Review: Technological Development of Heat Transfer Enhancement in Two Phase Flow by using Passive Method.

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Abstract. The Heating, Ventilation, Air conditioning & Refrigeration application always shows an opportunity to enhance the heat transfer rate. With these motives, researchers explored the use of passive methods in single phase flow which exhibits promising results of heat transfer enhancement. On the other hand, researchers investigated the effect of the passive method in Two phase flow, which also shows promising results in heat transfer enhancement. This paper focused on the review of the experimental studies conducted on the use of heat transfer enhancement in the condensation process mostly. Out of this passive method, Micro fin tube shows better heat transfer enhancement and less pressure drop compared to other methods. It has been observed that the use of porous media also showing promising effects in heat transfer enhancement and it’s fetching the attention of researchers. Therefore, this review work also reviewed the numerical studies on the use of porous media in two phase flow. It is needed to explore the different structure and optimum design of porous media, which have high heat transfer enhancement with low pressure drop penalty. Also, the use of low Global Warming Potential refrigerant effects needs to be explored, which could be a better alternative for existing refrigerants.

1. Introduction Two phase flow is a combination of Liquid-Gas, Liquid-Liquid, Liquid-Solid & Gas-Solid flows. Here we focused on Gas-Liquid Flow, again Gas-Liquid flow combination involves mainly Boiling, Condensation & Evaporation phenomenon. This review mainly features the studies and investigations performed on condensation process. Condensation refers to the process where saturated vapour comes in contact with the wall which is maintained at below saturation temperature. Vapour releases its latent heat and gets converted into the liquid. Since decade, researchers exploring the use of passive techniques in condensation, Evaporation and Boiling. Use of this techniques reveals satisfactory results in heat transfer enhancement, which encourages to researchers, to explore the effect of various parameters on HTC (Heat Transfer Coefficient) and pressure drop. With this aim, this review work focused on use of passive methods in two phase flow to improve the heat transfer rate. In the passive method researchers tried geometrical changes of tube and its parameters to improve heat transfer. Some of the active and passive techniques are shown in fig. 1. But the use of active method was not explored as much as the passive method explored therefore, most of researchers concentrates on the use of passive techniques rather than use of active techniques. This reviews considered the use of passive techniques. Researchers performs the experimental and numerical investigation to find the effect of these passive techniques. Fig. 2 Shows the main passive methods with the parameters that causes heat transfer increased in two phase flow.

On the other hand, most of researchers used numerical studies for single phase flow, but only few of researchers focused on use of these numerical studies in two phase flow [1]. With this objective, we reviewed, numerical studies on the use of metal foam in two phase flow in last section of paper.
2. Effect of Inclination

An experimental investigation was performed Kundu et al. [2] on refrigerants in a smooth copper tube by varying five different angles between 0 and 90°. Heat transfer coefficient for the evaporation process were compared with the variables mass velocity, heat flux, and vapour quality. Lips et al. [3] also performs experimentation on R134a condensation to find the inclination effect “from vertical downward to vertical upward” [3].
Experimental results found, the maximum heat transfer coefficient for downward flow with an optimum inclination angle in an inclination dependent zone. Khoeini et al. [4] Another study, which also varies inclination from -90 to +90°, investigates, the effect of mass flux and vapour qualities with corrugated tube on HTC and pressure drop. Results shows that, highest heat transfer coefficient observed at +30°, which were more than 1.27 to 1.41 times of tube with -90° with low vapour quality.

3. Effect of Dimple Tube
Aroonrat & Wongwises [5] This study experimentally investigates the effect of heat flux, saturation temperature and mass flux on the heat transfer coefficient & pressure drop. Comparison of smooth & enhanced tube were obtained, it had been observed that HTC and pressure drop increased over smooth tube. Subsequently, [6] in this experimental investigation, variation of helical pitch as well as dimple pitch with the effect of heat flux, mass flux & saturation temperature on the heat transfer coefficient and pressure drop were reported. As the helical pitch and dimple pitch decreases, it exhibits increase in HTC & pressure drop. At 5.08mm of helical pitch & 3.24 mm of dimple pitch maximum 88% & 630% higher HTC & pressure drop observed compared to smooth tube.

Solanki & Kumar [7] In this study, researchers compared the performance of straight smooth tube, helical coiled smooth tube, & helical coiled dimple tube. Effect of mass flux, vapour quality & saturation temperature on the HTC and pressure drop. Researchers also reported that smooth helical coiled tube shows high HTC than straight smooth tube. Aroonrat & Wongwises [8] Authors investigates the effect of dimple depth(0.5,0.75,1.0mm) on the HTC and pressure drop. It had been observed that, for all dimple depth, HTC & pressure drop increases significantly compared to smooth tube, highest HTC & pressure drop of 83% & 892% reported compared to smooth tube. Author also proposed correlation for Nusselt No. and friction factor.

4. Effect of Use of Micro fin
Sapali & Patil [9] Researchers conducted experimental investigation on HFC 134a & R-404A with micro fin tube, in this experimentation, effect of mass flux and condensing temp. drop were examined on pressure drop. Result shows that, the Pressure drop increased with mass flux, & condensing temperature for both smooth & micro fin tube. Sapali & Patil [10] also conducted experimental investigation work on micro fin tube with refrigerant HFC 134a, R404A. In this study researchers varies condensing temperature from 35°C to 60°C and found its effect on HTC. Results reveals that HTC improves with improving mass flux but it decreases by increasing condensing temperature. The average HTC with micro fin tube was 1.5-2.5 times greater than smooth tube for HFC 134a, whereas 1.3-2 times higher with micro fin tube of R404A compared to smooth tube.

Yang et al. [11] Examined the HTC & pressure drop through vertical upward flow in smooth and micro fin tube for the refrigerant R410A. Heat transfer enhancement factor investigated, which were reported in the range of 1.3-2.05 at saturation temp. of 40°C & 1.4-2.2 at 48°C. Researchers also developed revised correlation for vertical upward flow. Li et al. [12] In this experimental study, Authors examined four micro fin tube and compared its performance with smooth tube. Authors investigates the effect of mass velocity, Reynolds No. & condensation temp. on HTC & pressure
drop. Micro fin tube exhibits better performance over smooth tube was the conclusive remark of study.

Solanki & Kumar [13] also examined the effect of mass flux, condensing temperature, Vapour quality on HTC & pressure drop with helical coiled micro fin tube. Its performance was compared with straight smooth tube. It is reported that micro fin tube had higher HTC of 160-255% than smooth tube and 69-155% higher pressure drop than smooth tube. Ji et al. [14] In this study, condensation HTC outside plain tube & enhanced tube were investigated with the Refrigerants R134a, R1234ze (E) & R290. It had been reported that, performance of R134a was better than other two refrigerants over smooth and enhanced tube made from Titanium material. Later on, [15] HTC of R134a, R1234ze(E) & R1233zd (E) were experimentally investigated on two different enhanced tube. Here, fin on outside as well as inside of tube were used for experimentation. In this experimental work, Condensation HTC of R134a found higher than R1234zd (E).

5. Effect of Use of Porous Media

Shi et al. [16] In this experimental investigation, effect of Vapour mass flowrate, cooling water temp., inlet vapor pressure with different foam size enhanced tube on HTC and pressure drop were reported. Tube with 10PPI metal foam, exhibits high performance compared to micro fin tube. Author also obtained correlation for HTC & pressure drop for foam tube. Subsequently [17], investigates the effect of metal foam surface wettability on HTC & pressure drop with annularly partial filled hydrophobic metal foam inside tube. It is reported that, 30.158KW/m²K of HTC were obtained with mass flux of 65.8Kg/m²S and cooling water temperature of 55°C.

Nasr [18] numerically investigates the effect of porosity & thickness of porous layer on heat transfer and mass transfer for liquid film condensation. It is reported that decrease in porosity & porous layer thickness improve heat & mass transfer performances at liquid –gas interface. Wang et al. [19] In this study, researchers examined the selective laser melting fabricated enhanced tube, and compared its performance with plain tube. Effect of fin height, refrigerant flow direction and mass flux on HTC & pressure drop were investigated. HTC of foam tube were higher than that of plain tube. Preston et al. [20] In this experimental work, investigation of enhanced condensation heat transfers by wick condensation film through porous metal were examined. This study reveals that, the thermal resistance of wick condensation film is lower than the filmwise condensation which leads to higher magnitude of heat transfer enhancement.

6. Effect of Use Inserts

Moghaddam & Shafaee [21] In this experimental investigation, effect of wire coil with its diameter and three different pitch with mass flux, Vapour quality on HTC were examined. Highest HTC of 107% over plain tube were reported for coil index of 0.0185. Subsequently, Moghaddam et al. [22] researchers investigate the effect of twisted tape inserts with twist ratio of 4,10,15 with mass flux & vapor quality on HTC & pressure drop. It found that, performance factor varies from 0.39 to 1.05, which depend upon operating conditions & inserts type.

Hejazi et al. [23] In this experimental study, researchers examined the condensation HTC & pressure drop for the tube with insert tape of 6,9,12 &15 twist ratio. It is reported that HTC & pressure drop increased by 40% & 240% over the plain tube. Sajadi et al. [24] Also, examined the twisted tape
with twist ratio of 6,9,12 on R1234y, which is alternative to R134a with low GWP. Effect of mass flux, vapor quality of HTC & pressure drop was observed. An increment of 42% & 235% of HTC & pressure drop respectively over plain tube had been observed.

Table 1 Experimental studies on two phase flow by using passive method.

| Author | Enhanced Tube | Working Fluid | Test Section | Mass flux/Heat Flux/Vapor Quality | $T_{sat.}$ |
|--------|---------------|---------------|--------------|----------------------------------|------------|
| [5]    | Dimple Tube   | R134a         | Tube in Tube φ=8.1mm, l=1.5m | 300,400,500 Kg/m$^2$s | 40,45,50 oC |
| [6]    | Helical Dimple Tube | R134a | Tube in Tube φ=8.1mm, l=1.5m | 300-500 Kg/m$^2$s | 40-50 oC |
| [7]    | Helical coiled Dimple tube | R134a | Tube in Shell type | 75,115,156,191 Kg/m$^2$s | 35 & 45 oC |
| [8]    | Dimple tube with diff. depth | R134a | Tube in Tube φ=8.1mm, l=1.5m | 300-500 Kg/m$^2$s | 40-50 oC |
| [9]    | Microfin tube | R134a | Tube in Shell φ=8.96mm | 90-800 Kg/m$^2$s | 35-60 oC |
| [10]   | Microfin Tube | HFC-134a, R404A | φ=8.96mm | 90-800 Kg/m$^2$s | 35-60 oC |
| [11]   | Microfin | R410A | Tube φ=8.76mm | 80-345 Kg/m$^2$s | 40,45,48 oC |
| [12]   | Microfin four tube | R134a | Tube in Tube | 400-1100 Kg/m$^2$s | 35 – 45 oC |
| [13]   | Microfin | R134a | φ=8.58mm | 75,115,156,191 Kg/m$^2$s | 35-45 oC |
| [15]   | Microfin | R134a, R1234ze (E), R1233zd (E) | Tube φ=17.14 & 17.12mm | 20-90 Kw/m$^2$ | 36 oC |
| [16]   | Foam Tube (10,15,20PPI) | Water | Tube in Tube type φ=22mm | 20-100 Kg/hr | 1-3 m$^3$/h |
| [17]   | Treated Foam Tube (10,15,20PPI) | Water | Tube in Tube type φ=22mm | 20-100 Kg/hr | 1-3 m$^3$/h |
| [19]   | Foam Tube | R134a | Tube φ=8.7mm | 50-150 Kg/m$^2$S | 0.9,0.3 |
| [25]   | Tube (5PPI) | R1234yf & R1234ze (E) | | 50-200 Kg/m$^2$S | 30 oC |
| [26]   | Foam Thickness 1.6mm & 2.5mm, 40,80,130PPI | R134a | | 10-60 Kw/m$^2$ | 35 & 45 oC |
| [27]   | 30,60,90 PPI | DI Water | | 30-200 Kg/m$^2$S | 100 oC |
7. Numerical Studies
In previous section, we reviewed, mostly experimental studies on the use of passive method in two phase flow, while in this section, specifically, numerical studies on the use of porous media in two phase flow are reviewed. Modelling of Two phase flow in porous media is complicated phenomenon. Here the table 2 represents the numerical studies performed with its computation domain.

Table 2 Numerical studies on two phase flow in porous media.

| Author | Computation Domain | Remark |
|--------|---------------------|--------|
| [28]   | ![Diagram](image1)  | A copper foam of 0.94 porosity were used in thermal storage system. Effect of metal foam in heat transfer fluid and phase change material investigated. Use of metal foam shows enhancement in heat transfer. |
| [29]   | ![Diagram](image2)  | The 3D numerical model of porous media developed by using Micro-CT. A Lattice-Boltzmann method at pore scale were used to obtained velocity and temperature field with the help of contact angle. |
| [30]   | ![Diagram](image3)  | A Modified Separated Flow Model developed. Effect of capilarity, foam porosity and other parameters has great effect on heat &fluid flow. |
| [31]   | ![Diagram](image4)  | An efficient smoothing algorithm developed for effective diffusivity. Finite volume method adopted for discretization. |
| [32]   | ![Diagram](image5)  | One dimensional problem was developed for phase change heat transfer in porous media with local thermal equilibrium and Local non thermal equilibrium conditions. |
8. Conclusion
1. Use of passive techniques in two phase flow are increasing at higher rate, it exhibits beneficial results in term of heat transfer enhancement with a penalty of pressure drop.
2. Out of the various passive method of heat transfer enhancement, comparatively micro fin tube was investigated extensively. It’s clearly indicates other techniques need to be explored.
3. Experimental studies and numerical studies on the use of porous media in two phase flow reveals good heat transfer enhancement, a more study is required to find optimum parameters of metal foam and effect of use tailored porous media.
4. Refrigerants R1234yf, R1234ze (E) with low GWP could be a good alternative for R134a.

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