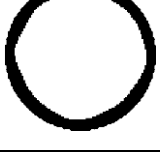
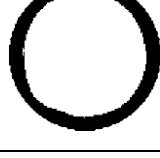
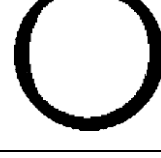
Method	Liquid Flow Rate (L/m)			
	0.4	0.6	0.8	1.0
Otsu				
Sauvola				
Kuo				

Figure 20 : Threshold's image at 600 L/m of gas flow rate in Inlet









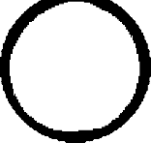



Method	Liquid Flow Rate (L/m)			
	0.4	0.6	0.8	1.0
Otsu				
Sauvola				
Kuo				

Figure 21 : Threshold's image at 650 L/m of gas flow rate in Inlet

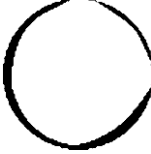

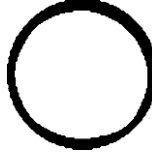








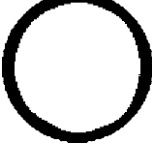



Method	Liquid Flow Rate (L/m)				
	0.2	0.4	0.6	0.8	1.0
Otsu					
Sauvola					
Kuo					

Figure 22 : Threshold's image at 700 L/m of gas flow rate in Inlet

These three threshold's method which are Otsu's, Sauvola's, and Kuo's method yield good images like expected images. But, all methods still can be used in two-phase image thresholding since there are no conventional methods in annular application. Therefore, for further discussion and analysis, liquid film thickness and liquid holdup are calculated.

4.1.2 Liquid Film Thickness (LFT)

Liquid film thickness is calculated by using equation (16) in order to observe its behaviour at different gas and liquid flow rate. The good threshold image is identified when its trending is $\pm 10\%$ of Otsu's trending which objective is to benchmark Otsu's performance with the more recent techniques.

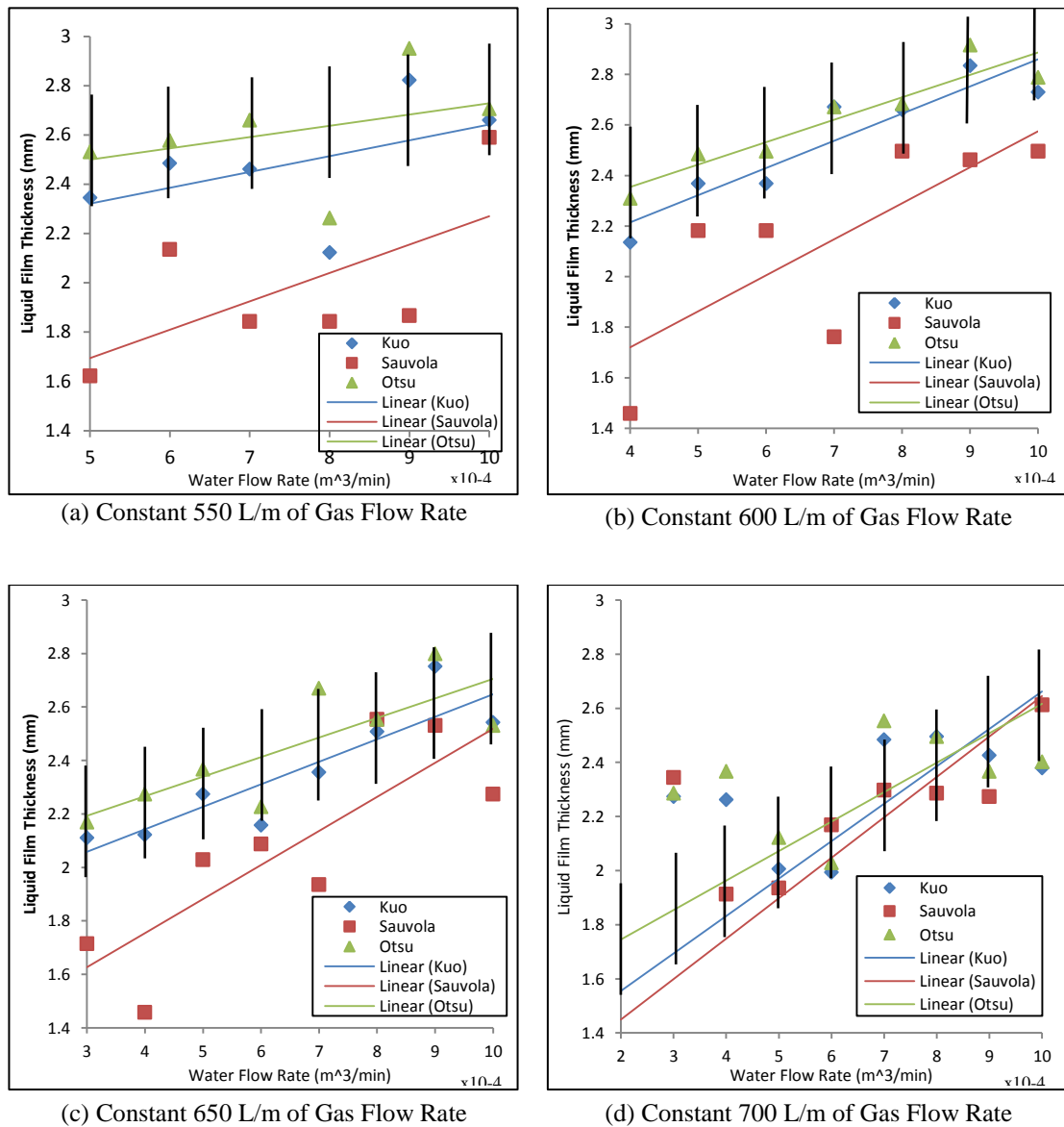


Figure 23 : Liquid Film Thickness in Inlet at different gas flow rate

Inlet is an interest location in verturi tube for this experiment and Otsu's method is a benchmark method. At the low of gas flow rate, only Kuo's method has $\pm 10\%$ difference with Otsu's method but at the high of gas flow rate, Sauvola's method also has $\pm 10\%$ difference. Therefore, Kuo's method also considered as preferable method

for two-phase ECT image applications but Sauvola's method is not recommended since its trending greater than benchmark's trending.

The other figures below do not have $\pm 10\%$ remark since the interest pipe's location only at inlet. Throat show unexpected result since liquid enters the converging section and high wavy disturbance and liquid out from converging section at outlet.

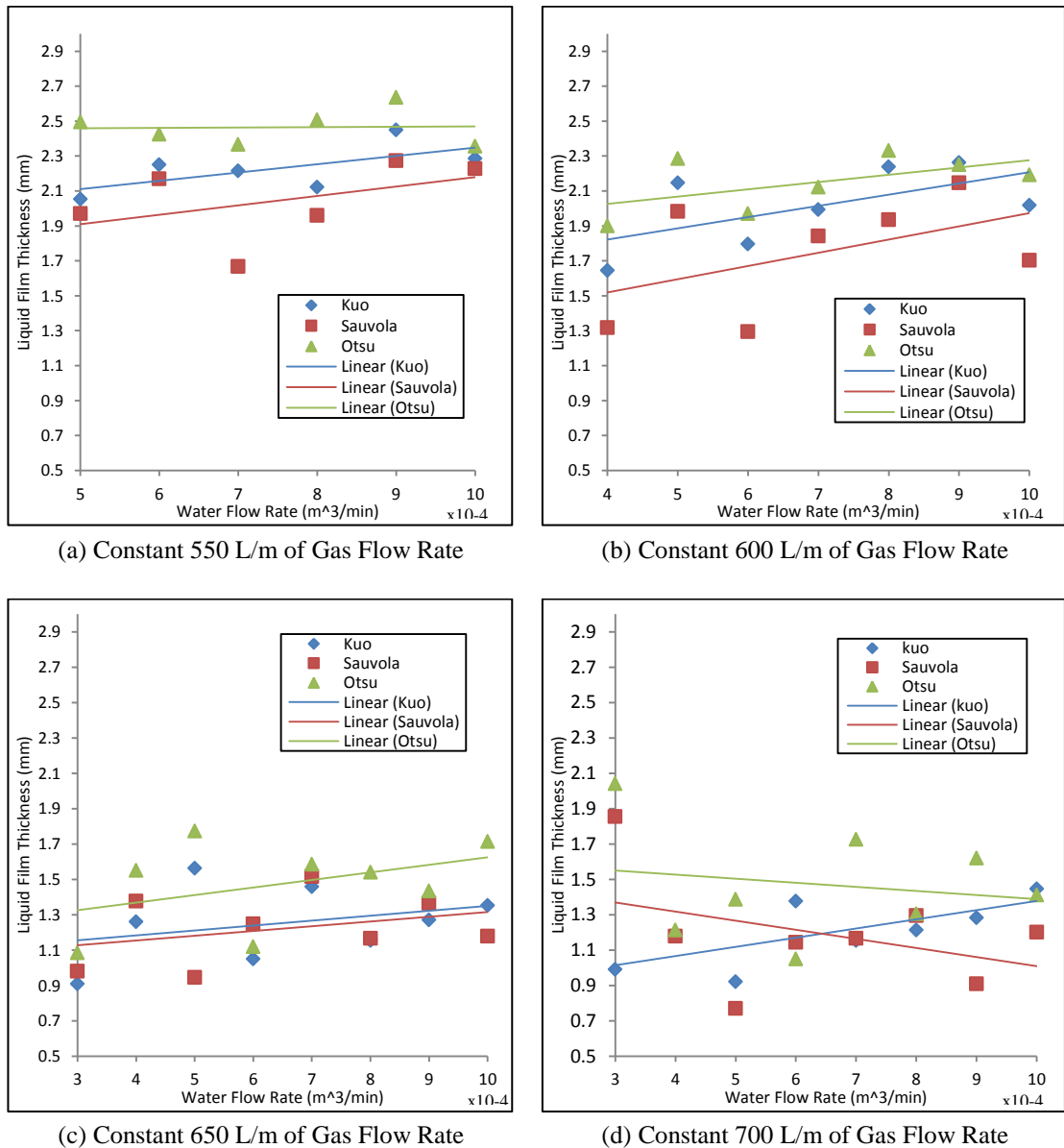
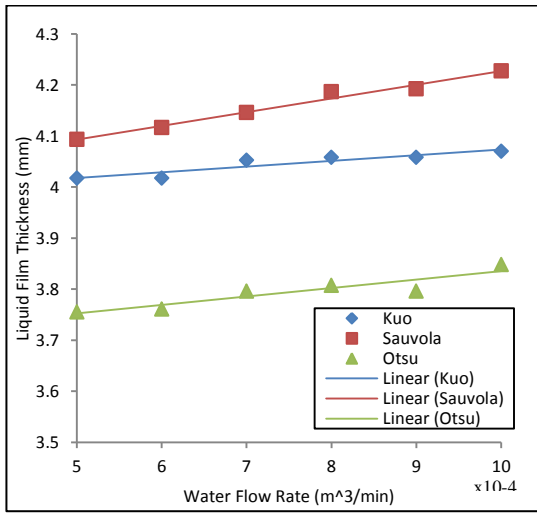
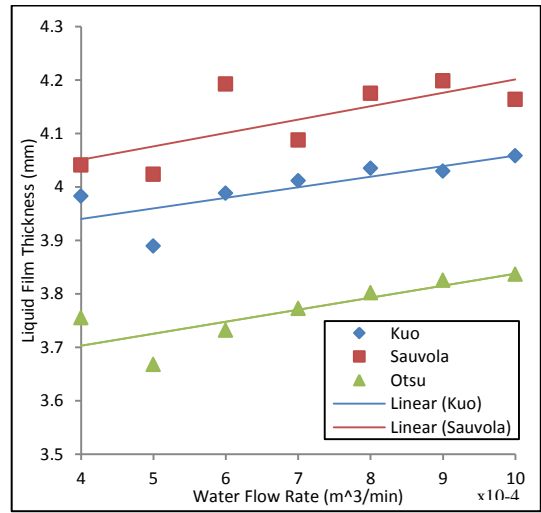


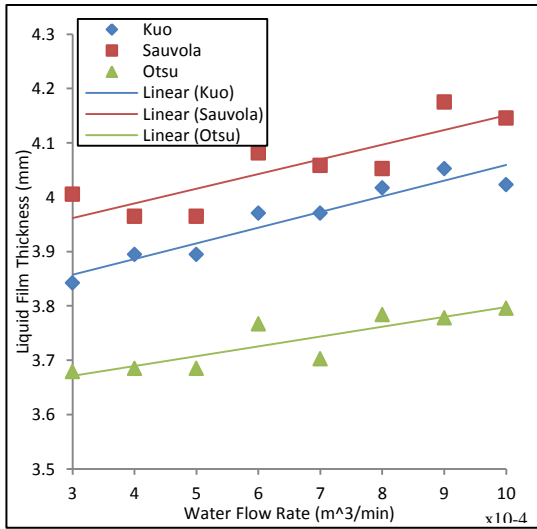
Figure 24 : Liquid Film Thickness in Outlet at different gas flow rate



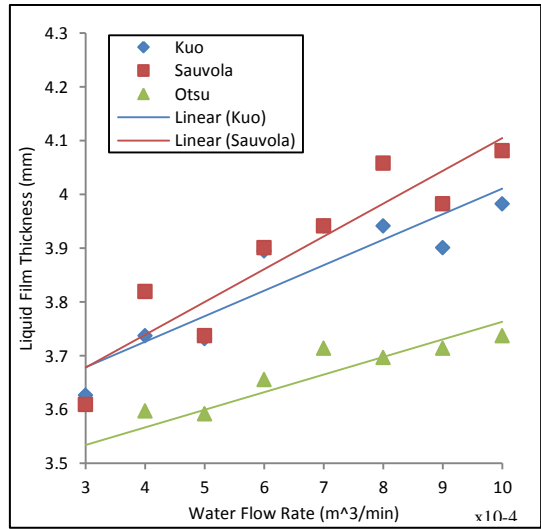
(a) Constant 550 L/m of Gas Flow Rate



(b) Constant 600 L/m of Gas Flow Rate

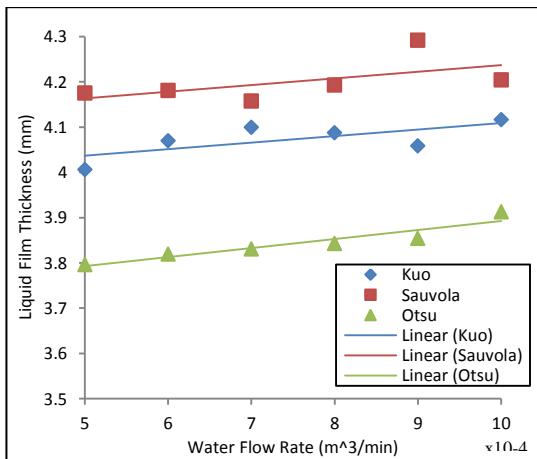


(c) Constant 650 L/m of Gas Flow Rate

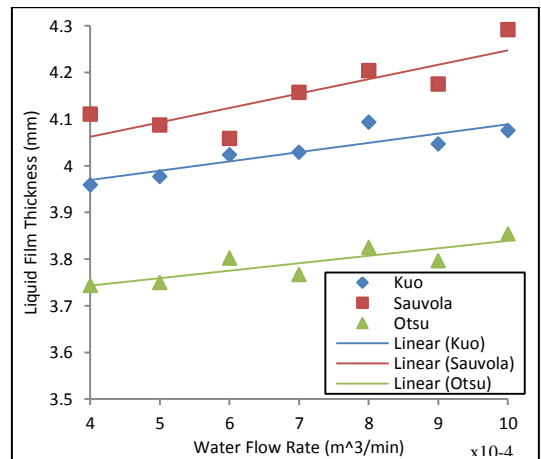


(d) Constant 700 L/m of Gas Flow Rate

Figure 25 : Liquid Film Thickness in Throat 1 at different gas flow rate



(a) Constant 550 L/m of Gas Flow Rate



(b) Constant 600 L/m of Gas Flow Rate

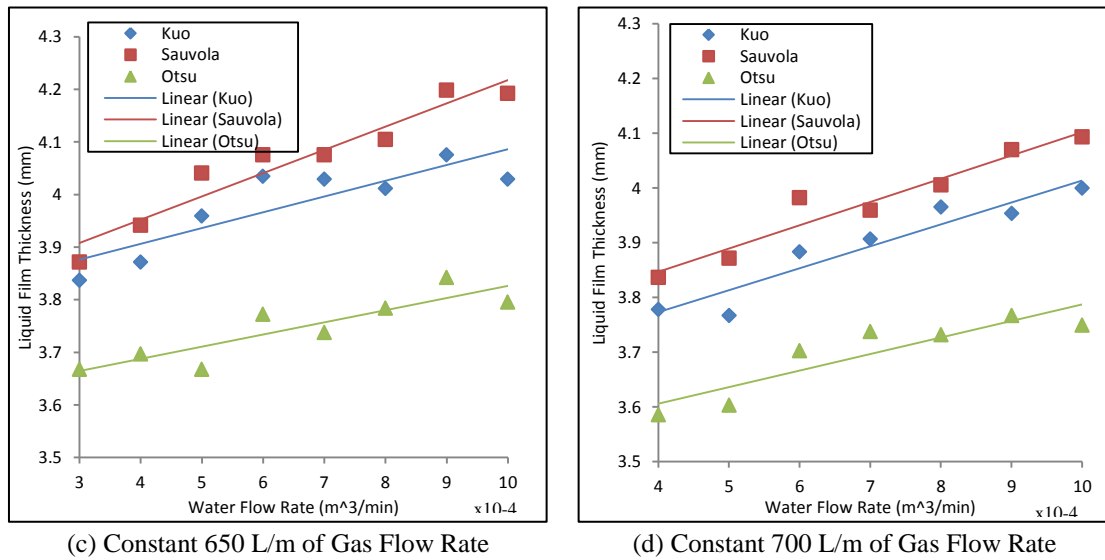


Figure 26 : Liquid Film Thickness in Throat 2 at different gas flow rate

Based on the results above, liquid film thickness is increasing when liquid flow rate is increased at a constant gas flow rate. This behaviour gives same results either at inlet, outlet, throat 1 or throat 2 and similar results for all threshold methods. For the case of constant liquid flow rate, the liquid film thickness is decreasing when gas flow rate increased. We also observed that, the liquid film thickness in throat are greater than liquid thickness in inlet or outlet. It is due to the liquid enters the converging section, there will be more resistance to the flow and it will cause liquid flooding at the inlet.

Based on distribution of thickness in inlet and outlet, the values are not constantly increase and randomly distributed at different water flow rate especially figure 24. It's due to the experiment was done with instantaneous measurement. It means, some unwanted condition might be occurred when the measurements were done such as liquid flow back when they lost their velocity against gravity and wavy liquid flow were formed.

Similar behaviour can be observed at inlet, outlet, throat 1 or throat 2 and for all threshold methods. All thresholds' methods yield same behaviour of gas-liquid flow and but Sauvola's method is not meet requirement which is greater $\pm 10\%$ with Otsu's method (benchmark). Therefore, only Otsu's and Kuo's method are acceptable and preferable for two-phase ECT image applications.

4.1.3 Liquid Holdup (LHU)

Liquid holdup is another parameter that can be calculated from threshold's image by summing the black pixels over the sum of pixels within the pipe.

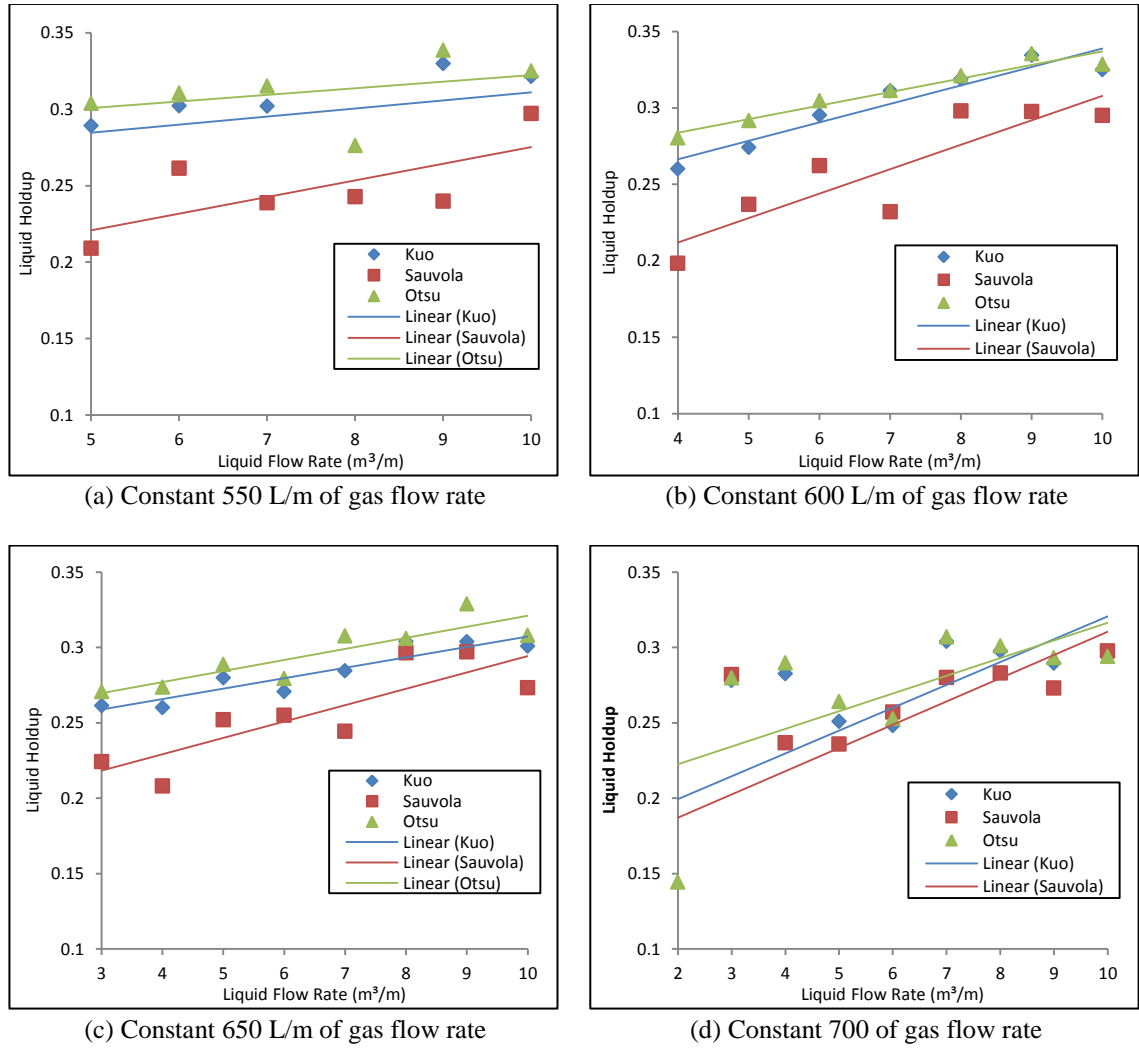
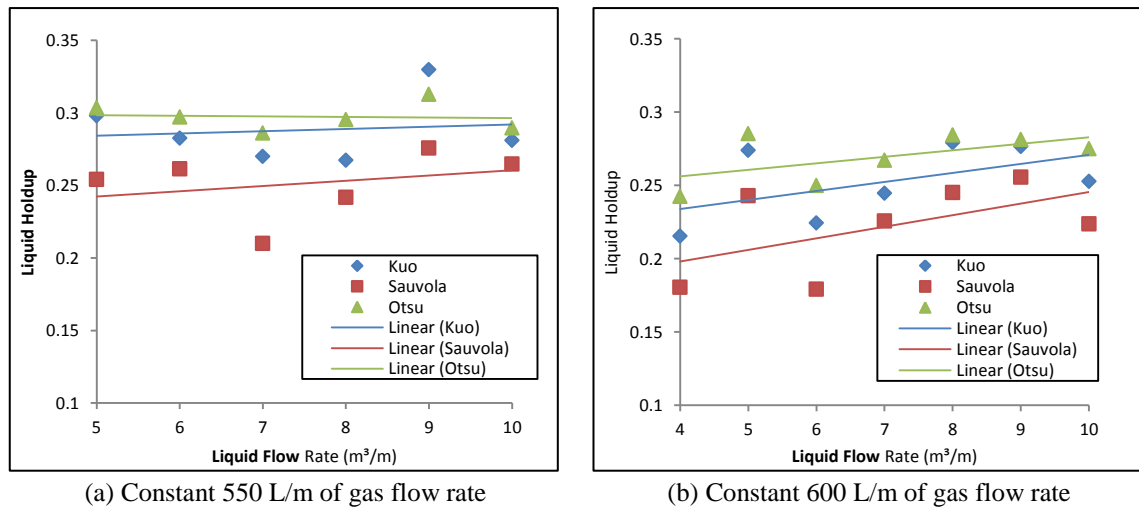
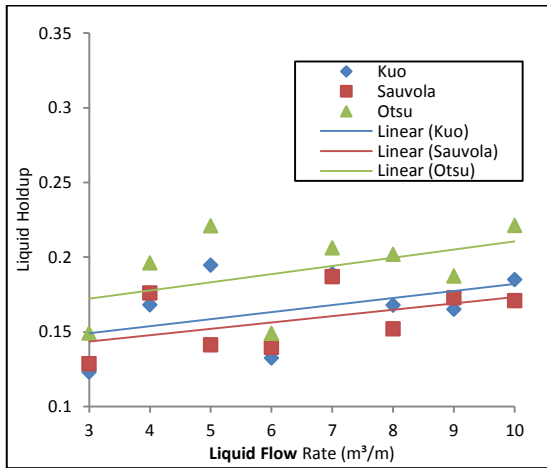
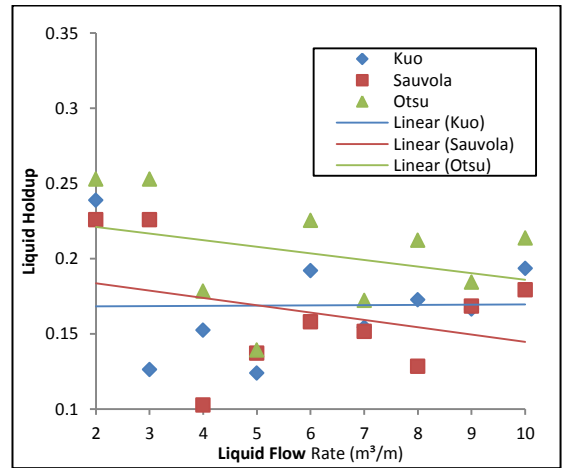


Figure 27 : Liquid Holdup in Inlet at different gas flow rate



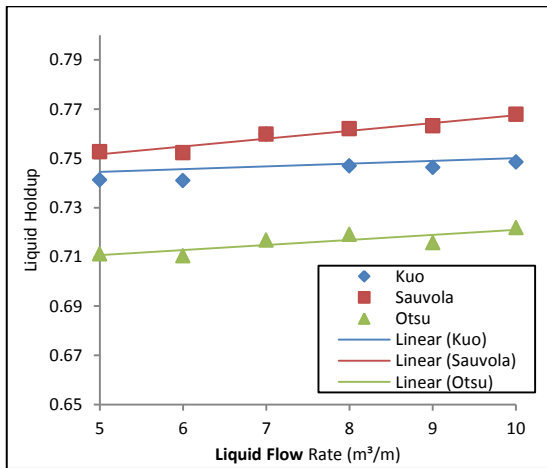


(c) Constant 650 L/m of gas flow rate

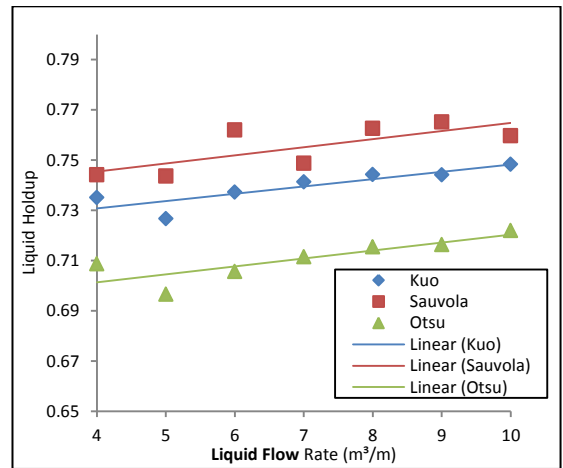


(d) Constant 700 of gas flow rate

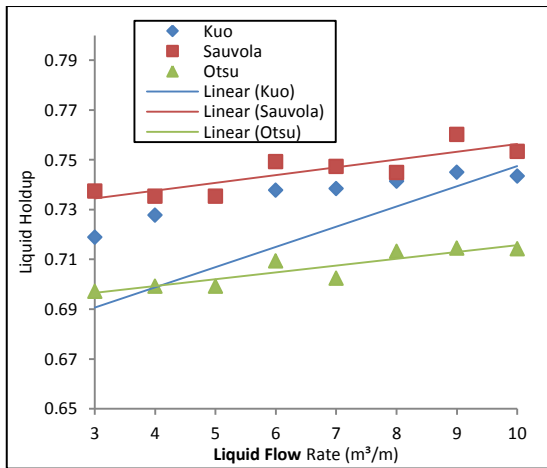
Figure 28 : Liquid Holdup in Outlet at different gas flow rate



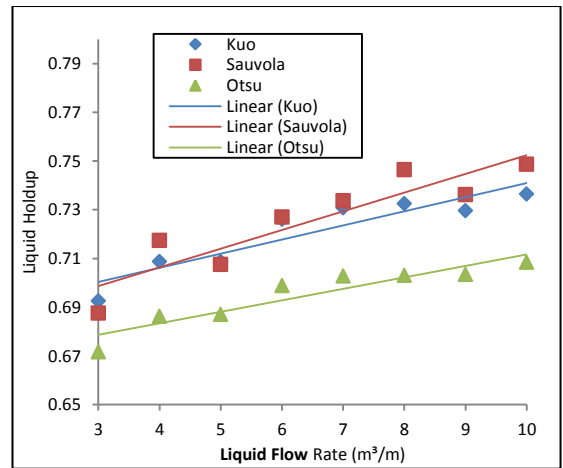
(a) Constant 550 L/m of gas flow rate



(b) Constant 600 L/m of gas flow rate

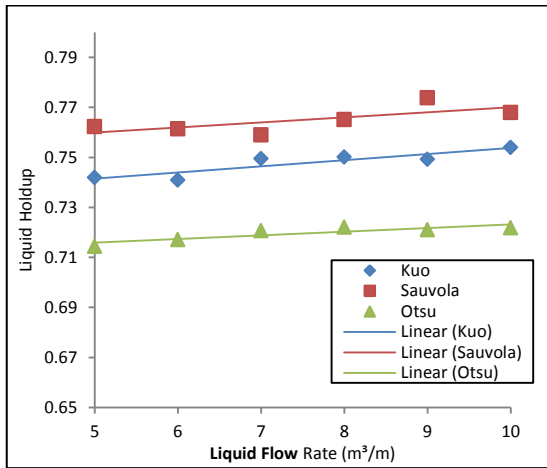


(c) Constant 650 L/m of gas flow rate

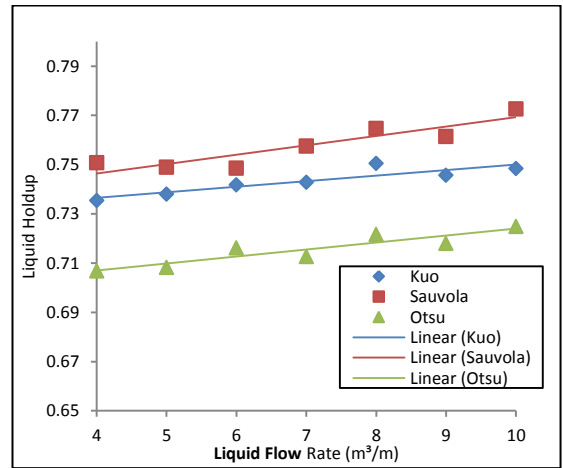


(d) Constant 700 of gas flow rate

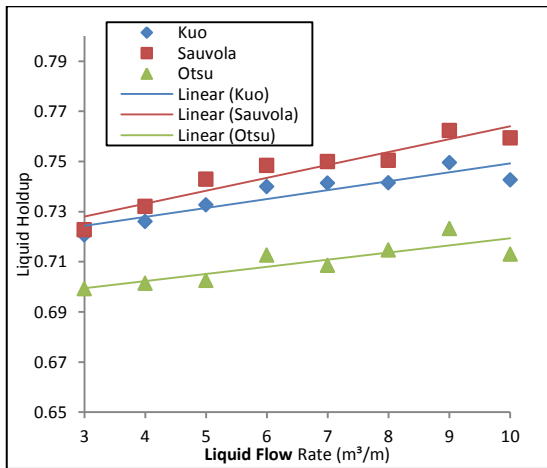
Figure 29 : Liquid Holdup in Throat 1 at different gas flow rate



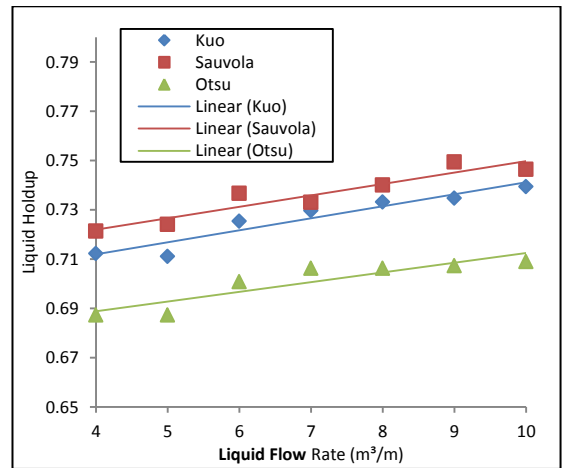
(a) Constant 550 L/m of gas flow rate



(b) Constant 600 L/m of gas flow rate



(c) Constant 650 L/m of gas flow rate



(d) Constant 700 of gas flow rate

Figure 30 : Liquid Holdup in Throat2 at different gas flow rate

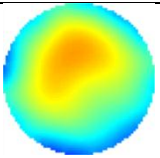
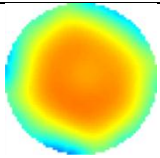
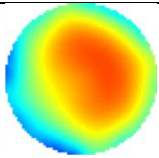
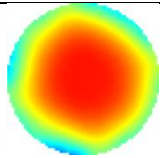
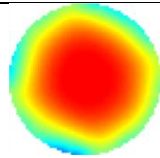

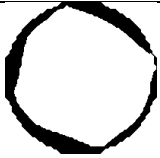
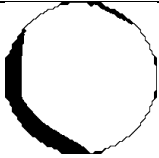
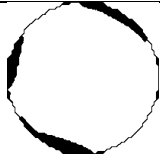
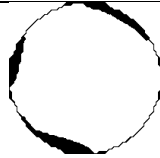

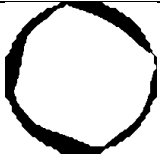
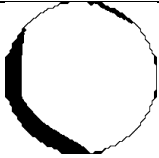
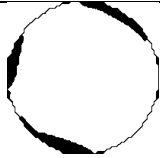
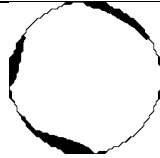


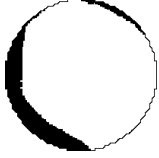
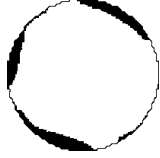
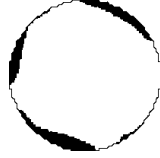
Since all threshold's methods yield same behaviour of gas-liquid flow, the selection of preferable methods will be based on part 4.1.2 which is liquid film thickness trending. It means Sauvola's method is not meet requirement which is greater than $\pm 10\%$ with Otsu's method (benchmark) but only Kuo's method are acceptable and preferable for two-phase ECT image applications.

4.2 Wax Volume Fraction (WVF)

When Otsu's, Sauvola's and Kuo's methods are identified as the good threshold methods in part 4.1.1 which is capable of obtaining the good threshold's image and capable of calculating liquid film thickness and liquid holdup for asymmetrical annular flow image, these methods are applied to another experiment which is liquid-wax waxy crude oil. This experiment is done by using ECT in order to observe the behaviour of gas void fraction in crude oil at different temperature.

Wax volume fraction is calculated by summing the black pixels over the sum of pixels within the pipe. Table 3 show the original and threshold's image that are captured by ECT. The threshold's images are used to calculate wax volume fraction and its distribution is shown in figure 31.

Table 3 : Original and threshold's image for crude oil

	Temperature (°C)				
	34	34.5	34.7	35.8	37
Two-Phase Image					
Otsu					
Sauvola					
Kuo					

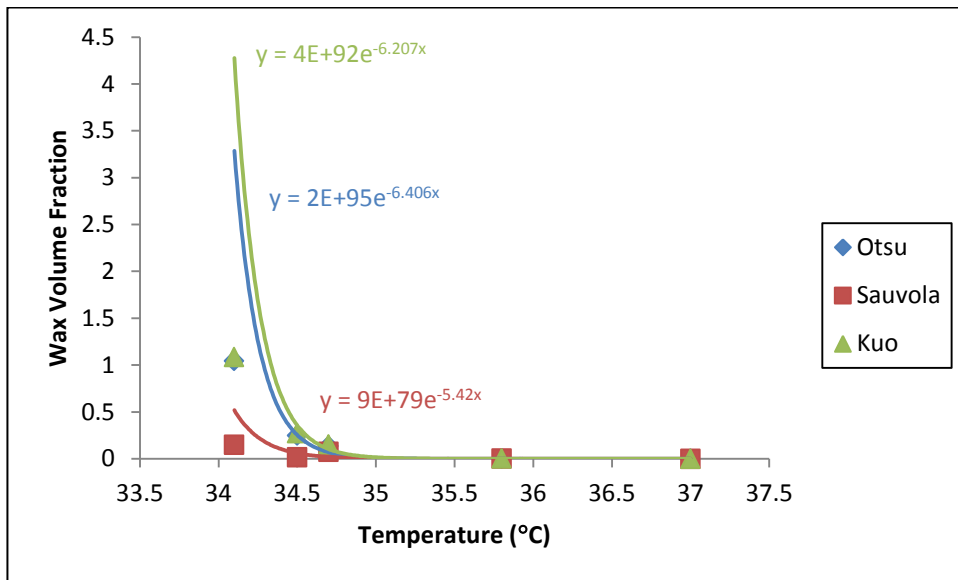


Figure 31 : Wax volume fraction in crude oil against temperature

Wax volume fractions in figure 31 are calculated by using equation (18) in part 3.7. The figure 31 shows that wax approximately starts to form below than 35°C which is the actual WAT for this type of crude oil.

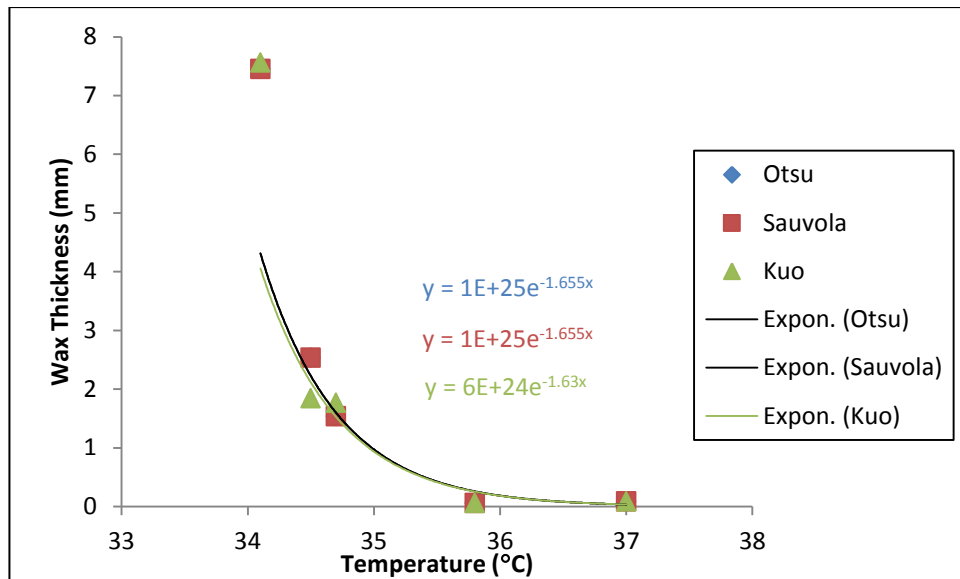


Figure 32 : Wax thickness against temperature

Figure 32 shows that there is minimal difference between threshold's methods in term of wax thickness that formed in the tube. All threshold's methods are capable of obtaining good threshold image in liquid-wax applications and yield minimal difference between them.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project considers that Electrical Capacitance Tomography (ECT) is the best method for capturing the images in the pipeline. The images of two-phase gas-liquid flow and two-phase liquid-wax in the pipeline are captured by using ECT. Several threshold's techniques are applied onto two-phase images in order to separate, analyse, and study the behaviour of two-phase at certain condition and in order to determine which threshold's techniques are suitable and preferable for two-phase ECT images.

Based on the chosen threshold's techniques, Niblack's method is unable to produce an acceptable post-threshold image. Based on figure 18, the Niblack's method will produce unacceptable images. Then, Otsu's, Sauvola's and Kuo's methods are applied onto the other images for the next calculation which are liquid film thickness and liquid holdup.

Since the objective is to benchmark Otsu's performance with the more recent techniques, the methods that are trending within $\pm 10\%$ of Otsu's method, those methods will be considered acceptable and preferable methods for two-phase ECT image application. Based on figure 23, Kuo's method is preferable technique since its trending within $\pm 10\%$ of Otsu's trending but Sauvola's trending is greater than $\pm 10\%$.

In liquid-wax experiment, wax (wax) starts to form at below 35°C which is considered as wax appearance temperature (WAT). The Sepat crude oil's WAT and pour point is both evaluated to be at 35°C by referring Wax Appearance Temperature (WAT) table from PETRONAS Carigali Sdn. Bhd. (PCSB). Besides that, all threshold's methods have minimal difference between them for this experiment.

5.2 Recommendations for Future Work

This project can be continued by running with other threshold's methods such as iterative, minimum error, fuzzy clustering, entropy and other methods. Based on literature review, there are a lot of thresholding techniques which are capable of improving the results that yield by global and local thresholding techniques. But, the problem is those techniques are more complex and to apply those algorithm, the project must take more time.

In order to determine the best threshold's method for ECT applications, the acceptable threshold's methods which are Otsu and Kuo need to be used in others application such as wet gas metering applications that was reported by Huang *et al.* [3]. They predicted the total mass flow rate in two-phase by calculating the gas void fraction in the pipeline. Therefore, when they try to apply different threshold's methods in their research, they will obtain different value of gas void fraction and different total mass flow rate. By comparing those data with their ground through, they will obtain the best methods for predicting the total mass flow rate in two-phase flow and will improve the online measurement in pipeline.

In liquid-wax experiment, the thickness of wax can be estimated at certain temperature by measuring the thickness of real wax in pipe. The measuring can be done by using any ruler tools but the problem is the thickness at top of pipe cannot be same at the centre and the bottom of the pipe. Therefore, in order to measure the thickness of wax, we can make an assumption that the thickness of wax is same from the top to bottom of the pipe.

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APPENDIX A

A.1 Programming for Main GUI

```
function varargout = SUHAIDIFINALYEARPROJECTGUI(varargin)

%% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                  'gui_Singleton',  gui_Singleton, ...
                  'gui_OpeningFcn', @SUHAIDIFINALYEARPROJECTGUI_OpeningFcn, ...
                  'gui_OutputFcn',  @SUHAIDIFINALYEARPROJECTGUI_OutputFcn, ...
                  'gui_LayoutFcn',  [], ...
                  'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargin
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before SUHAIDIFINALYEARPROJECTGUI is made
% visible.
function SUHAIDIFINALYEARPROJECTGUI_OpeningFcn(hObject, eventdata,
handles, varargin)
handles.output = hObject;
guidata(hObject, handles);

% --- Outputs from this function are returned to the command line.
function varargout = SUHAIDIFINALYEARPROJECTGUI_OutputFcn(hObject,
eventdata, handles)
varargout{1} = handles.output;

% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
[PathName,FileName] = directory ();
[PathName]
[FileName]

handles.FileName = FileName;
handles.PathName = PathName;

set (handles.edit2, 'string', 'OK');
```

```

guidata(hObject,handles)

% --- Pushbutton2 will read the images
function pushbutton2_Callback(hObject, eventdata, handles)
[Pipe, MG, ML, Method] = getparameter (handles);
  FileName=handles.FileName;
  PathName=handles.PathName;

[X] = getavgimage (PathName,FileName);
X = uint8 (X);
Y = crop (X);
axes(handles.axes1);
imshow (Y); axis('image','off');

handles.X=X;
handles.Pipe = Pipe;
handles.MG=MG;
handles.ML=ML;
handles.Method=Method;

guidata(hObject,handles)

% --- Thresholding process in different Techniques
function pushbutton3_Callback(hObject, eventdata, handles)
X=handles.X;
Method=handles.Method;
Pipe=handles.Pipe;

switch (Method)

    case 'Sauvola',
        [X] = sauvola (X,Pipe);

    case 'Otsu',
        [X] = Otsu (X,Pipe);

    case 'Kuo',
        [X] = Kuo (X,Pipe);

end

axes(handles.axes2);
imshow (X); axis('image','off');
handles.X=X;
guidata(hObject,handles)

% --- Liquid Film Thickness Calculation
function pushbutton4_Callback(hObject, eventdata, handles)
X=handles.X;
Pipe=handles.Pipe;

[X1,X2,X3,X4,X5,X6,X7,X8]=LFTA (X,Pipe);
avg = (X1+X2+X3+X4+X5+X6+X7+X8)/8;
Data = [X1,X2,X3,X4,X5,X6,X7,X8,avg]';

```

```

Avg = num2str (avg);
set (handles.edit1, 'String', Avg);

handles.Data=Data;
handles.X=X;
guidata(hObject,handles)

% --- Liquid Holdup Calculation
function pushbutton8_Callback(hObject, eventdata, handles)
X=handles.X
lhu = LiqHoldUp (X);
LHU = num2str (lhu);
set (handles.edit7, 'String', LHU);

handles.X=X;
handles.lhu=lhu;
guidata(hObject,handles)

% --- Save the Threshold Images
function pushbutton5_Callback(hObject, eventdata, handles)
X=handles.X;
Method=handles.Method;
FileName=handles.FileName;
PathName=handles.PathName;
imwrite(X , [PathName 'Save_Image\' Method \'_\' FileName]);
set (handles.edit3, 'string', 'OK');
guidata(hObject,handles)

% --- Save the Data of Liquid Film Thickness & Liquid Holdup
function pushbutton6_Callback(hObject, eventdata, handles)
Data=handles.Data;
Pipe=handles.Pipe;
MG=handles.MG;
ML=handles.ML;
Method=handles.Method;
lhu=handles.lhu;
savedata (Data, MG, ML, Pipe, Method);
saveholdup (lhu, MG, ML, Pipe, Method);
set (handles.edit4, 'string', 'OK');

% --- Clear the Field
function pushbutton7_Callback(hObject, eventdata, handles)
set (handles.edit1, 'string', '');
set (handles.edit2, 'string', '');
set (handles.edit3, 'string', '');
set (handles.edit4, 'string', '');
set (handles.edit7, 'string', '');

```

A.2 Otsu's algorithm in MATLAB

```

function [X] = Otsu (X, Pipe)
colormap ([0:255;0:255;0:255]'/255);
[Y,diameter] = RA (X); % Create boundary within pipe

switch (Pipe)

    case 'Inlet',

```

```

X = AF (X,Y); %Thresholding algorithm
case 'Outlet',
X = AF (X,Y); %Thresholding algorithm
case 'Throat1',
X = AF2 (X,Y); %Thresholding algorithm
case 'Throat2',
X = AF2 (X,Y); %%Thresholding algorithm

end

X = crop (X);

```

A.3 Sauvola's Algorithm in MATLAB

```

function [X] = sauvola (X, Pipe)

[bwRound,diameter] = RA (X); % Create boundary within pipe
bwRound = crop (bwRound);
X = crop (X);

% Select area of interest
switch (Pipe)
case 'Inlet',
X = X (:,:,3);

case 'Outlet',
X = X (:,:,3);

case 'Throat1',
X = X (:,:,1);

case 'Throat2',
X = X (:,:,1);
end

X = double (X);
row,col] = size(X);

%% initialize size windows
p = 5; % window_row
q = 5; % window_colum
norow = row/p; % no of row
nocol = col/q; % no of coloum
g = norow*nocol;

%% Iniatial value
means (1,1:g)=0;
SD(1,1:g)=0;
mean = 0;
sd=0;

%% find the means and standard Deviation, SD
k = 1;

for i=1:p:row
for j=1:q:col

mean = 0;
sd=0;

```

```

        for m=i:i+p-1
            for n = j:j+q-1
                mean = mean + X(m,n);
            end
        end
        means (1,k) = mean / (p*q);

        for m=i:i+p-1
            for n = j:j+q-1
                sd = sd + ((X(m,n)) - ( means (1,k) ) )^2;
            end
        end
        SD (1,k) = sqrt(sd/(p*q));
        k=k+1; % no. of windows
    end
end

%% find threshold value for every window
SDmax= max (SD);
T(1,1:g)=0;
t=0;
r=1;
k=0.8; % bias

for i=1:p:row
    for j=1:q:col
        for m=i:i+p-1
            for n = j:j+q-1
                t = (means(1,r))* (1+(k*(((SD(1,r))/SDmax)-1)));
            end
        end
        T (1,r) = t;
        t=0;
        r=r+1; % no. of windows
    end
end

%% rearrange threshold value
r=1;
Th (row,col)=0;
for i=1:p:row
    for j=1:q:col
        for m=i:i+p-1
            for n = j:j+q-1
                Th (m,n) = T(1,r);
            end
        end
        r = r + 1; % no. of windows
    end
end

%% threshold each pixels

for i=1:1:row
    for j=1:1:col
        if X(i,j)> Th(i,j)
            BW (i,j) = 0;
        else
            BW (i,j) = 255;
        end
    end
end

```

```

    end
end

```

```

BWoutline = bwperim(BW,8);
BW(BWoutline)=0;

```

A.4 Kuo's or Hybrid's algorithm in MATLAB

```

function [X] = Kuo (X, Pipe)

%% read the image
[bwRound, diameter] = RA (X); % roundAlgo
bwRound = crop (bwRound);
X = crop (X);

%% convert to grey level
X = rgb2gray(X);
[ row, col] = size(X);

%% Find the ThGlobal
level = graythresh(X);
ThGlobal = round (level*255);

%% create histogram of image
H = imhist(X);
H=H(:)';

%% initialize size windows
p = 5; % window_row
q = 5; % window_colum
norow = row/p; % no of row
nocol = col/q; % no of coloum
g = norow*nocol;
monitor=0;
monitor2 = 0;

%% evaluate window per window
for i=1:p:row
    for j=1:q:col

        % find the Num for each window
        % Num = number of pixels which grey values smaller than
ThGlobal
count = 0;
        for m=i:i+p-1
            for n = j:j+q-1
                if X(m,n) < ThGlobal
                    count = count + 1;
                else
                    count = count;
                end
            end
        end
        Num = count;

        % find value of S
        % S = number of pixels between S and ThGlobal are quarter of
Num
QNum = round ( Num /4 );
S = round (ThGlobal);

```

```

counter = 0;
while counter <= QNum && QNum ~= 0
    S = S-1;
    for m=i:i+p-1
        for n = j:j+q-1
            check = X(m,n);
            if X(m,n)>= S && X(m,n)<= ThGlobal
                counter=counter+1;
            else
                counter = counter;
            end
        end
    end
end
S = S ;

% find mean local and standard deviation
means =0;
sd=0;
for m=i:i+p-1
    for n = j:j+q-1
        means = means + X(m,n);
    end
end
means = means / (p*q);
for m=i:i+p-1
    for n = j:j+q-1
        sd = sd + ((X(m,n)) - ( means) )^2;
    end
end
SD = sd ;

% Global and Local Thresholding
for m=i:i+p-1
    for n = j:j+q-1
        if X(m,n) > ThGlobal
            X(m,n)= 255;
        else if X(m,n)> S && X (m,n) <= ThGlobal
            monitor = monitor +1;
            ThLocal = Local (X,means,SD,m,n,ThGlobal);
            if X(m,n) > ThLocal
                X (m,n)=255;
            else
                X(m,n)=0;
            end
        else
            X(m,n)=0;
        end
    end
end
end
end

monitor2 = monitor2 +1 ;

end
end

BWoutline = bwperim(X,8);
X(BWoutline)=0;

```

APPENDIX B

Table 4 : Gantt Chart of Final Year Project I

No	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Topic Selection														
2	Literature Review														
3	Run MATLAB simulation														
4	Analyze the results														
5	Prepare for Interim Report														

Table 5 : Gantt Chart for Final Year Project II

No	Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	Fix the errors in programming	■														
2	Integrate the programming with GUI			■												
3	Film thickness calculation using MATLAB programming						■									
4	Data gathering								■							
5	Task complete									●						
6	Prepare for technical paper									■			●			
7	Oral presentation											■		●		
8	Prepare for final report											■			●	

● Planned Milestone

■ Work Progress