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Experimental Study of Compact Multi-Pass Evaporator Two Phase Flow

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Abstract. The distribution of the liquid and gas flows in multi-pass channel that illustrate a compact evaporator for air-conditioning system was experimentally studies. The dividing header are design horizontal with a square cross section of 20mm x 20mm and length is 290mm, also ten curve multi-pass channel with length of 300mm each connected between the circle cross section 50mm combination tank. The distance between the dividing header and combing tank were 120mm. The test was conduct under uniform backpressure conditions; additionally, the working fluid used was water and air. This experiment conducted to examine the influence of inlet-flow at the header entrance (stratified flow and annular-mist flow) under uniform backpressure condition to improve the uniform of the water distribution inside every curve channels. It was found that the inlet-flow condition at the entrance header has relatively influence the water distribution. By comparison between two flow conditions, great value of uniformity for water distribution in each channel is improved under annular-mist flow condition.

1. Introduction

Major progress in the development of compact evaporator has been made by aerospace, automotive and cryogenic industries. Nowadays the global warming issue is the most significant aspect toward greater heat transfer rate per unit volume is needed to increase thermal duty and energy efficiency during this period. Macro compact multi-pass evaporator is one example of compact evaporator that base on multiple branching conduits to distribute refrigerant. At present, most of the problems in two phase flow are based on unsteadiness between the parallel multi-pass branches

This research is aimed to improve the Coefficient of Performance (COP) of the evaporator, which is, experiment on distribution characteristic of liquid and gas flow, the effect of the inlet-flow distribution (annular mist flow and stratified flow) and pressure lost condition.

A multi-pass evaporator usually creates a mal-distribution of gas-liquid flow among channel. This problem causes non-uniform evaporator heat transfer and mass transfer absorption. The problem may effect on evaporator Coefficient of Performance of the evaporator, which can deliver a high amount of energy usage.

The objective of this study are mainly to design experimental apparatus to simulate macro compact multi-pass evaporator with liquid-gas phase flow in uniform backpressure condition, by using air and water as working fluid. Also, to study experimentally base on the two phase liquid-gas flow distribution characteristic of (liquid phase and gas phase) in dividing header.

This study is conduct by limitation scope of experimental conditions as follows. The multi pass channel of branches from the dividing header is fixed with vinyl tube sized 2/8” or 6.35 mm of diameter. To generate the desired flow pattern, i.e., stratified and annular mist flow, some flow generator devices shall be used. Also, in this experimental study, a uniformed backpressure condition at the outlet of multi pass channel shall be applied.

2. Literature Review

Two-phase flow happens when distribution of liquid and gases in flow channel that have some commonly observe flow structures. This flow structure is known as two phase flow pattern, which have particular identifying characteristic. Prediction on pressure drop and heat transfer coefficient is nearly related to two-phase flow structure of fluid [1].

Mal-distribution occur when fluid and gas flow through header and divide into branches in refrigerant tube, it is frequently occurring in multi-flow evaporator and in worst case scenario it can cause no liquid provided into some of the branch [2].

Mader et al. [3] systematically investigate on mal-distribution in different path can cause decrease of COP and heat pump capacity as well as increased annual operating cost. Uneven distribution can likely reduce the effectiveness of heat exchanger and little impact on device mechanical failure also hydraulic instabilities. For example, Non-Uniform flow of heat exchanger-reactor among individual or differential channels may result substantial temperature deviations, resulting in thermal runaway, which could arise from an exothermic reaction studies by Rebrov et al [4].

Two phase flow of liquid and gas characteristic in one conduit was review significantly by Barnea D and Y. Taitel, main focus was on flow pattern identification which is to classify of various characteristic of flow pattern to sort into several groups also explanation on the method used to develop and conducted on flow pattern of two phase flow detection in conduit [5].

Two-phase flow pattern in different position of the tube cases, some researchers shows the definition which are nearly close to the resent pattern because of the flow pattern designation is not yet reach accurately standardize. The large amount of study and development have been done, deal with two-phase flow in vertical or horizontal tube, yet there is a small amount of studies with the whole range of inclination. The most acceptable flow patterns for vertical tubes with upward flow are defined by Bennett A.W [6] and from G. F. Hewitt D and N. Roberts [7]. Mandhane et al, is the most frequently use for liquid-gas flow pattern maps in horizontal tube [8].

The first step to predict or to understanding the characteristic of two-phase flow is to know the type of the flow, which is the pattern of the flow. Each flow has common different in physical phenomena such as, shear for annular flow and acceleration of gravity for stratified flow. The different correlation and model only can be applied to specific flow pattern. Thank to development of flow pattern map, thus can be used to determine the configuration of two phase flow depending on the flow condition [9]. The flow pattern prediction can be made by mapping the experiment data on flow pattern and transition boundaries using two dimensional plots. Two common type of coordinate that most-use are dimensionless coordinate’s map and dimension coordinate’s map [2, 5, 7, 8].

Dimension coordinate’s map is the basic form of coordinate condition that uses mass superficial, superficial velocity and momentum flux, but this mapping method are limited to the range of data collected as well as flow condition beneath which experiment were conducted.

This mapping method is straightforward dimension analysis approach to select or predict the physical variable that affected the flow pattern. The two phase flow transition boundaries must be a function of all variable. The reason why is that these set of variable already been reduced as it is assumed that geometric entrance has no effect on the steady state flow pattern. Baker (1954), use to account for the different physical properties and introduced non-dimensional parameters, which called Baker’s coordinates map [10]. Baker is the one proposed top lot the flow map with two parameter set $\dot{m}_G/\lambda$ and $\dot{m}_L/\psi$ where $\dot{m}_G$ and $\dot{m}_L$ are gas and liquid mass velocities flow rates, respectively and λ and ψ are defined as [11].

Jesus Moreno Quiben (2005), superficial velocities can be defined as the volumetric flow rate of the phase across the entire cross-sectional area of the liquid-gas flow. It is possibly being expressed as the phase velocity if it would flow alone in the total cross section. He describes the formulation of superficial gas velocity and superficial; liquid velocity [12]. Vapour quality (χ) is the ratio between of vapour mass flow rate ($\dot{m}_G$) to the sum of mass flow rate ($\dot{m}_G + \dot{m}_L$) [12, 13, 17]. Mass fluxes (G) is the ratio between mass flow rate ($\dot{m}$) divided with cross section (A) of the tube [12, 17]. The cross-sectional area of the channel or pipe can be subdivided into an area subject to the vapour phase (V) and the area led by the liquid phase (L) [17]. The mass flow rate ($\dot{m}$) of the liquid-gas flow mixture is the sum of the mass flow rates of vapour (V) and liquid (L)[17]. Void fraction is the one of most important parameter used to characterize two phase flow properties. It used as the key to unlock the physical value for determining various other significant parameters [14]. Jesús Moreno Quibén, void fraction is defined by the ratio between cross section divide with total of cross section [12].

The important hydrodynamic aspects of two-phase pressure drop in horizontal mini- and micro-channels have been studied by different researchers. Similar with the ordinarily sized channel, frictional pressure drop in the micro-channel still plays the dominant role when compared with other pressure drop components such as acceleration pressure drop and pressure drop due to an abrupt flow area [15].

Void fraction is one of the key parameters needed to evaluate the gravitational and acceleration terms in the total pressure drop of two-phase gas–liquid flow in different channels. Different methods available for void fraction estimation have been used by previous researchers [15, 16]. It is representing the ratio of the domain occupied by the vapour to the total domain that is occupied by the two-phase flow mixture. Void fraction can be defined as the ratio of the cross-sectional area occupied by vapor to the total cross sectional area of the conduit [17].

3. Methodology

This experiment was conducted to investigate the influence of inlet-flow header on two phase flow mal-distribution. In this experiment, water and compress air are used as a working fluid to simulate actual meal-distribution of two phase flow that occur in multi-pass branches in the evaporator. The investigations are based on several parameters which is, inlet-flow pattern in the header and the superficial velocities of both gas-liquid flow at the entrance of the header and uniform back-pressure at the dividing channel outlet.

3.1. Experimental study methodology flow

This investigation starts by viewing other researcher paper to investigate the importance factor that can give impact to mal-distribution in the dividing channels. Than the experiment apparatus need to be design base on uniform back-pressure condition at the outlet of the branches before contracting the apparatus. For the next step, the installation of annular mist flow generator and stratified flow generator device as the inlet-flow header, to ensure the entrance of two phase flow in the test channel in a desire flow condition; annular-mist flow and stratified flow.

Two phase flow is based on gas-liquid flow, since this test using room temperature water and compressed air as a fluid running in the test channels. The generating flow that generate at the inside of test channel can be examined using Baker's flow pattern maps to ensure the mal-distribution that need. The difference inlet flow at the header may give effect to the mal-distribution of two phase flow in the multi-pass branches. From the data receive on two phase flow under particular aspect of inlet flow that is presumed that this data can develop more understanding about two phase flow distribution behavior in multi-pass parallel channel.

3.2. Experimental apparatus and setup

Figure 1 shown experimental apparatus schematic diagram during this research. The experimental study will simulate actual gas-liquid flow in multi-pass channel on evaporator using isothermal air-water two phase flow test channel. Water supply and gas volumetric flow rate is controlled by the air flow meter and water flow meter.

To simulate the actual situation of evaporation, the test channel has been developed using transparent acrylic plate with 20mm wide, 20mm height also with 290mm of length that is set horizontally and equip with ten curve 5mm branches with 300mm length also distance between dividing header and combining tank is 120mm shown in figure 2.

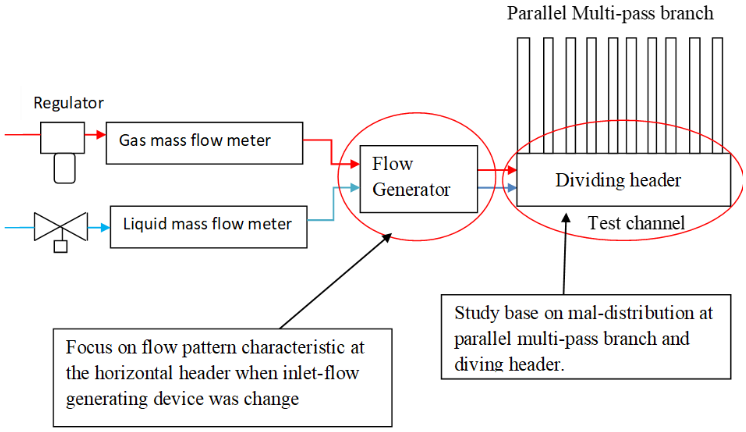


Figure 1. Experimental apparatus schematic diagram

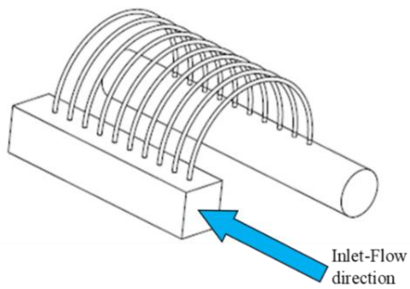


Figure 2. Display the details of test channel

The investigation will present the stratified flow and annular mist flow pattern. In this case, the inlet flow pattern at the entrance of the header is considered to give an effect on two phase mal-distribution among the channel. In this experimental study, two inlet flow condition at the entrance of the header are implemented which is an annular mist flow and stratified flow. The differences on flow pattern mal-distribution of both inlet flow conditions can be observed visually trough test channel. The flow generator device is attached at the header entrance of the dividing channels to create desire flow pattern. The developing region happen in the test channel that has the same cross section as the flow generator.

The actual evaporator refrigerant can be determined using vapour quality (quality x) and mass flow rate, due to the value of superficial velocity of gas (compress air), J_G and superficial velocity of liquid (water), J_L at the entrance of the header. Refrigerant R-134a has the value of 1.0m/s to 0.5m/s in superficial velocity of liquid and 0.015m/s to 0.045m/s in superficial velocity of gas, further with mass flow rate of M = 40kg/h to 160kg/h as well as a vapour quality range x = 0.2 up to 0.7 [2]. Addition, this experimental investigation is done in a room temperature.

Table 1. The experiment condition summary

Running fluid	Air and water
Header superficial air velocity	1.0m/s, 3.0m/s, 5.0m/s
Header superficial water velocity	0.015m/s, 0.03m/s, 0.045m/s
Back of the branches pressure condition	Uniform outlet pressure
Inlet-flow pattern at the header	Annular mist flow and Stratified flow
Condition of the header	Horizontal header
Condition of the channel	Parallel channel
Channel characteristic	Circle tube and Multi-channel tube

To claim the impact of the pressure at the back of the multiple branches on flow distribution, the experiment is done based on uniform pressure at the back of the multiple branches were conducted. Figure 3 shown the experimental apparatus for determine pressure at the back of the multiple branches. The experiment conduct by using either one of the multiple branches is connected to the separator and other branch is connected to combining tank, which have a great capacity or volume. The pressure in the combining tank and at the separator must have zero in pressure differences getting from u-tube or manometer. To ensure the pressure difference is at zero, the valve at the combining tank and separator outlet is used to regulate the pressure to get uniform pressure. Combining tank at the outlet of the divided branch is shown in Figure 4.

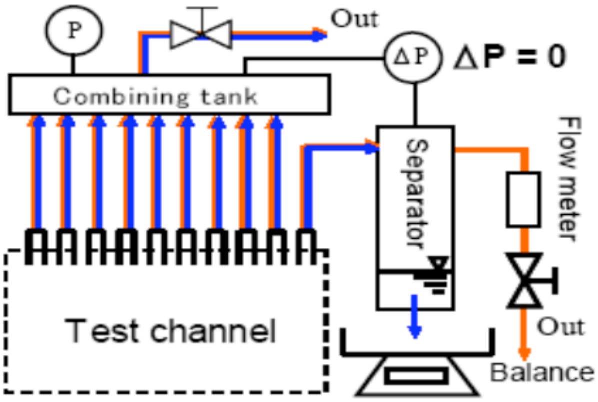


Figure 3. Uniform condition of pressure at the back of multi-pass channel test apparatus [2]

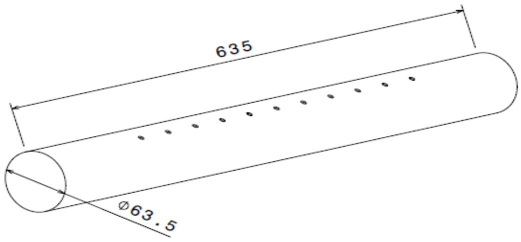


Figure 4. Combining tank

4. Results

In this section, the complete contraction of the experiment apparatus and experimental result are revealed. On the other hand, these study deliver two main result components that base of (i) design experiment apparatus for macro compact multi-pass channel with two phase flow and (ii) evaluation result depend on the impact of the entrance flow pattern before entering the dividing channel in water distribution ratio.

4.1. Completion of experimental apparatus for compact multi-pass evaporator

In this section, the author will give clear vision for the reader about the experimental apparatus arrangement to do the test. Figure 5 shows the arrangement of experimental apparatus.

1. Separator tank.
2. Air flow speed (l/min).
3. Water flow speed (l/min).
4. Flow generator.
5. Experimental apparatus table 2” x 1’ 1/2’ x 3”.
6. Flexible rubber tube 1/2".
7. Dividing header (in this figure stratified flow generator is use).
8. Flexible transparent tubing 5mm.
9. Combining Tank 2”.
10. Pressure differential manometer.

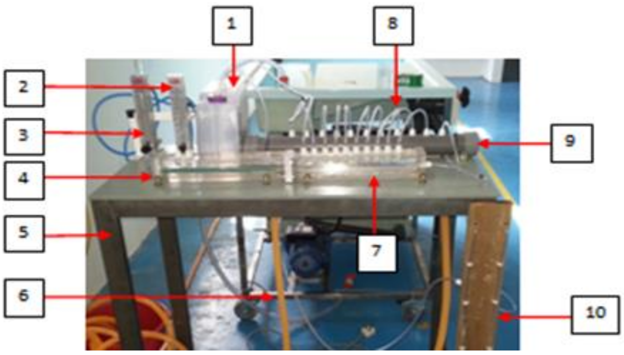


Figure 5. Experiment apparatus arrangement

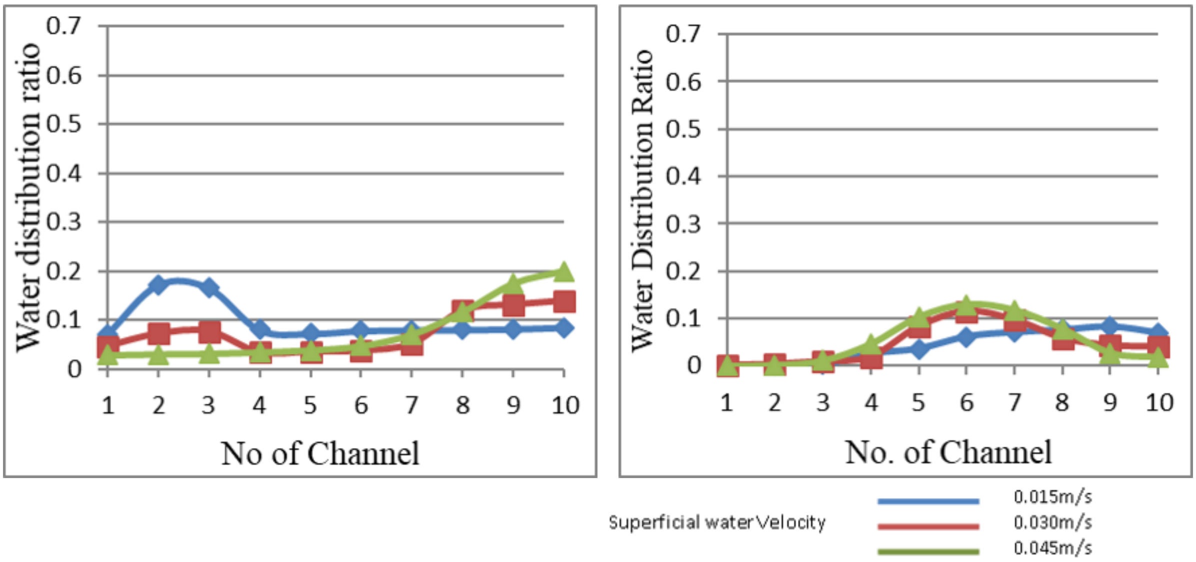
4.2. Comparison base on water distribution uniformity improvement occur between stratified flow and annular mist flow condition

From the result obtain under stratified flow and annular mist flow condition, as the result show in figure 6. Figure was pick from the highest result that possibly obtain under stratified and under annular mist flow condition, in other word by comparing the best from the best result to get obtain the greater improvement on uniform flow of the water distribution in every channel. Moreover, these two results can be compared on difference uniformity of the water distribution through every channel.

Firstly, the comparison can be made on the difference of the superficial air and water velocity of the experiment. The uniformly distribute was occurred when the superficial air and water velocity, J_G, J_L is increase to the highest value which is at J_G = 5.0 at J_L=0.045m/s for Case B (Stratified flow condition). The difference of result show in Case A (Annular-mist flow condition), when the superficial air velocity, J_G = 3.0m/s in all different value of superficial water velocity, the water distribution ratio is uniformly distribute in every channel was improve.

The improvement of uniformity water distribution occurs in Case A can easily be observe by the staged or horizontal line occur over the graph compare to the result obtain in Case B. As a result, shown in Case B, the curving line on the graph happened in every conditions, it is shown the sudden increment occur on the water distribution ratio. On the other hand, the smooth horizontal line shows the uniformity of the water distribution through every channel is represent in Case A.

Base on the result and the observation made on the influence of the superficial air velocity, J_G and superficial water velocity, J_L. Under annular-mist flow condition the uniformity of the water distribution inside the channel is improve especially when high superficial air velocity is implement [10].



(a) Case A (Annular-mist Flow condition (b) Case B (Stratified Flow Condition

Figure 6. Water distribution ratio under (a) Annular-mist flow (curve tube J_G = 0.3 m/s) and (b) Stratified flow (curve tube J_G = 5.0m/s)

5. Conclusion and recommendation

First of all, the experimental study was start by design the experiment apparatus for multi-pass curve channel under uniform backpressure condition to simulate the actual compact multi-pass evaporator. The design process start by design selection on the experimental apparatus, it involves experiment apparatus schematic diagram, header-entrance condition and the uniform backpressure condition at the outlet of the channels. Next, the material selection and fabrication process for each equipment, also the specific measuring device used in this experimental apparatus.

Stratified-flow condition is the first two-phase flow condition that examine. The water distribution at the multi-pass channel under stratified-flow condition is approve to have effect went the adjustment of superficial gas velocity is increase

Furthermore, for the annular-mist flow header entrance under uniform backpressure condition, this flow was observed to have an effect to the adjustment made on superficial air and water velocity is show that superficial air and water velocity have a certain effect to the distribution of water in the dividing channel under annular mist flow conditions.

On the other hand, the comparison can be made between these two different flows to obtain the greater uniformity improvement on water distribution of multi-pass channel. Generally, under annular mist flow the effect of superficial water and air velocity was give greater improvement to uniformly distribute the water through the multi-pass channel compared to stratified flow especially at high superficial air velocity.

These experimental studies have a lot of potential for future work. The uniform backpressure can be compare to un-uniform back pressure condition, to know the influence of the outlet channel pressure condition to the distribution liquid and gas in the dividing header. On only that, the adjustment in curve channel high can be made, to know the influence of the gravitational force when the two-phase flows start to distribute. In addition, the experiment can be test on velocity of the air inside the dividing channel by adding digital air flow meter and use of digital pressure differential meter get the exact measurement of uniform pressure between combining tank and separator tank. Besides that, to have better observation result for air flow, high speed camera and particle image (PIV) is suggest to be used in future. Not only that, to have greater accuracy of measurement and adjustment on the inlet-flow condition, the digital mass flow controller is suggested.

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References

[1] John R. Thome., (2007), Engineering Data Book III, 1st Edition, “Chapter 12: Two Phase Flow Pattern”, *Wolverine Tube, Inc., Switzerland*.

[2] Zuradzman bin Mohamad Razlan, Hiroaki Goshima, Masafumi Hirota, Ryota Isobe,Yasuhiro Mizuno, Naoki Maruyama and Akira Nishimura,(2011).Gas-Liquid Flow Distributions in Multipass Channels with Vertical Upward Branches, *The Open Transport Phenomena Journal*, 3, pp. 17-30.

[3] Mader, G., Palm, B., Elmegaard, B., (2014). Maldistribution in Air-Water Heat Pump Evaporators. Part 1: Effects on Evaporator, Heat Pump and System Level.

[4] E.V. Rebrov, J.C. Schouten, M.H.J.M. de Croon (2011), “Single-phase fluid flow distribution and heat transfer in microstructured reactors”,. *Chemical Engineering Science* 66, pp. 1374-1393.

[5] D. Barnea and Y. Taitel (1986), "Flow Pattern Transition in Two-Phase Gas Liquid Flows", Chapter 16, the Encyclopedia of Fluid Mechanics, 3, "Gas Liquid Flows", Gulf Publishing, N.P. Cheremisinoff, Editor, pp. 403-474 (1986)

[6] Bennett, A.W., Hewitt, G.F., Kearsey, H.A., Keeys, R.K.F. and Lacey, P.M.C. (1965). "Flow visualisation studies of boiling at high pressure". *Proc.Irut.Mech.Eng.*, 180, (Part 3c), 260.

[7] Hewitt, G.F., Roberts, D.N., (1969).” Studies of two-phase flow patterns by simultaneous X-ray and flash photography. UKAEA, Harwell: Report, AERE-M 2159.

[8] Mandhane, J.M., Gregory, G.A., Aziz, K., (1974).” A flow pattern map for gas–liquid flow in horizontal pipes*”. Int. J. Multiphase Flow* 1, pp. 537–553.

[9] Stéphane Lips, Josua P. Meyer. (2011), “Two-phase flow in inclined tubes with specific reference to condensation: A review”, *International Journal of Multiphase Flow*, 37, pp. 845–859.

[10] C. Foletti, S. Farise, B.Grassi, D.Strazza, M.Lancini, P.Poesio (2011). “Experimental investigation on two-phase air/high-viscosity-oil flow in a horizontal pipe”. *Chemical Engineering Science*, 66, pp.5968–5975.

[11] Jesús Moreno Quibén (2005). "Experimental and analytical study of two-phase pressure drops during evaporation in horizontal tubes". PhD thesis, University Pierre ana Marie Curic, France and Spanish.
[12] Bingdong Zhang, Xingkai Zhang, Dong Wang, Shanfang Huang (2013) "Equal quality distribution of gas–liquid two-phase flow by partial separation method". International *Journal of Multiphase Flow*, 57. pp.66–77.
[13] John R. Thome., (2007), Engineering Data Book III, 1st Edition, "Chapter 17: Void Fraction in Two-Phase Flow", *Wolverine Tube*, Inc., Switzerland, pp.1-33.
[14] Sira Saisorn and Somchai Wongwises. (2009). An experimental investigation of two-phase air–water flows through a horizontal circular micro-channel". *Experimental Thermal and Fluid Science* 33, pp.306–315.
[15] Kawahara, P.M.-Y. Chung, M. Kawaji. (2002), Investigation of two-phase flow pattern, void fraction and pressure drop in a microchannel". *International Journal of Multiphase Flow*, 28, pp.1411–1435.
[16] Julian Winkler, Jesse Killion, Srinivas Garimella, Brian M. Fronk (2012)." Void fractions for condensing refrigerant flow in small channels: Part I literature review". *International Journal of Refrigeration*, 35, pp.219 -245.
[17] F. Poggi, H. Macchi-Tejeda, A. Maréchal, D. Leducq, A. Bontemps (2007). Experimental study of single and two-phase adiabatic flow distribution in compact heat exchangers. 18th France Congress of Mechanics Engineering, Grenoble, France, pp.27-31.