ESTIMATION OF VOID FRACTION IN MICROCHANNEL CONDENSATION USING IMAGE PROCESSING TECHNIQUE

Submitted by: Jawad Mustafa

Submitted To: Dr Brian M. Fronk

Estimation of void fraction in microchannel condensation using image processing technique

Abstract:

In microchannel condensation, void fraction is calculated which is used in determining pressure drop, heat transfer and cost effectiveness. R134a is used as a refrigerant while cooling water is used as a cooling media. To calculate the void fraction image processing technique is applied through coding in MATLAB R2015b. Analysis of results shows the decrease in void fraction with the increase of cooling water flow rate. By keeping the refrigerant inlet temperature, refrigerant mass flux and cooling water flow rate constant, a very slight variation of void fraction is examined with time. The simulated model is validated by comparison with the experimental results.

1. Introduction:

Condensation is important industrial process through which vapors convert into liquid state by removal of heat. It is highly energy intensive process and required high heat transfer area. It is necessary to look into more robust design, effective flow distribution, moderate pressure drop, high volumetric heat flux and less space requirements. Micro channel is a latest technology which can achieve these goals [1]. In micro channels, refrigerant R134a is used as a heating media due to its less toxicity, explosiveness and little effect on greenhouse while cooling water is used as a cooling media. There are different flow regimes which are formed inside the channels like bubbly, cap bubbly, annular, slug and churn. In [2] Flow regime transition criteria is explained which is required to accurately modeled pressure drop and condensation heat transfer [2]. One of the flow regime is slug flow which is studied inside the micro channel at low mass velocities [3].

Image processing is used to calculate the void fraction in microchannel condensation. With the help of image processing internal process dynamics can be analyzed and interpreted. To achieve this, code is developed in matlab R2015b. Void fraction is important process parameter in characterizing two phase flow. With the help of void fraction, pressure drop and heat transfer rate can be predicted. In addition to this, it helps to develop reduced charge system which is cost effective and environmental friendly.

Image processing is very important to get useful data through images. Different software tools can be used to process images like Huygens, IDL (Programming language), Scikit-image, Matlab etc. The researchers prefer MATLAB over other tools owing to its robust and well-defined traits. It has also some specialize built-in functions for imaging processing. To analyze the image in matlab, there are different algorithms, each having specific applications and requirements. In [4] image processing technique is used through matlab to estimate the percentage of heat transfer coefficient and different flow regimes, as a function of mass flow rate, position and heat flux. Image processing has lot of applications in different fields such as medicines, agriculture, industry, law enforcement. In [5] MATLAB-based applications is presented which is useful for image quality assessment and adjustment. An image processing task will be accomplished through image preprocessing, segmentation, representation and interpretation.

In this case micro channels are positioned horizontally with high speed camera is adjusted to record the motion of both phases (gas and liquid) and its transformation. Reading is taken at different flow rates of refrigerant and cooling water and variation in temperature is analyzed through image processing. Images are obtained from videos at definite intervals and applied different filters through coding to improve their quality. Images are processed to predict void fraction through vapor and liquid cross sectional area. Computational model is validated by comparison with the experimental results. In order to calculate void fraction from the experimental results, two different groups are available to categorize void fraction. One group extends the homogenous flow model and the second one is further characterize based on Lockhart-Martinelli parameter. Rice in 1987 presents a detailed review of differences and similarities in models for different refrigerants [6]. As flow rate is high enough, so mostly annular flow regime is observed for which Zivi suggested a model to predict void fraction considering assumption that no liquid is present in the central vapor core [7]. This model is used to calculate void fraction from experimental results and then compare it with mathematical model results.

2. Process description:

Micro channels with diameter 0.84mm are used to deal with two phase flow which make the process efficient in terms of heat transfer rate and compactness. R134a is used as a refrigerant and water is used as a cooling media. Channels are set in horizontal position where vapors of refrigerant passes through it and transfer heat to the cooling water which raises its temperature. Complete conversion of vapor refrigerant into liquid state usually cannot take place and two phase mixture of liquid-vapor is obtained. Stainless steel 316L is used as a construction material for micro channels. High speed camera is used to record videos of the process which takes place into the micro channels. The parametric effect of temperature (refrigerant and cooling water) and flow rate of water and refrigerant is analyzed on the void fraction and flow regimes.

2.1 Image processing:

Image processing is a technique to interpret the image by manipulation of pixels. Image is made up of pixels distributed in rows and columns. Each color is a combination of red, green and blue which have values from 0 to 255. Final color is black when all three colors are zero. Similarly final color appears to be white when all three colors have maximum value i.e. 255.

Matlab considers an image to be a three dimensional matrix. First two dimensions are for rows and columns while third dimension have three values i.e. red, blue and green. Matlab programming language is chosen for coding due to its inbuilt functions specifically designed to incorporate image processing. To make the image ready for interpretation, it is sometimes necessary to apply filters to remove noise and distortion. To process the images it is important to understand the different aspects of image processing. The steps of image processing consists of image enhancement, restoration and segmentation. Image enhancement is performed to remove the noise, de-blurring the out of focus image and improve the contrast of image. Image restoration and segmentation is used to remove periodic interference and pinpoint different objects in main image. Conversion of image in fig. 1, 2 and 3 shows step wise separation of liquid and vapor areas. In fig. 1 cropping of the image is performed with the help of coding and in fig. 2 contrast adjustment takes place to identify the vapor region which is known as equalization of the histogram. In equalization pixels at each intensity level is changed and total number of pixels at higher intensity level is increased .In Fig. 3 equalized image is converted into binary image to calculate the area of vapors.

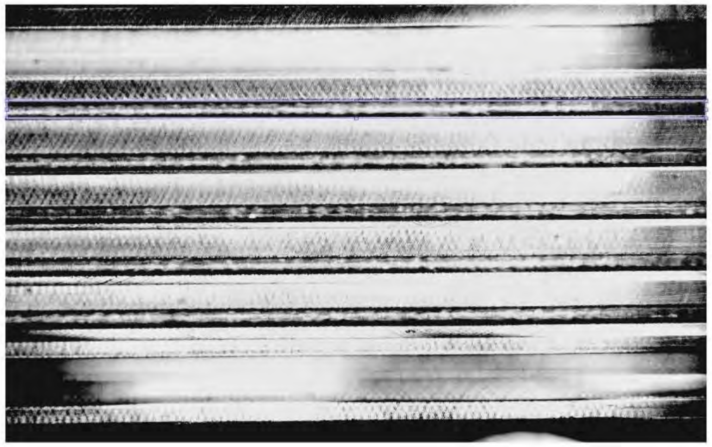

Figure 1-Image cropping

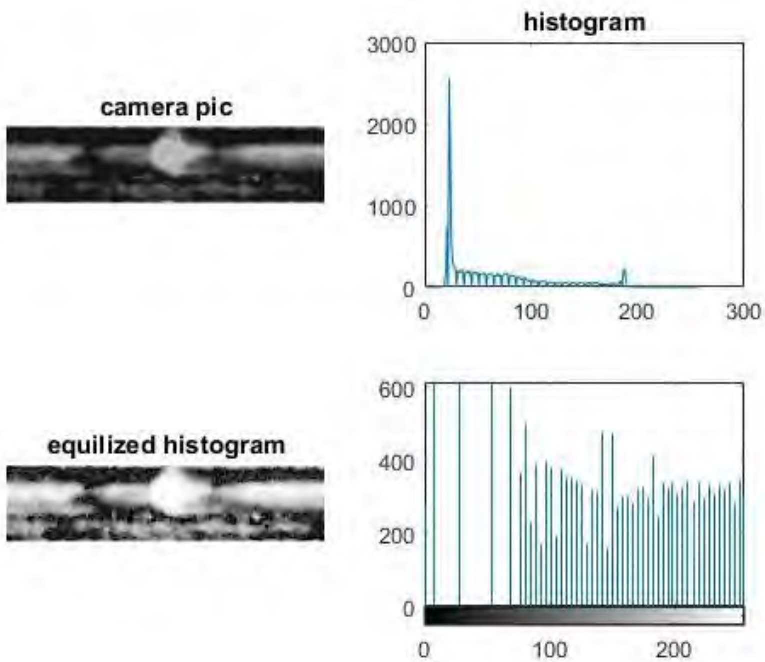

Figure 2-Equalization of the Histogram

Figure 3-Conversion of Equalized image into binary image

2.1.1 Description of MATLAB coding:

The MATLAB code along with its full description which includes capturing of images, image resize, image cropping, Histogram plots, Histogram equalization, Thresholding and Area calculation is as given

- Capturing images from video:

"For loop" is used to capture images from video in a definite interval of time. This loop is used to directly process videos to obtain images.

- Image sizing:

In image processing every image is required to have same spatial resolution (pixels density over the image). MATLAB built-in function "imresize" is used to equalize the spatial resolution of all images. So, that comparison of result at different conditions can be performed between images.

- Image cropping:

"Imcrop" function creates an image cropping tool. The tool is resizable and movable that is manipulated with the help of mouse.

- Histogram equalization:

The main advantage of histogram is that it shows possible values of threshold that can convert a grayscale image into binary image. "Imhisteq" is a function used to define histogram which is a plot of intensity versus the number of pixels. As images are converted into greyscale which include 8 bits per pixel. So, each image has 2^8= 256 different shades of grey. To increase the contrast of image, grey level is changed to

$$\left(\frac{n_0+n_1+n_2 \ldots\ldots\ldots\ldots n_i}{n}\right)(L-1) \qquad (1)$$

where n shows total number of pixels, L represents the total shades of grey and i shows grey level that is present n_i times in a image. "Histeq" is a MATLAB built in function used to equalize the histogram. It is technique for adjusting image intensities and linearize the frequency (cumulative) distribution which enhance contrast. It is specifically useful in that case where the images having close contrast values are present. Through the histogram equalization, pixels are distributed over the whole intensity range.

- Thresholding:

Thresholding is used for segmentation of images and conversion of grayscale image into binary image. With the help of histogram, the dominating color is identified. The most important part of detecting abnormality is thresholding. The image is converted into binary by choosing the greyscale value in the image. A pixel becomes white in color if a greyscale value is greater than the original greyscale value. Otherwise, pixel appears in the black color.

- Area calculation:

MATLAB inbuilt "bwarea" function is incorporated to calculate the area of white pixels by multiplying the height and width of pixels. So, by applying thresholding, total area and vapor area is calculated.

```
a=VideoReader('T55_G150_13ml.mp4')
for image=1:7;
    video_file=strcat('frame',num2str(image),'.jpg');
    b=read(a,image);
    imwrite(b,video_file);
end
for i= 1:5
[fname path]=uigetfile('*.*','Enter an image');
fname=strcat(path,fname);
imm=imread(fname);
im=imresize(imm,[800 1280]);
[immm, rect] = imcrop(im);

% im=imresize(im,[256 256]);
imshow(immm);
im1=rgb2gray(immm);
figure;
subplot(2,1,1);
imshow(im1);
subplot(2,1,2)
imhist(im1)

subplot(2,2,1);
imshow(im1);
title('camera pic');
%%histogram
h=imhist(im1);
subplot(2,2,2);
plot(h);
title('histogram');

%%histogram equilization
im2=histeq(im1);
subplot(2,2,3);
imshow(im2);
title('equilized histogram');
subplot(2,2,4);
imhist(im2);

% %thresholding to calculate Vapour area
imA=im2>90;
figure;
imshow(imA);
Vapour_area=bwarea(imA)

% thresholding to calculate total area
imB=im2>1;
figure;
imshow(imB);
Total_area=bwarea(imB)

% Calculation of void fraction
Voidfraction(i)=(Vapour_area)/(Total_area)
End
```

```
voidfraction=[Voidfraction(1) Voidfraction(2) Voidfraction(3) Voidfraction(4)
Voidfraction(5)]
Meanvoidfraction=mean(voidfraction)
```

3. Methodology:

In this process (microchannel condensation), camera is fixed in a horizontal position to record videos of the flow of refrigerant from inlet to the outlet. To process the videos, code is developed in MATLAB which takes images from the videos at the equal interval of time. Initially preprocessing is done to remove the noise, adjust the contrast level and identify the edges. Then, extend the code to resize the images which is required for the comparison of images obtained at different conditions. Cropping tool is also incorporated to crop the images with the help of coding. It provide aid to examine the void fraction of any specified region. After cropping, histograms of images will obtained to examine the pixel distributions over the entire intensity range. To equally distribute the pixels, equalization of the histogram will performed through inherited MATLAB functions. After equalization, thresholding is used to convert the grayscale image to binary image. As light emit on channels, motion of vapors can be identified by white pixels. The area of white pixels are calculated with the help of MATLAB inbuilt “bwarea” function to find out vapors area. Again by utilizing the thresholding, total area is find out by using same function. Then subtracting the backgrounds from vapor and total area, vapors and total area of channels are obtained. With the help of areas, void fraction is find out by the ratio of vapors area with the total area. After that, graphical analysis of void fraction is performed with respect to time at different variables. Variation of void fraction with flow rate of cooling water is also obtained. This gives void fraction for a particular cooling water flow rate. Model is validated by comparison of its void fraction with the void fraction obtained through experimental runs. Zivi model is used to calculate the void fraction from quality for the experimental data [7][8].

$$\alpha = \left[1 + \left(\frac{1-x}{x}\right)\left(\frac{\delta_v}{\delta_l}\right) S\right]^{-1} \tag{2}$$

$$S = \left(\frac{\delta_l}{\delta_v}\right)^{\frac{1}{3}} \tag{3}$$

where α is the void fraction, δ_v and δ_l are symbolic representation of gas and liquid density, x is the quality and S represents the slip ratio. Slip ratio is cube root of ratio of liquid and gas density.

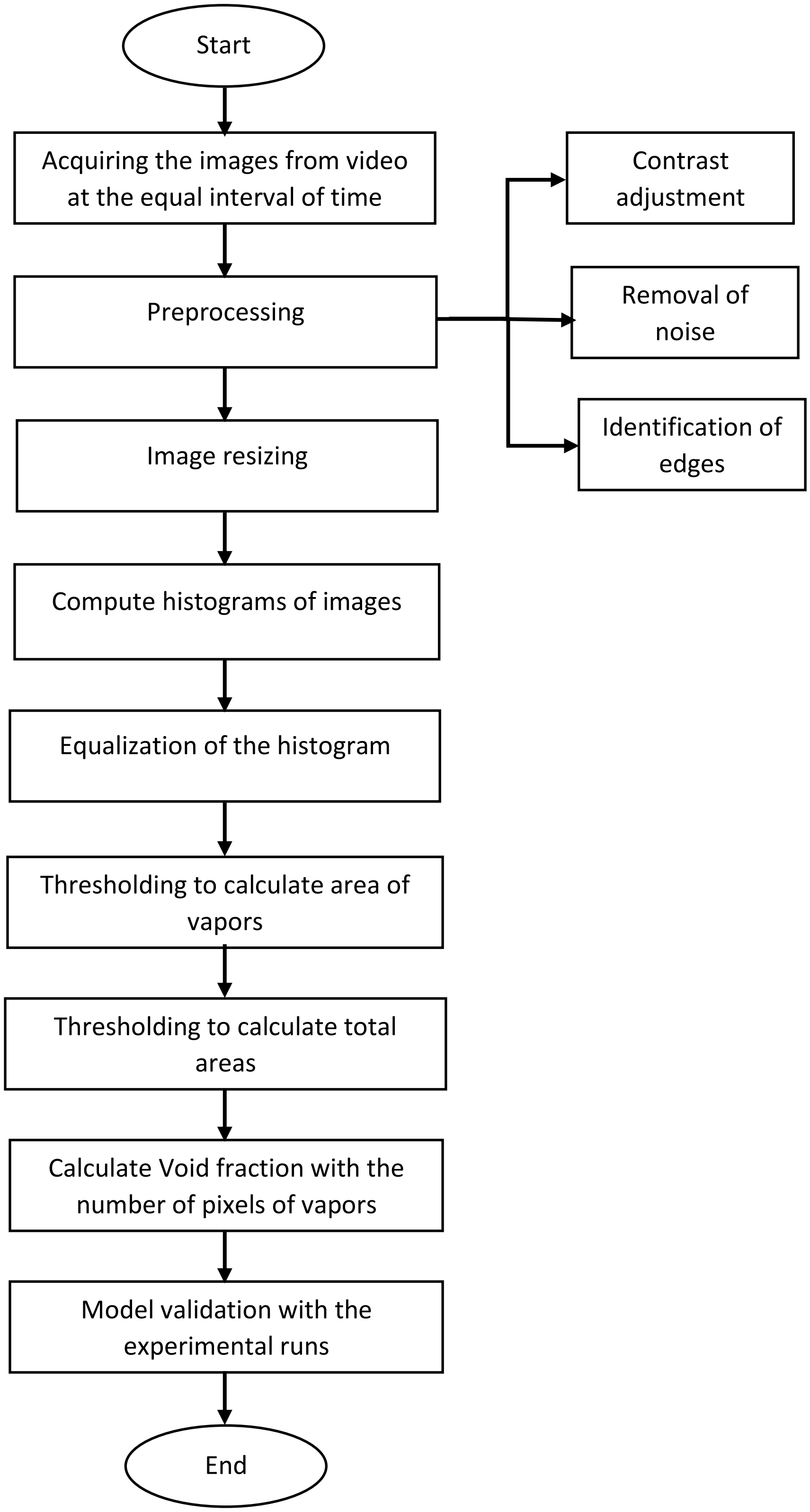

Figure 4-Methodology

4. Results and Discussion:

In figure (5) and (6) void fraction is plotted against time obtained at constant conditions of inlet temperature, Mass flux of refrigerant and cooling water flow rate. In figure (5) variation is within a void fraction of 0.64-0.62 and in figure (6) the variation in void fraction lies in the range of 0.65-0.66 in a definite time interval. In figure (7), Void fraction is plotted against cooling water flow rate. As cooling water flow rate increases, more heat transfer take place and more conversion of refrigerant vapors into liquid takes place which decreases the void fraction. A sharp decrease of void fraction from 0.647 to 0.632 takes place when cooling water flow rate increases from 13mL/min to 15 mL/min. The decrease of void fraction become small after increasing flow rate from 15mL/min. So, at 40^0C and mass flux of 100 Kg/m^2-sec maximum heat transfer takes place in the range of 10-15mL/min. In figure (8) void fraction decreases from 0.67 to 0.66 by increasing flow rate of cooling water from 10mL/min to 30mL/min.

The figure (5) represents the comparison of void fraction obtained through this model with the experimental void fraction. There is around 11.288% error in experimental and simulation results which is calculated from equation (4). There are basically two main reasons for this error. One is the due to the uncertainty in performing experiments and equipment. The other one is caused due to the non-uniform light intensity emitted from high speed camera.

$$\%\ \text{Error} = \frac{(\text{Void fraction(Exp)} - \text{Void fraction (MATLAB model)})}{(\text{Void fraction (Exp)})} \qquad (4)$$

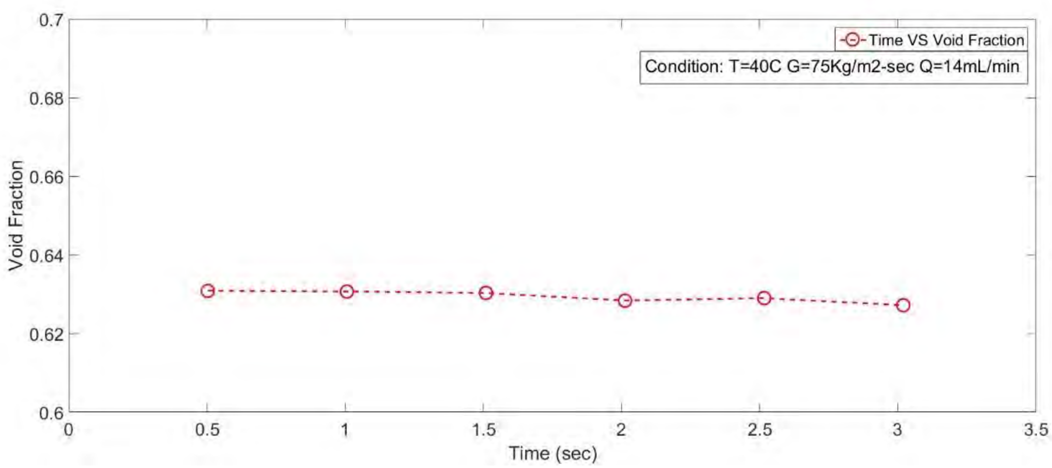

Figure 5-Void Fraction Vs Time

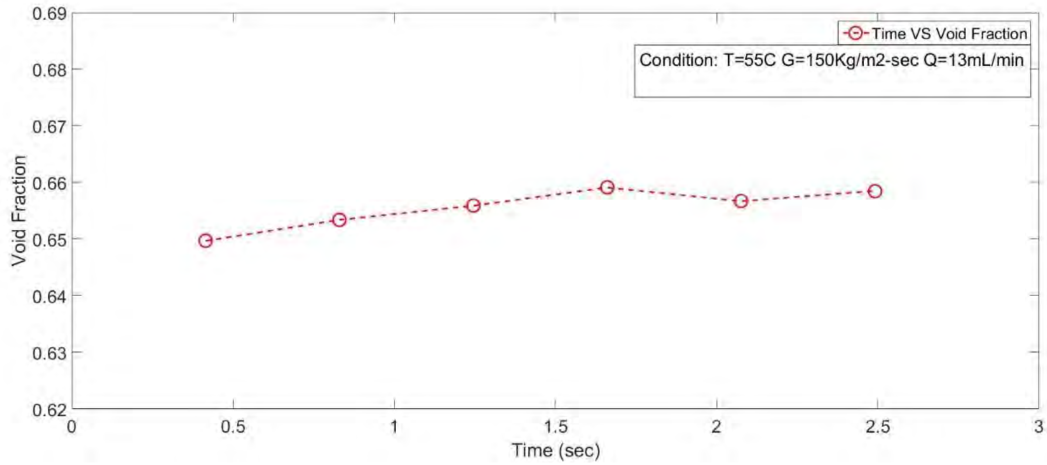

Figure 6-Void fraction vs time.

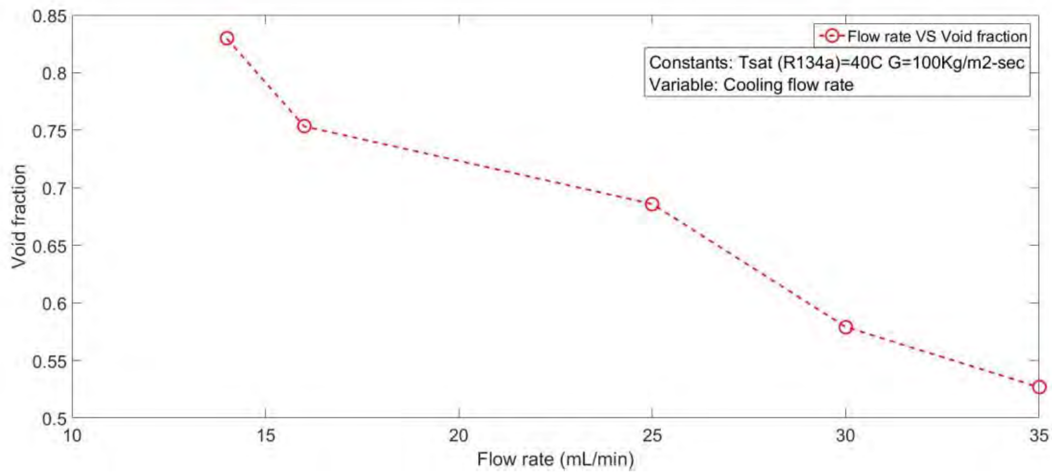

Figure 7-Void fraction Vs cooling water flow rate

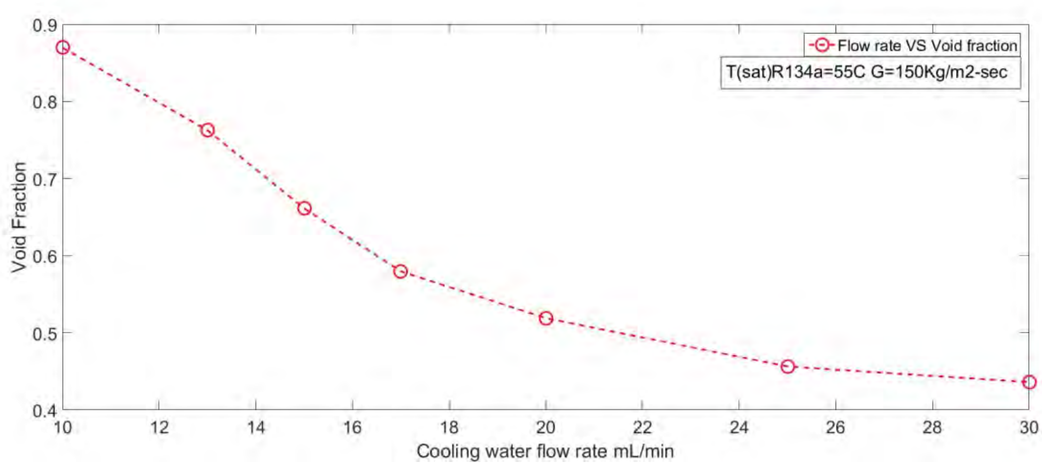

Figure 8-Void fraction Vs cooling water flow rate.

Table.1 Percentage error calculation of experimental and simulation results

Void fraction (MATLAB model)	Void fraction (Experimental)	% Error
0.85	0.9148	7.08
0.82	0.9120	10.09
0.72	0.8265	12.88
0.66	0.7711	14.4
0.56	0.6898	18.8
0.43	0.4502	4.48
		Average=11.288%

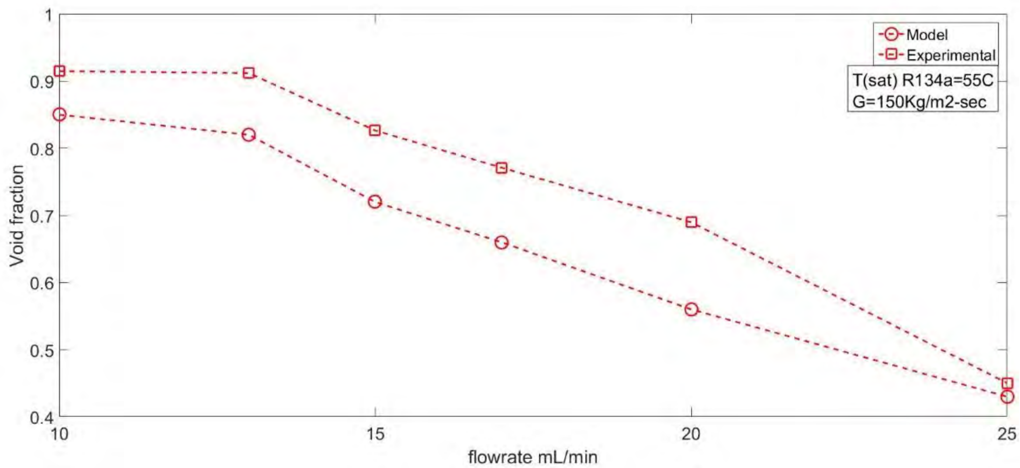

Figure 9-Comparison of simulation results with the experimental one

5. Conclusion:

In micro channels, different parametric effects in two phase flow were investigated using refrigerant R134a. No significant change in void fraction is observed with respect to time while keeping inlet temperature and mass flux of refrigerant and cooling water flow rate constant. Void fraction decreases from 0.83 to 0.53 when cooling water flow rate decreases from 14mL/min to 35mL/min at Tsat=40^{0}C and G (mass flux of refrigerant) =100Kg/m2-sec. Initially a sharp decrease in void fraction takes place due to high heat transfer. Similar trend is found at saturation temperature of 55^{0}C and mass flux of 55Kg/ m2-sec. Void fraction decreases from 0.87 to 0.44 as the cooling water flow rate increases from 10mL/min to 30mL/min. To validate the results comparison of void fraction obtained from simulation model is performed with the experimental results. It is found that the total percentage error is around 11.288% in void fraction.

References:

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Cultural exchange highlights

I have visited many beautiful places in America among which some are famous for its state of the art technology and some for its cultural heritage. In Oregon Coastline I have seen hundreds of sea lions and experience different sea foods. The most fascinating thing about Oregon coast is the most diverse marine ecology. I have also visited different famous shopping centers in Portland from which I have bought some gifts for my friends and family back in home. During this tour I have also come across the Powell's City of Books which I have spent a lot of time. It has huge number of books caring every people interests. The next coming holidays I have seen Basketball match in Moda center. The match is very thrilling and full of excitements. It makes me realize the importance of leadership and discipline which is very essential in every walk of life. During my tour to Arizona State, I have visited the Heard museum Phoenix, Grand Canyon and downtown. Apart from the historic perspective of the Heard museum it also gave us the insights of contemporary and artifacts art of Native cultures. I have also witnessed the Grand Canyon which puts light Earth's geological history of two billion years. I have taken a lot of pictures of this wonder. I have learned a lot about this natural wonder in my school age and to see this live is just unforgettable moment. In Arizona I also enjoyed roller coaster, free fall, zip line and racing cars which is first time experience for me.

I also really enjoyed Tulip festival excursion trip. First time in my life, I have come across so many different kinds of flowers in one place. In this festival I have also enjoyed jumping pad, bull ride and wall climbing which all have a great learning experience. In aviation museum trip, I have seen the different categories of aircrafts. By knowing about these aircrafts, I have realized that the important aspects of technological transformation. During my stay in US I have met people with different counties and cultures. Diversity is inherited in US culture which is very important for a nation to progress and excel. I have communicated people with diverse cultures and share ideas with each other.

To introduce our Lab-mates, Faculty and others about the historical perspective of emergence of Pakistan on map of the world, we have celebrated Pakistan day in 23rd March. In this event we have portraits the cultural heritage and religion diversities in Pakistan.

I have experience American culture from exposure of day-to-day life, books movies, music, sports, foods and excursion trips. From these, I have learned very important lessons like optimism, openness to new ideas and tolerance of failure. Americans are motivated at early age to be independent and set their own goals to follow. Apart from that, equality and informality are also very important aspects of American culture. These aspects of American culture is a way of inspirational source for me. I have learnt these important lessons from here which I believe will stay forever and will convey to others.

Training activities

Field Trips (Energy related):

I have attended workshop in Arizona state university on energy policy which emphasized on entrepreneurship and innovation in energy leadership and presented by Clark A. Miller (Director, Center for Energy & society). In this workshop we have learn about the importance of foresight and anticipation, indirect risks and consequences, socio-financial entrepreneurship and socio-technical innovation in energy leadership. We have also come across some of the key components of energy policy analysis which includes policy process, institutions, methods and comparison. Apart from the key components, we have also learnt about policy evaluation, assessment and implementation. In this workshop we also have given a task to propose the energy policy for Pakistan and justify it with logical reasoning. This activity help us to gain an understanding of policy framework and engineers role in policy making.

I have also visited ATAMI (Advanced Technology and Manufacturing Institute) and experience the research, development and commercialization of microchannel technology. I have seen advanced manufacturing processes laboratory, energy technology innovation lab, industrial sustainability laboratory and materials manufacturing process control lab. In energy technology innovation lab we met with Dr Hailei Wang (senior investigator in Energy technology innovation lab) who gave us an overview of research on advanced energy recovery, conversion to improve overall energy efficiency and enable renewables, through component designs and innovative system. Researchers of ATAMI exploring ways to capture and use waste heat from exhaust pipes of millions of diesel generators and automobiles which is very admirable and inspirational source for me.

As I arrive late in US, so I have attended only two sessions of Toast master program. It improve my public speaking, communication and leadership skills. This program also polished my presentation skills which is very important in every field. I will complete their remaining modules in Pakistan.