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Review Article

A Review on Thermal Characteristics of Single and Two-phase Flow in Mini channel for Refrigeration

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Abstract

Convective air cooling techniques are facing a unique challenge in cooling of high power Components by removing high heat flux under space constrains, that brings limit in the size of the thermal solution. This paper presents an idea of combining the Conventional Vapour Compression Refrigeration concept with an innovative engineering approach by placing Mini Channel Heat Exchanger instead of Conventional Heat Exchanger in the system that can break the barriers to provide much compact and energy efficient refrigeration system. Characteristics of air conditioning system with Mini Channel Heat Exchangers under single amp; multi-phase fluid flow are analysed. So, a review has been done to understand different Parameters which affect the behaviour of fluid flow such as — mass flow rate, specific heat of fluid, heat transfer coefficient, pressure drop, heat flux, geometry of channel, dimensionless numbers and many such parameters that would play major role over here.

Keywords*: Mini channel, Evaporator, Mini channel evaporator, VCR, Single phase flow, Double phase flow*

1. Introduction

From the last few decades there is a continuously demand of scaling down the components and compactness of the devices. To feed this demand the engineering community is has been focused on the scaling down the components and increase their functionality. The introduction of the Mini/Micro channel in the field of the refrigeration and cooling department is the biggest step towards the compactness. Mini/Micro channel allow developing high cooling effect and pressure with less amount of refrigerant and also less efforts and it can work with all types of refrigerant. Mini/Micro channel can develop under extremely high pressure in compact area. With the help of Mini/Micro channel it is possible to compact the size of the components. By using this in refrigeration and air conditioning system the global worming impact can be reduced.

Jaeseon Lee (2004): The pressure drop characteristics of a heat sink with parallel rectangular micro channel were investigated experimentally. Here R134a is used as refrigerant. For pressure drop prediction a new correlation of two-phase micro-channel is developed. Also is observed that as mass velocity or heat flux increases pressure drop increases.

Jaeseon Lee(2004): It is observed that heat transfer in micro-channel heat sink is linked with different mechanisms for low, medium and high quality flows for two phase flow. Bubbly Flow and nucleate boiling occurs at low quality vapour. Also high quality vapour generates high heat flux, here the heat transfer is dominated by annular film evaporation. A new three range three range correlations is suggested which excellently predicts the heat transfer coefficient for both water and R134a.

Zhaogang Q *et al*. (2009): They have studied about mini channel evaporator. It has been experimentally proved that new mini channel evaporator has benefits on volume, weight and heat transfer. The experiment shows that the louver fin is more suitable for mini channel evaporator than corrugated louver fin in reduction of air side pressure drop.

Z. Wu *et al*. (2010) design miniature vapour compression refrigeration system. System is designed for 200 W. They used compressor, capillary tube, old plate and condenser along with control circuit. System dimension will be 300 x 230 x 70 mm^3. Capillary tube length 1800 mm, refrigerant 100 g, 2858 RPM compressor speed. System efficiency varies from 23 % to 31 %.

Guilherme B. Ribeiro *et al*. (2010): This research paper concluded that increasing refrigerant mass flow rate increases the refrigerant heat transfer coefficient. Also, the heat transfer rate and the saturation temperature have a small influence on the heat transfer in the evaporator.

Zhang Huiyong (2010) conducted an experiment by placing Micro Channel Wall Tube Heat Exchanger in

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place of convention Round Tube Heat Exchanger in Domestic Refrigerators. Theoretical model of MCHX is prepared and the performance is evaluated by placing it in Domestic Refrigerator. The result concluded that there is a relationship in number of tubes and tube diameter with downward section height. Which means that as MCHX is used in which minimum numbers of tubes are present with small diameter so a decrease in downward section height is observed compared to conventional HX. Moreover, total metal mass of the HX is also reduced by 48% in two wall two side design and 26% in two wall one side design. Thus, this shows that use of MCHX is more suitable compared to the conventional HX in Domestic Refrigerator.

Jacqueline B. Copetti (2010): In this research it is observed that there is significant influence of heat flux on heat transfer coefficient in low quality region. In high quality region, for high mass velocities this effect disappears. The analysis of local heat transfer shows distribution long the tube perimeter showed changes in coefficient due to location where transition of flow pattern occurs. The friction pressure drop increased with increase in vapour quality and mass velocity.

S. Senaye, M. Dehghandokht (2012) conducted an experimental investigation by thermal modelling of mini-channel and laminated types evaporator. The laminated type's evaporator which is generally used in automotive industries is compared with mini channel evaporator. Result where analysed from experiments performed (such as ϵ- NTU method) on mobile air conditioning system. The Cooling capacity of laminated evaporator is 7.2% and the pressure drop of refrigerants is 45%. Moreover, the mini-channel evaporator's outlet air temperature and enthalpy where respectively 11% and 8% are low as compare to laminated evaporator. This results in reducing the power & time consumption to reach desired effect as the exit air temperature of mini channel evaporator is much lower than that of laminated evaporator. However, by using mini channel evaporator the whole system gets 33% compact and 20% lighter as compared to the earlier laminated evaporator.

Hicham El Mghari *et al.* (2013): Yhey have study on the shape and contact angle of the micro channel. They have compared non-circular channel. Numerical model of mini channel is developed focusing mass transfer and heat transfer for condensation. Numerical and available results are also compared. As the hydraulic diameter decreases the condensation and heat transfer increase. And with increasing contact angle the heat transfer increases. For the same hydraulic diameter they have compared the average Nusselt number for different Shape and aspect ratio of micro channel. As a result of that investigation, the cross section area and perimeter of square micro channel is smaller as compared to the rectangular micro channel. The contact angle is less in square shape as compare to rectangular shape. The lowest Nusselt are obtain in the case of square shape and highest Nusselt number is obtain in case rectangular shape.

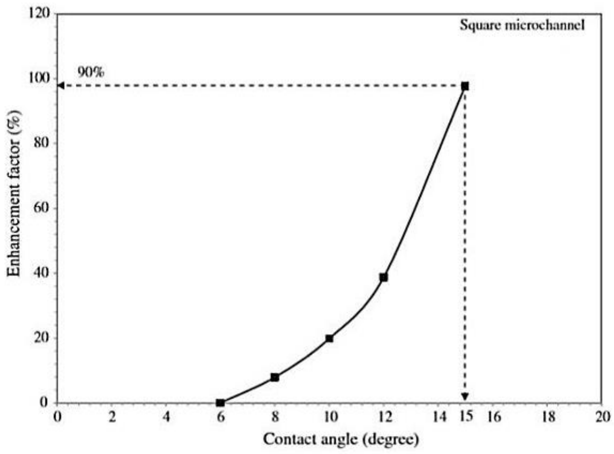

Fig.1 Enhancement factor of condensation average heat transfer Coefficient versus contact angle

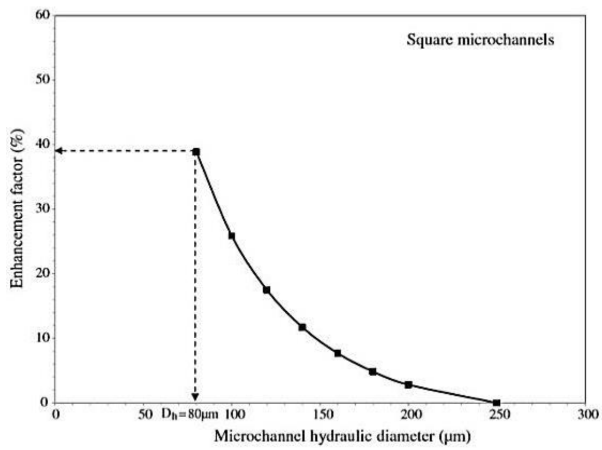

Fig. 2 Enhancement factor of condensation average heat transfer Coefficient versus microchannel diameter

Minhhung Doan and Thanhtrung Dang (2013) have conducted experimental study on condensation heat transfer of two microchannel heat exchangers - one with parallel flow and other with counter flow arrangement. Here the two micro channels have same dimensions but differ in substrate and length of channel. Firstly, it was found that the pressure drop not proportional to the oscillation of condensation profile i.e. when the pressure drop in low the oscillation profile is more which results into large distance between the condensation point of the last channel to manifold and the first channel to the manifold. When the pressure drop increases the oscillation profile decreases which results in more distance between the last and first channel to manifold. From the experimental data it was found that, in the case of the counter flow arrangement heat transfer rate is always higher as compare to the parallel arrangement. The value of counter flow arrangement exceeds 1.04 to 1.05 times that from the parallel flow. The results also shows that the two phase arrangement is more preferable than single phase arrangement. In addition, the heat transfer coefficient of condensation decreases as the inlet temperature of the cooling water increases. And it was also found that the performance index is also inversely proportional to the mass flow rate of steam.

Keyur Thakkar *et al.* (2014) have studied the different parameter which is affecting the performance of single phase liquid flow. According to the scaling law the length scale is directly proportional to the four times of mass flow rate and indirectly proportional to the two times of the pressure drop.

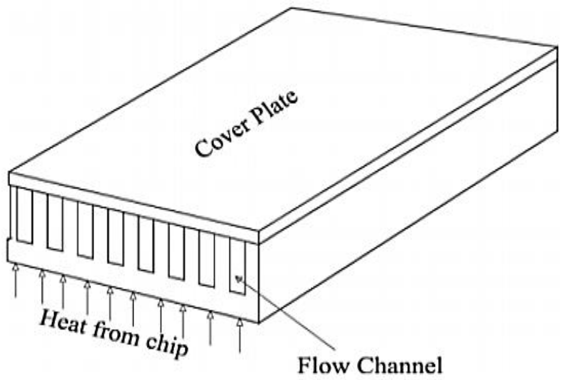

Fig.2 Enhancement fact

The Continuum assumption applied for miniscale refrigeration. The fluctuating property of molecules is governed by Knudsen number (Kn). The Knudsen number is ratio between molecules and increased collision. In the case of miniaturization the distance between molecules are reduce and collision increased. Mass flow rate, surface texture, hydraulic diameter, type of refrigerant and thermal entrance length all are governing parameters for heat transfer co-efficient.

J. He *et al* (2014) used series and parallel combination of mini channel evaporated. They concluded when heating load become greater than heat sink capacity, heat sink in parallel system is better than heat sink in series. COP of series system stayed in range of 1.81 to 3.22 and COP for parallel system is in range of 1.51 to 2.92 for 100 W capacity.

T. Sung *et al*. (2014) developed meso scale VCRS system. System dimension 60 x 60 x 100 mm^3. Pressure ration was 3.07 and flow rate will be of 10 LPM, nozzle is used as expansion device. COP of the system 2.15 for 80 W capacity.

Dnnis M. van de Bor *et al*. (2014): They have concluded that by increasing heat flux, inlet vapour quality and mass flow rate the heat transfer coefficient increases. At flow rates of 100 and 175 kg/m^2s, the heat transfer coefficient increases for low inlet vapour qualities and constant heat flux. Also with increasing vapour quality and mass flow the pressure drop increases. The pressure was compared against the homogeneous pressure drop model, Zhang *et al*. When the pressure drop is 0.3 bar the model by zhangg *et al*. for gas-liquid flows predict the pressure drop best. When heat transfer coefficient is set as function of pressure drop, it increases initially up to a certain limit after that it does not enhance the heat transfer coefficient.

Deepak P. Patil *et al*. (2014) analyzes performance of refrigeration system on three condensers viz. micro-channel, round tube and coil tube using R134a and R290 refrigerants. It is observed that for both refrigerants R134a and R290, coefficient of performance increases with increase in cooling load. The cop of the system using micro channel condenser is found 19.75% higher than with round tube condenser and 8.65% higher than with coil tube condenser using R134a. The cop of the system using micro channel condenser is found 8.21% higher than with round tube condenser and 4.04% higher than with coil tube condenser using R290.

D.M. Khovalyg and A. V. Baranenko (2015) have performed and shows that thermo hydraulic characteristics of the two-phase flow of boiling of R134a refrigerant in micro channel. From the experimental conditions studied, it is found that intermittent flow regimes are observed of vapour qualities below 0.1; variations of the annular regime are observed for x=0.1~0.5, while above x~0.5, the dry out of inside the wall surface is observed. The intensity of heat transfer sharply decreases due to dry out and boiling crisis are the vapour qualities above 0.5. New correlations are proposed for vapour qualities ranging from 0 to 0.1 and from 0.1 to 0.5.The experimental study of flow instability showed that, for heat fluxes below 10 kW/m^2, stable boiling of R134a in a micro channel is observed for the refrigerant flow rates above 70 kg/ (m^2s).

Oana Giurgiua *et al*. (2015): They have studied the two models of mini channel with 30 and 60 degrees value of inclination were designed. And they have concluded that for better heat transfer of the mini channel the inclination angle should be there. And The Inclination angle of 60 degrees provides best heat transfer.

Ahmed A. Hussien and Mohd Z. Abdullah b (2015): They have studied about the behaviour and various properties of the Nano fluids in micro/mini channels. The thermal conductivity and viscosity of Nano fluid depend primarily on particle volume fraction, nanoparticle size, and nanoparticle material and pH value. The enhancement of convective heat transfer using Nano fluid flow is effective in the entrance region.

Karan Ghule, M.S. Soni (2016): They have concluded that heat transfer coefficient increases by increasing the amplitude of waves. Addition of notch to the circular section has an adverse effect on the heat transfer coefficient. Heat transfer coefficient for a notched circular channel with waviness equal to 200 micro-meters is the highest among all the considered cross-sections.

D.R.S. Raghuraman (2016): It is observed that the pressure drop of micro channel heat sink with aspect ratio 20 is higher than micro channel heat sink with aspect ratio 30 and 46.66, whereas pumping power is more in aspect ratio 46.66 then other aspect ratio. The mass flow rate through aspect ratio 46.66 MCHS is higher for the same Reynolds number considered. Also thermal resistance of aspect ratio 20 is higher than the other two types of MCHS. The Nusselt number of MCHS with aspect ratio 30 is higher than the other two of MCHS, it is found that MCHS with aspect ratio 30 has higher heat removal rate compared to other two types of MCHS.

Byongjoo Kim (2016): An empirical study has been performed to check the validity of the theoretical correlations based on conventional sized channels for predicting fluid flow and heat transfer characteristics in microchannel. The single-phase laminar friction factor in the micro channel confirmed to the conventional poiseuille flow theory. The critical Reynolds number increased from 1700 to 2400 with decrease in the aspect ratio from 1 to 0.25 in channel. At Reynolds number less than 180 the experimental Nusselt number were lower than theoretical values and increased rapidly with the refolds number. The Nusselt number began to exceed the theoretical value at Reynolds number greater than 180.

Amirah M. Sahar *et al*. (2017): To study the effect of hydraulic diameter and aspect ratio on fluid and heat transfer in rectangular micro channels numerical simulations were carried out to investigate. It is observed that hydrodynamic entrance length is independent of hydraulic diameter and aspect ratio. As aspect ratio increases the friction factor decreases until 2 after which it increases continuously. Increasing the aspect ratio beyond 2 resulted in a significant effect on the velocity profile, It changed from a fattened at high aspect ratio to a parabolic shape at low aspect ratio. The friction factor and average Nusselt number increases with increasing hydraulic diameter.

Minxia Li (2017): In this paper, the condensation heat transfer characteristics of R447A in 0.86 mm hydraulic diameter multi-port extruded micro-tubes were investigated. For binary mixture of R32, with increasing concentration, the heat transfer coefficient increases. The heat transfer coefficient of R32/R134a are better than 32/R1234ze. The condensation heat transfer coefficient of R32 is best, followed by R134a. The heat transfer coefficient of R447Aa is lower than those of R32, R134a and R32/R134a, but higher than RR410A.R447A can be potential alternative for R410A.

Conclusion

- A new correlation was developed for two-phase flow in high-flux micro-channel heat sink for pressure drop. The total pressure drop increases with increasing mass velocity and heat flux.
- For two phase flow of R134a low vapour quality corresponds to bubbly and nucleates, also to low heat fluxes. At high fluxes produces high or medium quality of vapour, where heat transfer is dominated by annular film evaporation.
- The experiment results reveal that louver fin is more suitable than corrugated louver fin for mini-channel in reduction of air side pressure drop. Also two-pass arrangement is better than four-pass arrangement in heat transfer.
- Increasing the refrigerant mass flow rate increases the refrigerant heat transfer coefficient. The heat transfer rate and the saturation temperature have small influence on heat transfer in evaporator.
- Using MCHX with minimum number of small tube diameter results in reduction of downward section height of tube. Designing Domestic Refrigerator with MCHX reduces the use of metal in the walls of the tube.
- Heat flux directly affects the heat transfer coefficient in low vapour quality region. In high quality region this effect vanishes. The frictional pressure drop increased with increase in vapour quality and mass velocity.
- MCHX is compared with Laminated HX and observed that the MCHX has:
- High heat transfer rate in all operating conditions.
- Low air exit temperature
- Low power consumption, compact & light weight system.
- The rectangular geometry is best for the mini/micro channel because of it highest Nusselt number and high contact angle. Heat transfer and mass transfer rate is high in rectangular shape. Pressure drop is inversely proportional to the oscillation of condenser profile which has a significant effect on distance between the last and the first channel to the manifold.
- Performance index is inversely proportional to the mass flow rate of steam.
- Heat transfer co-efficient is govern by following parameter; hydraulic diameter, thermal entrance length, type of flow, flow pattern, Reynolds number, mass flow rate, heat flux.
- Inside a mini-channel annulus with a hydraulic diameter of 0.4 mm, a length of 0.8 m, heat transfer coefficient increases with increasing mass flow, increasing inlet vapour quality and increasing heat flux
- For both refrigerant R134a and R290, C.O.P increases with increase in cooling load. It is observed that C.O.P of R134a is more than R290 in all three condensers.
- The heat transfer decrease sharply due to dry out and boiling crisis at the vapour qualities above 0.5.Stable boiling of R134a in a micro channel is observed for the flow rates above 70 kg/ (m^2s).
- After both the experimental analysis as well as the numerical of the two different models of mini channels tested, it is observed that the channel with inclination 60° provides best heat transfer coefficient. The convective heat transfer using Nano fluid is more effective in the entrance region. This applies that short channels are more effective for enhancement of heat transfer coefficient.
- In rectangular microchannel critical Reynolds number increases with decrease in aspect ratio from 1 to 0.25. Nusselt number increases with increase in Reynolds number, After Reynolds number is greater than 180. The pressure drop and

thermal resistance of micro channel heat sink with aspect ratio 20 is more than aspect ratio 30 & 46.66. The mass flow rate and pumping power loss are more in micro channel with aspect ratio 46.66. Although Nusselt number of micro channel with aspect ratio 20 is higher, but higher heat transfer rate is observed in micro channel with aspect ratio 30.

- Among all the section of channel tested in this research, the notched circular channel has the highest heat transfer coefficient with waviness equal to 200 μm.
- The hydrodynamic entrance length does not depend on aspect ratio and hydraulic diameter. Friction factor decrease up to aspect ratio 2 after which is increases continuously with aspect ratio. Channel with aspect ratio=0.39 gave best performance when heat transfer and thermal performance index is used as evaluation criterion.
- Binary mixture of R32, as concentration of R32 increases, the heat transfer coefficient increases. The condensation heat transfer coefficient of R32 is best, followed by R134a.

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