

CFD Analysis of Condensing Heat Transfer Through Minichannel

Shah Ketul D.¹ H.A.Vaidhya.² T.B.Patel³

¹P.G Student ²Associate Professor ³Assistant Professor

^{1,2,3}Department of Mechanical Engineering

¹Gujarat Technological University, India ²GEC, Surat ³M.G.I.T.E.R, Navsari, India

Abstract— The study of the condensation heat transfer coefficient inside microchannels and minichannel is still somewhat difficult task, particularly when studied within single minichannel. The application of minichannel in industrial cooling, electronic cooling, compact heat exchanger, space cooling, railway cooling, etc. The heat transfer coefficient h is a measure of the effectiveness, and important to determine the value of it in the two-phase condensation area in a tube condenser. The local heat transfer coefficient will be measured and analysed during condensation of different refrigerant with 0.3 to 3 mm diameter circular minichannel and will be compared versus different correlations. Tests are carried out at mass fluxes ranging between 100 and 800 kg/m² s. The volume of fluid (VOF) is used to track the vapour-liquid interface, with the effect of shear stress, gravity and shear tension taken into account. Experimental and CFD data analyzed to show the influence of saturation temperature, mass velocities, vapour quality and fluid properties in heat transfer rate.

Key words: Condensation, Mini channels, Local heat transfer coefficient, Refrigerants, Experimentation, CFD

I. INTRODUCTION

Condensation is defined as the phase change from the vapor state to the liquid or the solid state and occurs when the temperature of the vapor is reduced below its saturation temperature. Condensation is usually done by bringing the vapor into contact with a solid surface whose temperature is below the saturation temperature of the vapor. But condensation can also occur on the free surface of a liquid or even in a gas when the temperature of the liquid or the gas to which the vapor is exposed is below the saturation temperature.

II. CONDENSATION PROCESS

Condensation is classified into two groups; one is bulk condensation and the other is surface condensation. In bulk condensation vapor condenses in a gas phase. Formation of fog is an example of this type of condensation. Surface condensation occurs when the vapor contacts with a surface whose temperature is below the saturation temperature of the vapor. There are a lot of applications with this type of condensation. Surface condensation is classified as film-wise condensation and drop wise condensation.

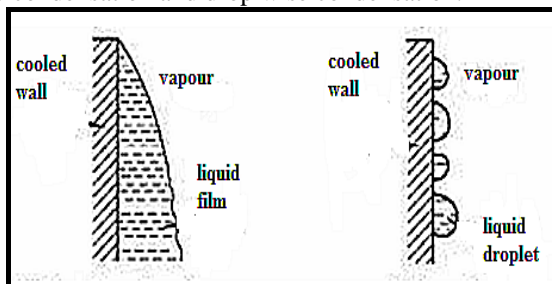


Fig. 1: Film-wise and Drop-wise condensation

When saturated vapour comes in contact with a surface having a temperature below the saturation temperature, condensation occurs. There are two types of condensation:

- Film-wise condensation: condensed liquid wets the surface and forms a film covering the entire surface.
- Drop-wise condensation: surface is not totally wetted by the saturated vapour, and the condensate forms liquid droplets that fall from the surface.

Compared to film-wise condensation, drop-wise condensation has a greater surface heat transfer coefficient as it has a greater area exposed to the saturation vapour.

III. NEED OF MINIATURIZATION

Energy is a fundamental aspect of modern society. The continuous growth and increase in welfare of the world's population is accompanied by an increasing demand for energy. With limited available resources it is crucial to change our way of life to a more energy-efficient and a more sustainable one. The largest portion of the world's energy consumption originates from industry, specifically the chemical industry. Heating and cooling of various process streams hold a large contribution in the energy consumption of the chemical industry. Companies are interested in increasing the efficiencies of their systems without large investments. Mini-channel heat exchangers have a large surface to volume area, which results in a large heat duty and a small material requirement. Therefore the application of mini channels makes it possible to increase the efficiency and reduce the investment cost for similar capacities as compared to macro-channel exchangers.



Fig. 1.3: Pipe mini channel used in the study

IV. FLOW CHANNEL CLASSIFICATION

The distinction between minichannel and microchannels is given by Kandlikar as below:

- Microchannels $200 \mu\text{m} \geq D \geq 10 \mu\text{m}$.

- Minichannel $3 \text{ mm} \geq D > 200 \text{ }\mu\text{m}$.
- Conventional channels $> 3 \text{ mm}$.

D: smallest hydraulic channel diameter

Davide Del Col et al ^[5] had worked out on “Condensation Heat Transfer and Pressure Drop with Propane in a Minichannel”. The use of propane as a good opportunity to develop environmentally friendly heat pump and air-conditioning equipment, since the direct effect on the anthropogenic global warming due to atmospheric emissions is almost completely avoided, while the indirect effect can be reduced by exploiting the favorable thermodynamic properties of these fluids. In these paper, the local heat transfer coefficient measured during condensation of propane in a 0.96 mm diameter circular minichannel is reported and compared versus available correlations. Tests are carried out on the experimental apparatus available at the Heat Transfer Lab of the University of Padova. During condensation tests, the heat is subtracted from the fluid by using cold water. The heat transfer coefficient is obtained through the measurement of the local heat flux and the saturation-to-wall temperature different. Tests are carried out at fluxes ranging between 100 and 800 kg/m²·s with different saturation temperature 30°C, 40°C and 50°C. This was demonstrated at university of Padova in a heat pump with 100 kW heating capacity, using minichannel shell-and-tube heat exchangers. The length of the measuring sector between the pressure ports is 0.22m. Since the saturation temperature drop directly affects the heat transfer rate, also pressure drop during adiabatic two phase flow of propane is measured and compared to predicting models and conclude that the heat transfer coefficient increase with increase in temperature^[1].

Henryk Charun ^[6] had worked out on “Thermal and Flow Characteristics of the Condensation of R404a Refrigerant in Pipe Minichannel”. This article presents the results of experimental investigations of heat exchange and pressure drop during the condensation of R404A refrigerant in stainless steel pipe minichannel with internal diameters of 1.4–3.30 mm. A review is provided of the present state of knowledge concerning the condensation of this refrigerant in conventional channels and in small-diameter channels. It is emphasized that there are few prior publications concerning this issue. The test setup is described as well as the results of the experimental tests. They discuss the dependence of the heat transfer coefficient and the pressure drop of the R404A refrigerant on both minichannel diameter and process parameters. The pressure drop during the condensation of this refrigerant is satisfactorily described by the Friedel and Garimella correlations. Based on the experimental tests, we propose a new correlation for the calculation of the local heat transfer coefficient. The values calculated from this correlation were in agreement with the experimental results to within $\pm 20\%$.

Primal Fernando ^[7] had worked out on “A Minichannel Aluminium Tube Heat Exchanger – Part Iii: Condenser Performance with Propane”. This paper reports heat transfer results obtained during condensation of refrigerant propane inside a minichannel aluminium heat exchanger vertically mounted in an experimental setup simulating a water-to-water heat pump. The condenser was constructed of multiport minichannel aluminium tubes assembled as a shell-and-tube heat exchanger. The applied heat transfer rate

was within 3900–9500W for all tests. Experiments were performed at constant condensing temperatures of 30°C, 40°C and 50°C, respectively. The cooling water flow rate was maintained at 11.90 l/min for all tests.

The experimental heat transfer coefficients in the different regions were higher than those predicted by the available correlations. The heat transfer coefficient increase with increase in temperature.

Marko Matkovic ^[8] had done worked out on “Experimental Study on Condensation Heat Transfer inside a Single Circular Minichannel”. The present paper reports local heat transfer coefficients obtained from the measurement of the local heat flux and the direct measurement of the saturation and wall temperatures during condensation of R134a and R32 within a single circular 0.96 mm diameter minichannel.

When comparing the heat transfer coefficient of R134a to the one measured for R32, one can see that the latter fluid displays a higher coefficient at the same operating conditions, and this is related to the properties of R32, particularly to the high conductivity of the liquid. At 40°C, the thermal conductivity of saturated liquid is equal to 74.7 W/m·K for R134a and 114.6 W/m·K for R32^[5].

J.B. Copetti ^[9] had worked out on “Design and Optimization of Minichannel Parallel Flow Condensers”. This work presents a methodology and the results of the performance and optimization analyses of this heat exchanger with refrigerant R-134a. A computer program was developed to study the condenser pass to pass. The mass and volume of heat exchanger decreased 24% and 36%, respectively. Minichannels heat exchanger technology maximizes the contact area, increasing heat exchanger performance when compared with finned tube condensers, and, due to the same reason, reduce pressure drop. Parallel flow heat exchangers with minichannels appeared in the end of 1980 with the substitution of R-12 for R-134a. Conventional round-tube, plate fin condensers using R-134a presented high reduction of capacity when compared with R-12.

H. Ganapathy et al ^[10] had worked out on “Volume of fluid-based numerical modeling of condensation heat transfer and fluid flow characteristics in microchannels”. The present work proposes a numerical model for the simulation of condensation heat transfer and fluid flow characteristics in a single microchannels. The model was based on the volume of fluid approach, which governed the hydrodynamics of the two-phase flow. The condensation characteristics were governed by the physics of the phenomena and did not include any empirical expressions in the formulation. The conventional governing equations for conservation of volume fraction and energy were modified to include source terms that accounted for the mass transfer at the liquid–vapor interface and the associated release of latent heat, respectively. A microchannel having characteristic dimension of 1mm was modeled using a two-dimensional computational domain. The working fluid was R134a and the vapor mass flux at the channel inlet ranged from 245 to 615 kg/m²·s. The channel wall was maintained at a constant heat flux ranging from 200 to 800 kW/m². The predictive accuracy of the numerical model was assessed by comparing the two-phase frictional pressure drop and Nusselt number with available empirical correlations in the literature.

Davide Del Col et al [11] had worked out on “The importance of turbulence during condensation in a horizontal circular minichannel”. In this paper three-dimensional simulations of condensation of refrigerant R134a in a horizontal minichannel are presented. Mass fluxes ranging from $50 \text{ kg/m}^2 \text{ s}$ up to $1000 \text{ kg/m}^2 \text{ s}$ are considered in a circular minichannel of 1mm diameter, and uniform wall and vapour–liquid interface temperatures are imposed as boundary conditions. At high mass fluxes the turbulent condensate flow is found to be almost perfectly annular: the condensate thickness is ax symmetrical and increases along the channel length. Even if the condensate thickness can be higher than at low mass fluxes, much higher heat transfer coefficients are achieved since the turbulent conductivity is dominant over the laminar value for tar compounds. At high mass fluxes the turbulent condensate flow is found to be almost perfectly annular: the condensate thickness is ax symmetrical and increases along the channel length. Even if the condensate thickness can be higher than at low mass fluxes, much higher heat transfer coefficients are achieved since the turbulent conductivity is dominant over the laminar value.

V. CONCLUSION

Experimental analysis & Develop new Correlation and compare for R404A with R134a but they did not change another parameter to increase the heat transfer coefficient. Condensation heat transfer in square, triangular, and semi-circular mini-channels, HTC 20% more in circular shape is more. Experimental analysis was done & developed the new Correlation and MAE decrease by 20-30%. Experimental analysis for R134a & R404A for different dia. with constant Temperature. HTC more in R134a, decrease MARD by new correlation & experimental analysis is done for R1234yf, R134a & R32 with 1.16 diameter. HTC Increase with reduction in width, mass and volume decreased by 24% & 36%. Computer program is done by E-NTU method & and VOF method is applied for CFD analysis is done but the selection of refrigeration is not proper.

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