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DETERMINATION OF VOID FRACTION BY IMAGE PROCESSING

Burak DİBEK *

Hakan DEMİR *

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Abstract: Void fraction is one of the key parameters for defining the characteristics of a two phase flow. However, determination of void fraction is not easy due to changing conditions of flow and the type of fluid. In literature, there are plenty of works on determination of void fraction in two-phase flow in a pipe or channel which uses psychical parameters and properties of the system, flow and fluid. Since there are plenty number of correlations for various flow types, an experimental method has been suggested to determine the void fraction according to flow type without using any physical parameter of the flow and fluid. Image visualization methods have been applied to two-phase flow of refrigerant R600a in a circular tube. The images from high speed photography have been processed using a software developed with MATLAB Image Processing Toolbox. The results were also compared with the well-known correlations.

Keywords: Image processing, Two-phase flow, Void fraction

Boşluk Oranının Görüntü İşleme Yardımıyla Bulunması

Öz: Boşluk oranı iki fazlı akışta akışın karakterini tanımlamak için kullanılan önemli parametrelerden biridir. Bununla beraber değişken akış koşulları ve akış türü nedeniyle boşluk oranını belirlemek çok kolay değildir. Literatürde bir boru veya kanal içinde boşluk oranını tanımlama üzere sistem, akış ve akışkan ile ilgili parametreleri kullanan pek çok model bulunmaktadır. Farklı akış tipleri için pek çok korelasyon bulunduğu için bu çalışmada akışla ilgili herhangi bir parametre kullanmayan bir deneysel yöntem önerilmiştir. Görüntü işleme yöntemi R600a akışkanının dairesel bir boru içerisinde iki fazlı akışına uygulanmıştır. Yüksek hızlı kamera ile elde edilen görüntüler MATLAB görüntü işleme aracını kullanarak geliştirilen bir yazılımda işlenmiştir. Ayrıca sonuçlar literatürde sık kullanılan korelasyonlarla karşılaştırılmıştır.

Anahtar Kelimeler: Görüntü işleme, İki fazlı akış, Boşluk oranı

1. INTRODUCTION

Developments on the process engineering makes two-phase flow more important for HVAC systems, cooling systems, power generators, chemical industry etc. Studies on two-phase flow are getting more and more important.

Void fraction is one of the key parameters to determine the properties of a two-phase flow. However determination of exact value of void fraction for a two-phase flow is not an easy issue to handle for the researchers. Especially, if the two phase flow is in a small channel, determination of void fraction becomes more difficult. In the literature, there are various correlations and flow maps to find out the void fraction for a given flow conditions.

* Yıldız Technical University, Department of Mechanical Engineering, Heat and Thermodynamics Division, Yıldız, Beşiktaş, İstanbul 34349, Turkey

Correspondence Author: Hakan DEMİR (hdemir@yildiz.edu.tr)

Correlations depend on physical properties of the flow such as mass flow rate, temperature and viscosity.

Correlations may fail to determine the void fraction accurately when flow type changes. Therefore, the flow type should be determined initially before the determination of void fraction. When gas phase of a fluid contacts with a surface that is cooler than the fluid, the condensation process starts. During condensation process, various flow types exist due to the effect of gravity, tube shape, mass flow rate and velocity of the flow. Figure 1 shows the flow types which can be seen two-phase flow of a fluid condensing in a circular tube. The flow types can be classified into two parts according to void fraction: bigger than 0.5 and smaller than 0.5.

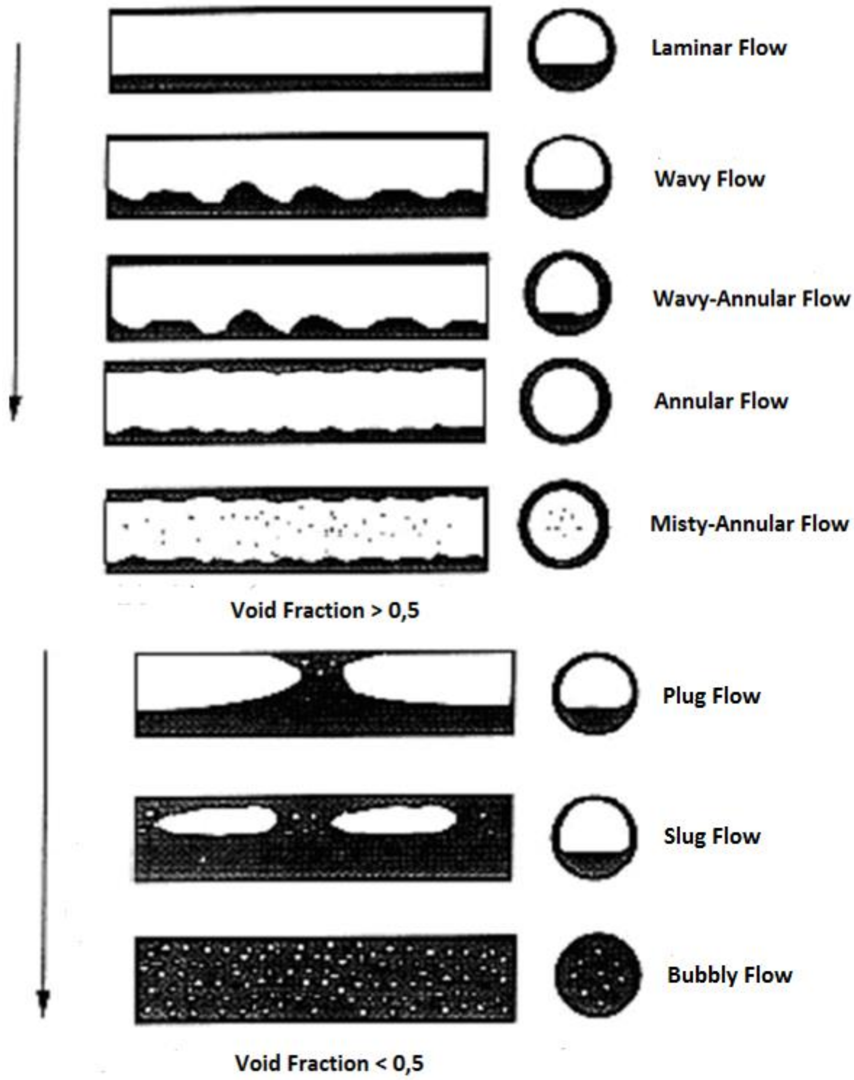


Figure 1:
Flow types

If the void fraction is bigger than 0.5, five different main flow types can be seen: Laminar flow, annular flow, wavy flow, wavy-annular flow, annular flow and misty annular flow. On the other hand slug flow, plug flow and bubbly flow types can be seen if the void fraction is lower than 0.5. The arrow shows the variation of the flow type with increasing flow velocity for the first group in Figure 1. Also, the arrow shows the variation of the flow type with increasing liquid mass for the second group in Figure 1

Void fraction is the most important parameter for determination of pressure drop, thermal conductivity and the flow type. It is defined as the ratio of cross sectional area of gas to total cross sectional area of the tube. Figure 2 shows the definition of void fraction.

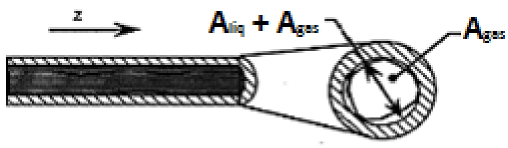


Figure 2:
Schematic explanation of void fraction

$$\alpha = \left(\frac{A_{gas}}{A_{gas} + A_{liq}}\right) \tag{1}$$

Bowers and Rnjak (2010) used refrigerant R134a on their studies and determined the void fraction with image analysis technique. Three different sized transparent pipes (7.2 mm, 8.7 mm and 15.3 mm) were used. The flow was analyzed using "Change Point Analyze" method. A pump was used to reduce the negative effect of vibration on the test setup instead of a compressor. While the developed method gives successful results on stratified flow, has some problems with the other flow types. In another study conducted by Winkler et al. (2012), R134a flow in 4.91 mm diameter circular and 1x1, 2x2, 3x3 and 4x4 mm square sectional channels were investigated. Annular, wavy, slug/plug and dispersed flow types were visualized in the test section. The effects of the tube size, mass flow rate and vapor quality on the two phase flow were presented. Godbole et al. (2011), used water-air mixture and determined the volumetric void fraction for 12.7 mm diameter pipe and presented on flow maps.

Triplett et al. (1999), used water-air mixture as well. Various shaped micro channels were used with inner diameters of 1.1 mm and 1.45 mm and hydraulic diameters of 1.09 mm and 1.49 mm. Temperature was maintained at 25°C. The velocities of the gas phase were between 0.02 – 80 m s^{-1} while the flow velocities of liquid phase were between 0.02 – 8 m s^{-1}. Experimental results obtained for bubbly, plug and annular flows. Researchers pointed out that the results have a weak compatibility with the similar studies in the literature.

Saisorn and Wongwises (2009) studied on two-phase flow in horizontal circular tubes. Air or nitrogen gas was used as gas phase and water or ionized water was used as liquid phase to obtain gas-liquid mixture. On the other hand, the air or nitrogen tanks were integrated to the test setup as pneumatic pump instead of conventional pump in order to reduce the vibration effect of the conventional pump. The test section has a diameter of 0.15 mm and a length of 104 mm. High and low pressure transducers were installed to test setup to determine the pressure drop between single-phase flow and two-phase flow. The experiments were conducted on single-phase flows initially and then on two-phase flows with different ratios of liquid-gas mixture. For lower gas-liquid ratios, four different flow types were observed: single-phase liquid, throat-annular, serpentine like gas core and annular flow. On the other hand, when the liquid ratio of the mixture was higher, only 2 of 4 flow types (single-phase liquid and annular) were observed. Also, when the gas ratio of the mixture was higher, only annular flow was observed.

Winkler et al. (2012), studied refrigerant R134a flow in mini channels. Square, circular and rectangular cross sectional tubes with hydraulic diameters of 2 – 4.91 mm were used. In experimental study, 140 different void fraction values were obtained for slug, wavy and slug-wavy flow types. The cross sectional areas of liquid and gas were converted volumetric void fraction values by using transform equations. The effects of hydraulic diameter, mass flow rate and vapor quality were investigated. As result, it was pointed out that flow rate and hydraulic diameter has not an important effect on the void fraction. In addition, similar studies are summarized in Table 1.

In this study, a flow visualization and image processing technique are presented. Refrigerant R600a flow visualized with a high speed camera. Images obtained from the visualization study have been processed with a software developed in Matlab environment and void fraction values were calculated. Furthermore, the results were compared with the well-known void fraction correlations given in Table 2.

Table 1. Basic information about the studies in the literature

Researcher	D_h	Fluid	Tube / Channel Position	Working Conditions	Techniques, Results, Comments, Inferences
Premoli et al. (1971)					*Correlation depends on drifting ratio
Smith (1969)	6 mm	Boiling heavy water	Vertical	0.7<P<5.9 MPa 0<x<0.38 650<G <2050 kg m^{-2} s 380<q<1200 kW m^{-2}	*Semi-empirical model *For both of phases; velocity of stratified annular flow (liquid phase) and velocity of liquid drifting vapor phase (homogenous mixture phase) are assumed as equal.
	38 mm	Boiling water	Horizontal, Vertical	1.725<P<14.5 MPa 0.003<x<0.17 750<G <1950 kg m^{-2} s^{-1} 20<q<140 kW m^{-2}	* Flow model is free of P, G, x; can be used for both of horizontal and vertical flows. * Model can be applied only for cylindrical pipes when K=0.4.
	11 mm	Air-Water	Vertical	Atmospheric pressure 0.005<x<0.525 50<G <1330 kg m^{-2} s^{-1}	* Not recommended for boiling flow when x<0.01.
Zivi (1964)	Various	Vapor - Water	Horizontal, Vertical		* Analytical void fraction model makes the ratio of energy lost to minimum. * There are 3 models; 1) Fluid drift and wall friction 2) Wall friction 3) Liquid drift * Data show that effect of wall friction is too small than effect of liquid friction. * If P increases, model 1 gets closer to homogenous model. * The model 1 which does not depend on data and is easy, has huge using area.
Armand (1946)		Air - Water	Horizontal	β<0.9 Atmospheric pressure	* Experimental correlation
Kariyasaki et al. (1991)	1, 2.4, 4.9 mm	Air - Water	Horizontal	$0.1<j_G<25$ m s^{-1} $0.03<j_L<2$ m s^{-1}	* Lots of lines are compatible with data without psychical study.

Table 1. (continued)

Researcher	D_h	Fluid	Tube / Channel Position	Working Conditions	Techniques, Results, Comments, Inferences
Tandon et al. (1985)	6.1 mm 22 mm	Boiling heavy water Vapor - Water	Vertical	0.7<P<6 MPa, x<0.41 650<G <2050 kg m^{-2} s^{-1} 380<q <1200 kW m^{-2} 0.24<α<0.92 Atmospheric pressure x<0.04	* Semi-empirical void fraction model * Assumptions: no friction of liquid and turbulent flow for both of two phases in annular flow. * Model is good as Smith's (1969) model and better than Wallis' (1969) and Zivi's (1964) correlations.
Yashar et al. (2001)	*Microfin pipes: 0.2 mm fin height *7.3, 8.9 mm (evaporation) *8.9 mm (condensation)	R-134a, R-410A	Horizontal	75<G <700 kg m^{-2} s^{-1} 0.05<x<0.8	* Calculations on condensing microfin pipes (estimated 10%) * Shows same effect on microfin and smooth pipes. * At same G and x, lower void fraction compared with evaporation. * Fin locations have not any effect.
El-Hajal et al. (2003)	8 mm	R-22 R-134a R-236ea R-125 R-32 R-410A	Horizontal (Condensation)	65<G <750 kg m^{-2} s^{-1} 0.22<P <3.15 MPa 0.15<x<0.88	*Formed according to previous boiling adaptations (Kattan et al., 1998a, b, c; Zurcher et al., 1999) *Concluded on void fraction with the database from annular flow (Cavallini et al., 2001; 2002a, b) and film thickness. * Log mean homogenous and Stenier (1993) models.
Koyama et al. (2004)	7.52 mm (smooth) 8.86 mm (microfin)	R-134a	Horizontal (Adiabatic)	0.01<x<0.96	* Void fraction increases if pressure drops (for smooth and microfin pipes) * Models of Smith (1969) and Baroczy (1965) are matching with smooth tube data. * The values of microfin tubes are lower than smooth tube. * Results are different from Yashar et al. (2001) for both of tubes. * Correlation of Yashar et al. (2001) gives better results for microfin data. * At high x values, model gives better results for annular and stratified annular flow.

Table 1. (continued)

Researcher	D_h	Fluid	Tube / Channel Position	Working Conditions	Techniques, Results, Comments, Inferences
Mishima and Hibiki (1996)	1–4 mm	Air - Water	Vertical	$0.0896<j_G<79.3$ m s^{-1} $0.0116<j_L<1.67$ m s^{-1}	* Void fraction values were determined by using visualization of neutron radiography method. * Drift flux model used for experimental parameters of vertical bubbly flow and wavy flow. * D gets higher value on thin channels. * Compatible with Kariyasaki et al. (1992) correlation.
Hibiki and Mishima (1996)	1–4 mm	Air - Water	Vertical	$j<19$ m s^{-1}	* Gives best results for 1 mm. * Also useful for annular flow which has high α value in large channels.
Hibiki et al. (1997)	3.9 mm	Air - Water	Vertical	$j_G=0.131$ m s^{-1} $j_L=0.0707$ m s^{-1}	* Correlation of radial void fraction in vertical wavy flow.
Mishima et al. (1997)	2.4 mm	Air - Water	Vertical	$j<8$ m s^{-1}	* Neutron radiographic image process used for determination of void fraction of wavy flow through a channel.
Triplett et al. (1999)	1.1, 1.45 mm	Air - Water	Horizontal (adiabatic)	$0.02<j_G<80$ m s^{-1} $0.02<j_L<8$ m s^{-1}	* Volumetric void fraction in pictures were determined. * Void fraction increases with increasing gas velocity. * Homogenous model is the best for wavy and bubbly flow.
Kawahara et al. (2002)	100 μm	Nitrogen - Water	Horizontal	$0.1<j_G<60$ m s^{-1} $0.02<j_L<4$ m s^{-1}	* Time averaged void fraction and angle is compatible with video analysis. * Void fraction increases with increasing homogenous void fraction. * Different from Serizawa et al. (2002) who find outs homogenous linear correlation for low α. * At low α, includes high gas velocity, high flux rates and weak momentum between phases.
Kawahara et al. (2005)	50, 75, 100, 251 μm	Water-Nitrogen, Ethanol-Water/Nitrogen	Horizontal	$0.08<j_G<70$ m s^{-1} $0.02<j_L<4.4$ m s^{-1}	* No effect on fluid characteristics. * Used for separate micro and mini channels.

2. EXPERIMENTAL SETUP

Visualization study conducted using the experimental setup at the Laboratory of Yıldız Technical University – Mechanical Engineering Department. Experimental setup was prepared for visualization of R600a flow in a horizontal smooth circular tube. Two phase flow characteristics and void fraction values were determined according to flow types. The experimental setup is able to adjust the vapor quality between 0.1-1 and the mass flux is between 50 – 100 kg m^{-2} s. Experimental setup consists of 20 parts (Figure 3 and 4): refrigerant pump (1), pre-heater (3), evaporator (4), mixture chamber (6), flowmeter (7), transparent flow visualization section (8,11), condensing chamber and heat exchanger 10), liquid-gas separator (12), condenser for uncondensed vapor which comes from the test unit (13), measuring cylinder to determine the condensed liquid amount (14), flowmeter for cooling water (17), water-tank to transfer the cooling water to test unit without effects of pump induced vibration (18), pump for the cooling water (19) and cooling water tank (20).

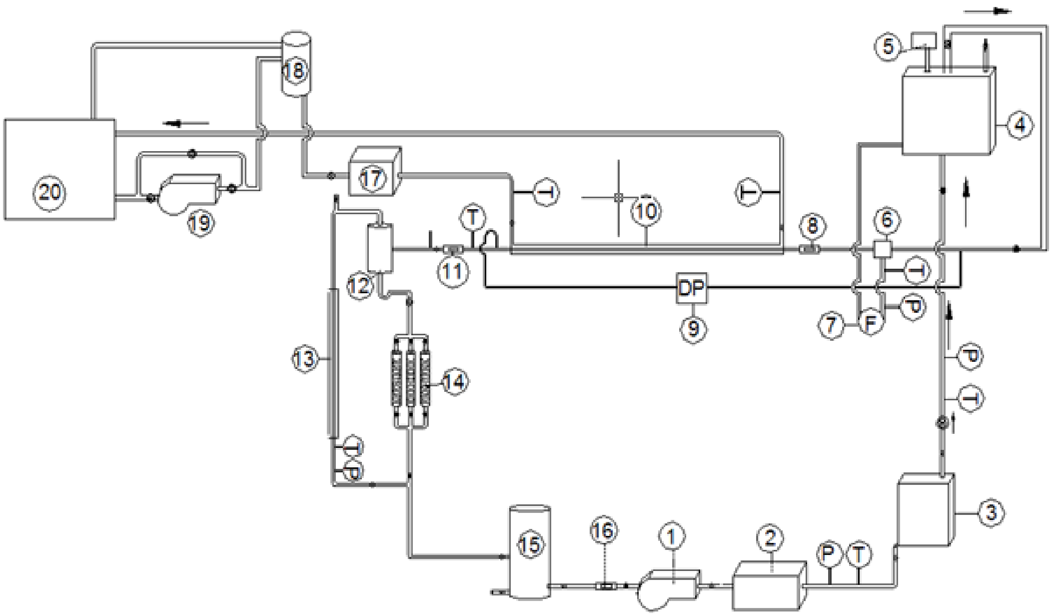
Table 2. Well-known void fraction correlations

Homogenous Model	$\alpha = \left[1 + \frac{1-x}{x}\left(\frac{\rho_v}{\rho_l}\right)\right]^{-1}$
Baroczy (1965)	$\alpha = \left[1 + \left(\frac{1-x}{x}\right)^{0.74}\left(\frac{\rho_v}{\rho_l}\right)^{0.65}\left(\frac{\mu_l}{\mu_v}\right)^{0.13}\right]^{-1}$
Zivi (1964)	$\alpha = \left[1 + \frac{1-x}{x}\left(\frac{\rho_v}{\rho_l}\right)^{2/3}\right]^{-1}$
Lockhart and Martinelli (1949)	$\alpha = \left[1 + 0.28\left(\frac{1-x}{x}\right)^{0.64}\left(\frac{\rho_v}{\rho_l}\right)^{0.36}\left(\frac{\mu_l}{\mu_v}\right)^{0.07}\right]^{-1}$
Thom (1949)	$\alpha = \left[1 + \left(\frac{1-x}{x}\right)\left(\frac{\rho_v}{\rho_l}\right)^{0.89}\left(\frac{\mu_l}{\mu_v}\right)^{0.18}\right]^{-1}$
Steiner (1993)	$\alpha = \frac{x}{\rho_v}\left([1 + 0.12(1-x)]\left[\frac{x}{\rho_v} + \frac{1-x}{\rho_l}\right] + \frac{1.18(1-x)\,[g \times \sigma(\rho_l - \rho_v)]^{0.25}}{G \times \rho_l^{0.5}}\right)^{-1}$
El Hajal et al. (2003)	$\alpha = \frac{\alpha_h - \alpha_{Steiner}}{\ln\left(\frac{\alpha_h}{\alpha_{Steiner}}\right)}$
Smith (1969)	$\alpha = \left\{1 + \left(\frac{\rho_v}{\rho_l}\right)\left(\frac{1-x}{x}\right) \times \left[K + (1-K)\sqrt{\frac{\left(\frac{\rho_l}{\rho_v}\right) + K\left(\frac{1-x}{x}\right)}{1 + K\left(\frac{1-x}{x}\right)}}\right]\right\}^{-1}$
Premoli et al. (1971)	$\alpha = \frac{x}{x + S(1-x)\,\rho_v/\rho_l}$
Yashar et al. (2001)	$\alpha = \left[1 + \frac{1}{Ft} + X_{tt}\right]^{-0.321}$

Visualization of a flow in a small diameter pipe is very difficult. Human eyes can only see the details of the flow type and people can make comments on it. However we need something more than comments on the flow type. It is aimed to determine the gas and liquid areas from the images. Therefore, the computer, high speed camera and other technological devices and software are needed to determine the void fraction.

The key point is to obtain a clear image to distinguish the liquid-gas film successfully. Of course, it is expected to have some unwanted lines or objects in the images due to the reflection.

In this study, various visualization techniques have been applied to get the best images possible. Locations of the light source, camera and test section are the key parameters. After a trial and error process, the best images were obtained with by using the configuration as shown in Figure 5. The Phantom Micro Ex4 high speed camera and Sigma 180 mm macro lens have been used for visualization studies and images were obtained at a resolution of 512x256 pixels.



1. Liquid Refrigerant Pump
2. Filter
3. First Heater
4. Evaportor
5. Level Indicator
6. Liquid-Vapor Mixing Chamber
7. Flowmeter
8. Flow Visualization Glass
9. Differential Pressure Sensor
10. Test Section
11. Flow Visualization Glass
12. Liquid Vapor Seperator
13. Air Cooling Condenser
14. Liquid Tank
15. Liquid Refrigerant Tank
16. Visualization Glass
17. Flowmeter
18. Cooling Water Tank
19. Pump
20. Water Tank

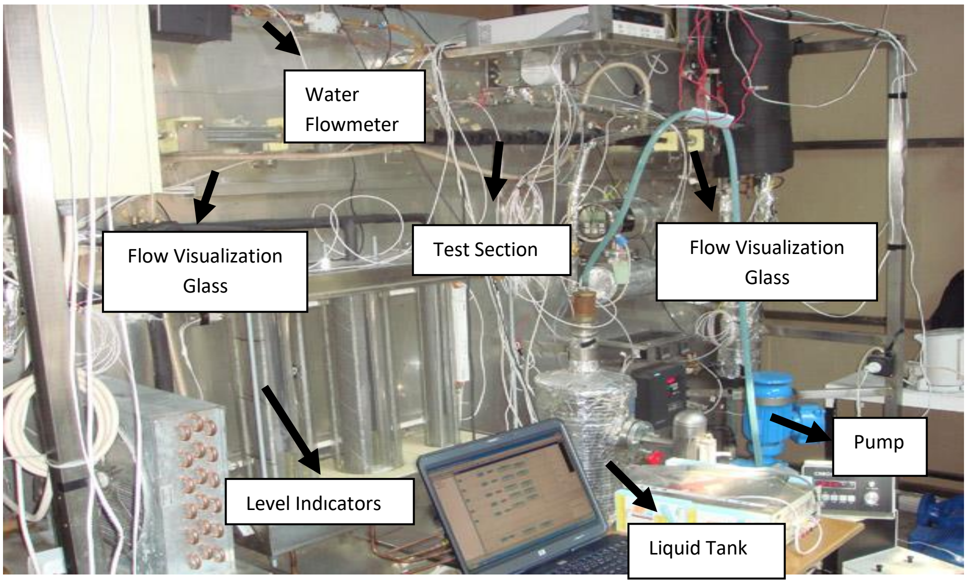
***Figure 3**:*
Schematic diagram of experimental setup

As shown in Figure 5, the light source has been located as vertical and perpendicular to the camera at the top of the test section. Also an aluminum plate has been located to background of the visualization section to have homogenous light reflection at the test section.

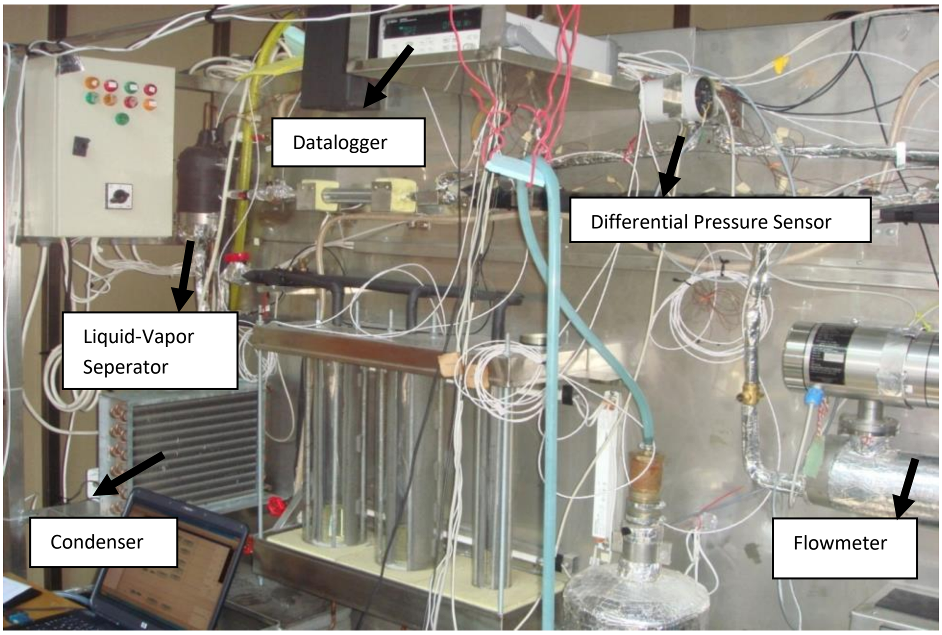
Vapor qualities were obtained from experimental study and used in well-known void fraction models. Power given in the evaporator for steady state conditions is,

$$\dot{Q} = \dot{m}_v (h_o - h_i) \tag{2}$$

Inlet and outlet temperatures are precisely measured and then mass flow rate of the vapor is calculated by using enthalpies of inlet and outlet temperatures. Mass flow rate of the refrigerant



(a)



(b)

Figure 4:
Images from experimental setup

vapor is adjusted by heat given to the evaporator. Mass flow rate of the refrigerant at fluid phase is measured by flow meter. Then, vapor quality is calculated from:

$$x = \frac{\dot{m}_v}{\dot{m}_v + \dot{m}_l} \tag{3}$$

Experimental vapor qualities were used for calculating the void fraction values together with the equations in Table 2.

3. IMAGE PROCESSING

By the development of the technology, image processing techniques are getting widely used for medicine, geography, defense industry, security systems etc. In this study, image processing technique is used to determine the void fraction from images obtained from experimental study.

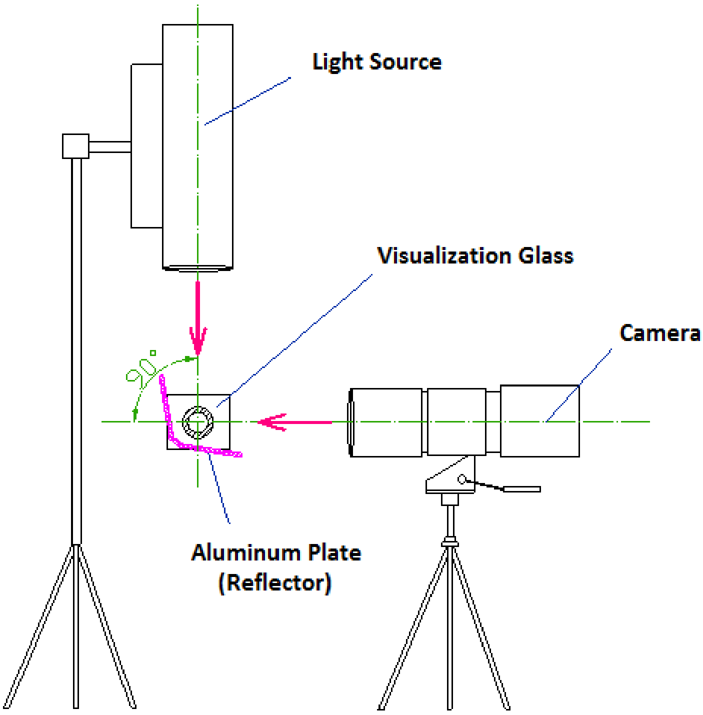


Figure 5:
Schematic diagram of camera and light location and reflector plate

For this aim, software has been developed in Matlab and 100 images of the flow are processed to obtain single void fraction value. The liquid and gas areas are calculated for each image. Images taken by high speed camera are 512 by 256 pixels which represent the limits of our visualization study and approximately 6 by 15 mm. Pixels corresponding to the vapor and liquid areas are separated by liquid-vapor interface. The most important part of visualization study is tracking the liquid-vapor interface. Liquid-vapor interface is determined by a given threshold value using image processing toolbox in Matlab environment. Then, areas between the interfaces and image upper and lower boundaries are calculated as liquid film area. Area between the interfaces is gas/vapor area. After all photos are processed, the void fraction is determined according to average of gas/vapor and liquid areas by Eq. (1).

Although the pipe boundaries are constant, the liquid-gas film has transient behavior. Therefore, getting an average of void fraction value obtained from 100 images should be enough to obtain a satisfactory result and information. However, if it is needed, the developed code is able to process more than 100 images as well. A schematic of algorithm of Matlab code is shown in Figure 6. Also an explanation is shown in Figure 7 for calculation of liquid and gas areas. On the other hand, an example of processed image by the code is shown in Figure 8.

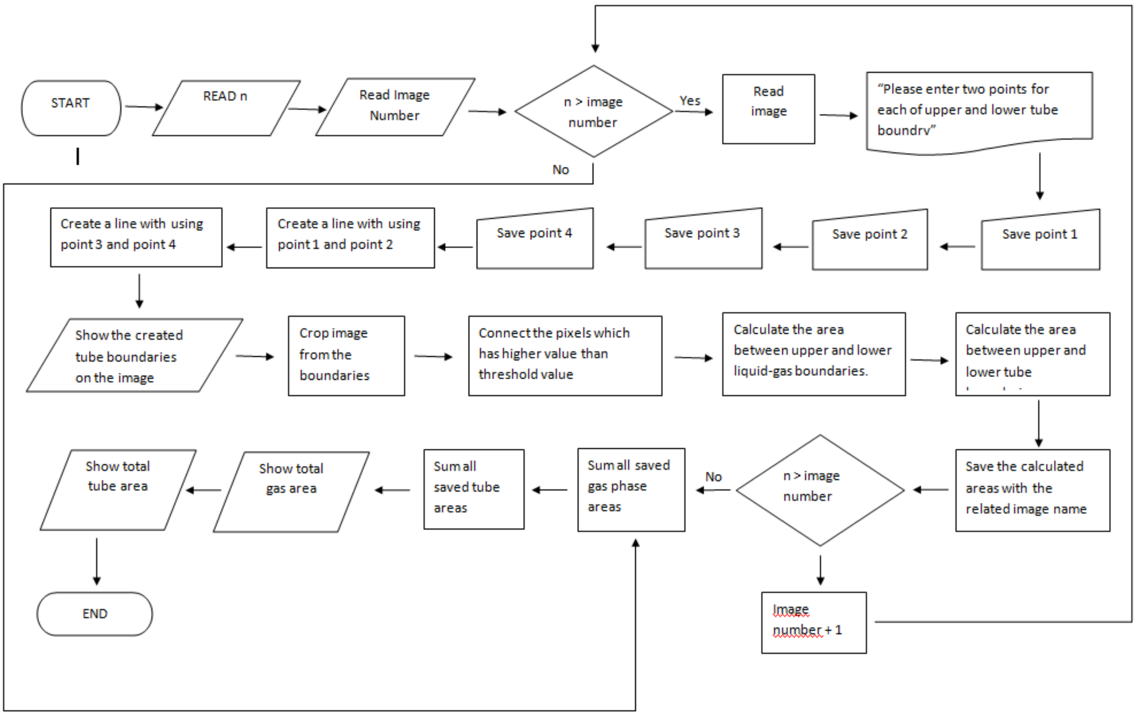


Figure 6:
Schematic diagram of the algorithm

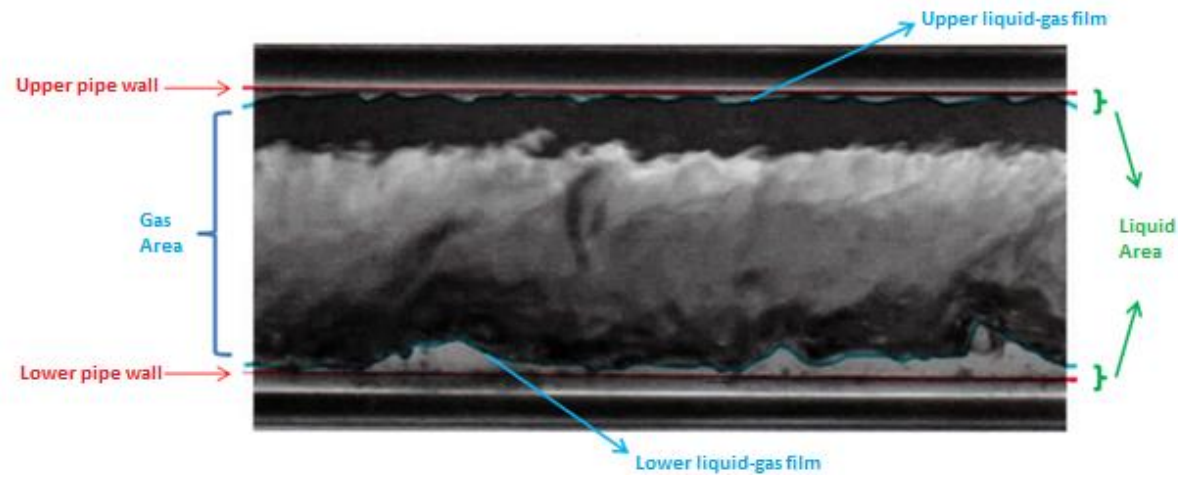


Figure 7:
Explanation of calculation of the gas and the liquid areas

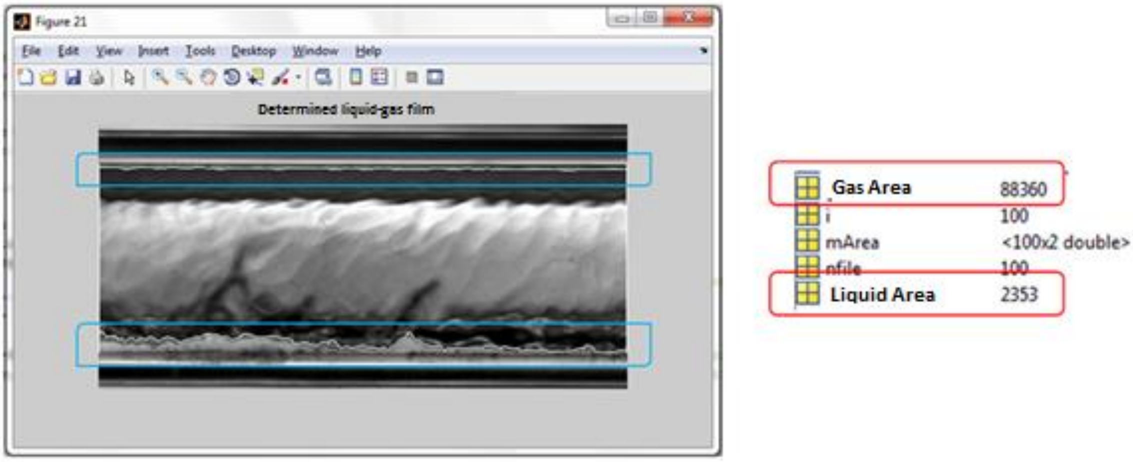


Figure 8:
Example of processed image and calculated areas by the Matlab code

4. RESULTS AND DISCUSSIONS

Studies have been conducted for two phase flow of refrigerant R600a in a horizontal circular tube with an inner diameter of 4 mm. A high speed camera was used for taking photos of the flow. Images from the camera were transferred to the computer and processed by the Matlab code. Initially, experiments were repeated with the same thermo-physical conditions at different times to check the reliability of the system. Then, the calculated void fraction values were compared with the well-known correlations in the literature. Also, deviations from the experimental study were calculated.

The experiments were conducted at a constant temperature of 35°C with a variable mass flux (G) and vapor quality (x). For each experiment, 100 images were saved in bitmap format and processed by the Matlab code. Experiments repeated for same G, x and then images and void fraction values were compared to check reliability/repeatability of the experiments. In Figure 9 and 10, images obtained from experiment 1 and experiment 7 are given. Void fraction values calculated from experimental study are shown in Table 3.

Figure 9:
Image taken from experiment 1 (G=81.549 kg m^{-2} s^{-1} and x=0.907)

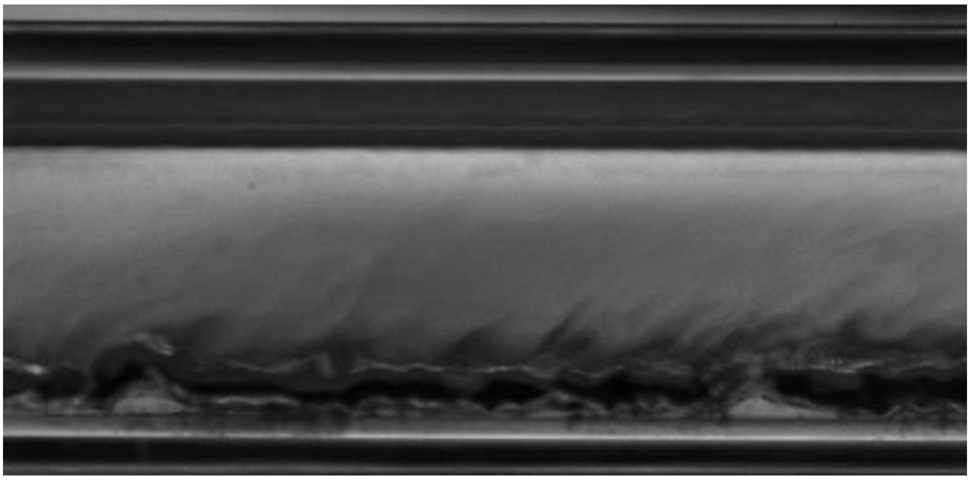


Figure 10:
Image taken from experiment 7 (G=80.43 kg m^{-2} s^{-1} and x=0.932)

In previous sections, the well-known void fraction correlations have been stated. Void fraction values were calculated for the conditions (G and x) given in Table 4 and Figure 11 using well-known correlations and compared with the results from image processing study. Also, at the bottom of the Table 4, deviations from the well-known correlations are given.

Table 3. Calculated void fraction values obtained from measurements of experimental study

Experiment No	G (kg m^{-2} s^{-1})	x	Void Fraction (Image Processing)
7	80.43	0.932	0.9864
1	81.549	0.907	0.9840
3	101.33	0.731	0.9741
9	102.26	0.733	0.9623
4	121.54	0.61	0.9399
10	122.04	0.616	0.9443

It can be easily seen that the results from image processing study are in a good agreement with well know correlations. Maximum deviation is less than 7% for the homogenous model. It is expected, because the homogenous model assumes the perfect mixing of the phases. On the other hand, this method can be used to determine the void fraction values even if we only have sufficient images of a flow without any knowledge about thermo-physical properties of gas/vapor and liquid phases and flow parameters.

Table 4 Comparison of void fraction values with the correlations

Experiment No	G (kg m^{-2} s)	x	Homogeneous Model	Barozcy (1956)	Zivi (1964)	Lockhart and Martinelli (1949)	Thom (1964)	Steiner (1993)	Tandon et al. (1985)	El Hajal et al. (2003)	Smith (1969)	Premoli et al. (1971)	Yashar et al. (2001)	This Study (Image Processing)
1	81.549	0.907	0.9977	0.9778	0.9919	0.9801	0.9942	0.9848	0.9603	0.9912	0.9902	0.9701	0.9887	0.9840
2	88.632	0.835	0.9956	0.9644	0.9846	0.9701	0.9889	0.9729	0.9494	0.9842	0.9815	0.9542	0.9813	0.9762
3	101.33	0.731	0.9919	0.9447	0.9717	0.9561	0.9795	0.9555	0.9390	0.9736	0.9670	0.9346	0.9698	0.9741
4	121.54	0.61	0.9859	0.9191	0.9518	0.9386	0.9650	0.9345	0.9312	0.9600	0.9461	0.9127	0.9538	0.9399
5	147.8	0.502	0.9783	0.8914	0.9271	0.9203	0.9467	0.9142	0.9275	0.9459	0.9221	0.8920	0.9359	0.9101
6	84.83	0.883	0.9971	0.9733	0.9896	0.9767	0.9925	0.9809	0.9563	0.9889	0.9874	0.9646	0.9863	0.9815
7	80.43	0.932	0.9984	0.9826	0.9942	0.9840	0.9959	0.9889	0.9656	0.9936	0.9929	0.9767	0.9914	0.9864
8	90.405	0.829	0.9954	0.9633	0.9839	0.9693	0.9884	0.9720	0.9488	0.9836	0.9807	0.9532	0.9807	0.9735
9	102.26	0.733	0.9919	0.9451	0.9719	0.9564	0.9797	0.9559	0.9393	0.9738	0.9673	0.9352	0.9701	0.9623
10	122.04	0.616	0.9863	0.9205	0.9529	0.9396	0.9658	0.9357	0.9318	0.9608	0.9472	0.9142	0.9548	0.9443
1			1.371	0.639	0.796	0.398	1.023	0.074	2.476	0.725	0.619	1.438	0.476	0
2			1.949	1.224	0.851	0.630	1.285	0.337	2.827	0.815	0.542	2.304	0.522	0
3			1.794	3.103	0.248	1.878	0.559	1.938	3.739	0.049	0.731	4.227	0.442	0
4			4.667	2.265	1.245	0.137	2.596	0.580	0.935	2.091	0.651	2.978	1.460	0
5	**Deviation from image processing study (%)**		6.975	2.098	1.833	1.108	3.863	0.446	1.872	3.784	1.306	2.034	2.753	0
6			1.562	0.843	0.822	0.491	1.114	0.063	2.635	0.754	0.600	1.745	0.493	0
7			1.200	0.381	0.791	0.247	0.952	0.252	2.152	0.728	0.661	0.991	0.501	0
8			2.201	1.060	1.058	0.436	1.509	0.158	2.601	1.031	0.739	2.126	0.739	0
9			2.984	1.819	0.988	0.622	1.776	0.668	2.447	1.181	0.513	2.905	0.798	0
10			4.254	2.590	0.901	0.507	2.225	0.924	1.343	1.711	0.308	3.298	1.099	0

(a)

(b)

Figure 11:
Comparison of calculated void fraction values

5. CONCLUSIONS

Image processing technique was used to determine the void fraction values of a two-phase flow. The results were compared with well-known correlations in the literature. It is concluded that:

- Image processing technique gives reliable results for void fraction values of a two-phase flow,
- Results from the image processing study are in a good agreement with the results of well-known correlations and maximum deviation is less than 7% by the homogenous model,
- Image process technique allow us to determine the void fraction of a two-phase flow even if there is no information about the flow conditions and flowing fluid,

As result the method which is presented in this study gives reliable results and with developments on the software and visualization technique, it will be applicable to all flow types.

NOMENCLATURE

A	area, [m^2]
g	gravity, [m s^{-2}]
G	mass flux, [kg m^{-2} s^{-1}]
j	superficial velocity, [m s^{-1}]
P	pressure, [Pa]
X	Lockhart-Martinelli parameter
x	vapor quality
Greek letters	
α	void fraction
ρ	density, [kg m^{-3}]
μ	viscosity, [Pa s]
Subscrips	
g	gas
h	homogenous
l	liquid
tt	turbulent gas and turbulent liquid
v	vapor

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