ANALYTICAL INVESTIGATIONS OF BOILING HEAT TRANSFER IN SMOOTH MICRO-FIN TUBES OF DIFFERENT REFRIGERANTS

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ABSTRACT- Micro-fin tubes are characterized by high heat transfer coefficients, low pressure drop penalty, less material consumption in manufacturing and reduction of refrigerant charge. Due to these excellent advantages, micro-fin tubes are widely used in residential air-conditioners and automobile cooling systems. Air conditioner condensers are a heat exchanger device; AC condenser units are grouped according to how it rejects the heat to the medium (surround air). The primary component of a condenser is typically the condenser coil, through which the refrigerant flows. Since, the AC condenser coil contains refrigerant that absorbs heat from the surrounding air, the refrigerant temperature must be higher than the air.

In this thesis, analytical investigations are performed to determine boiling characteristics in micro-fin tubes for different refrigerants R22, R134A, R407C and R410A. The performance of the micro fin tubes is determined by changing fin heights 5mm and 3mm.

3D models of the tubes are done in 3D modeling software Creo 2.0. CFD and Thermal analysis is performed on the tube to determine the heat transfer coefficients, pressure drop and heat transfer rates. Thermal analysis is performed for different materials Aluminum alloy, Copper alloy and Titanium alloy. Analysis is done in Ansys.

I. INTRODUCTION

Conventional resources of energy are depleting at an alarming rate, which makes future sustainable development of energy use very difficult. As a result, considerable emphasis has been placed on the development of various augmented heat transfer surfaces and devices. Heat transfer augmentation techniques are generally classified into three categories namely: active techniques, passive techniques and compound techniques. Passive heat transfer techniques (ex: tube inserts) do not require any direct input of external power. Hence many researchers preferred passive heat transfer enhancement techniques for their simplicity and applicability for many applications. Tube inserts present some advantages over other enhancement techniques, such as they can be installed in existing smooth tube that exchanger, and they maintain the mechanical strength of the smooth tube. Their installation is easy and cost is low. It relatively easy to takeout for cleaning operations too.

The process of improving the performance of a heat transfer system is referred as the heat transfer enhancement technique .In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment .The major challenge in designing a heat transfer is to make the equipment compact and achieve a high heat transfer rate using minimum pumping power. The subject of heat transfer growth in heat exchanger is serious interest in the design of effective and economical heat exchanger. Augmentation techniques increase convective heat transfer by reducing thermal resistance in a heat exchanger. A decrease in heat transfer surface area, size, and hence weight of heat exchanger for a given heat duty and pressure drop. The heat transfer can be increased by the following different augmentation techniques. They are classified as (i) Passive Techniques (ii) Active Techniques (iii) Compound Techniques.

PASSIVE TECHNIQUES

- Treated surfaces are heat transfer surfaces that have a fine-scale alteration to their finish or coating. The alteration could be continuous or discontinuous, where the roughness is much smaller than what affects single-phase heat transfer, and they are used primarily for boiling and condensing duties.
- Rough surfaces are generally surface modifications that promote turbulence in the flow field, primarily in single-phase flows, and do not increase the heat transfer surface area. Their geometric features range from random sand-grain roughness to discrete three dimensional surface protuberances.
- Extended surfaces, more commonly referred to as finned surfaces, provide an effective heat transfer surface area enlargement. Plain fins have been used routinely in many heat exchangers. The newer developments, however, have led to modified finned surfaces that also tend to improve the heat transfer coefficients by disturbing the flow field in addition to increasing the surface area.

ACTIVE TECHNIQUES

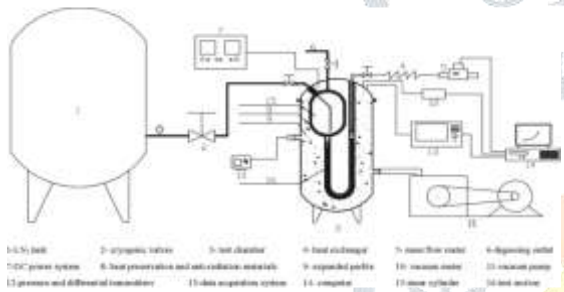
- Mechanical aids are those that stir the fluid by mechanical mean or by rotating the surface. The more prominent examples include rotating tube heat exchangers and scraped-surface heat and mass exchangers.
- Surface vibration has been applied primarily, at either low or high frequency, in single phase flows to obtain higher convective heat transfer coefficients.
- Fluid vibration or fluid pulsation, with vibrations ranging from 1.0 Hz to ultrasound, used primarily in single-phase flows, is considered to be perhaps the most practical type of vibration enhancement technique.
- Electrostatic fields, which could be in the form of electric or magnetic fields, or a combination of the two, from dc or ac sources, can be applied in heat exchange systems involving dielectric fluids. Depending on the application, they can promote greater bulk fluid mixing and induce forced convection (corona “wind”) or electromagnetic pumping to enhance heat transfer.

Classic twisted tape

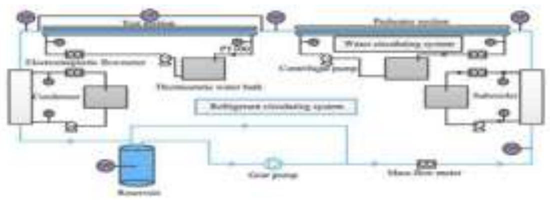
Perforated twisted tape

MICRO FIN TUBES

Micro-fin tubes are characterized by high heat transfer coefficients, low pressure drop penalty, less material consumption in manufacturing and reduction of refrigerant charge. Due to these excellent advantages, micro-fin tubes are widely used in residential air-conditioners and automobile cooling systems. Since the development of micro-fin tubes for improving the heat transfer coefficient in evaporators and condensers in refrigeration applications started by Hitachi, Ltd in 1977, a number of researches have been conducted to improve the performance of micro-fin tubes by changing geometric parameters like fin number, fin height, fin angle and helical angle. Some typical results are reported in. In order to protect environment, various R22 alternatives are now used in refrigeration applications. There are many literatures on the performance of heat transfer coefficients and pressure drop in flow condensation and boiling. Some correlations of R22 and its alternatives have been obtained in recent years.



On the other hand in-tube boiling heat transfer is a very complicated phenomenon. In order to develop a generally-accepted correlation much more reliable test data should be accumulated. This study investigates boiling heat transfer and pressure drop characteristics in a smooth and micro-fin tube which has been used in air-conditioning engineering in China. The working fluids include R22, R134a, R407C and R410A within a certain ranges of mass flux and heat flux.



II. LITERATURE REVIEW

The paper is written by G.B. Jiang[1], The refrigerants tested were R22, R134a, R407C and R410A while vapour quality ranges from 0.1 to 0.9, mass flux 50, 250, 450 kg m2 s 1 and heat flux of 5, 12.5, 20 kW m2 . The saturation temperature is 5 C. For the smooth tube, the average heat transfer coefficients of R134a, R407C and R410A are 110.9%, 78.0% and 125.2% of those of R22 in test conditions respectively. For the micro-fin tube, the average heat transfer coefficients of R22, R134a, R407C and R410A are 1.86, 1.80, 1.69 and 1.78 times higher than those of the smooth tube. The pressure drop of R22, R407C and R410A for the smooth tube is similar to each other while the pressure drop of R134a is 1.7 times higher.

The average pressure drop of R22, R134a, R407C and R410A for the micro-fin tube is 1.42, 1.30, 1.45 and 1.40 times higher when compared with that for the smooth one. Considering the effect of heat transfer enhancement and pressure drop augment, the efficiency index g1 which values the thermo-hydraulic performance at identical flow rate of R22, R134a, R407C and R410A in the micro-fin tube used is 1.31, 1.38, 1.17 and 1.27 respectively compared with the smooth tube.

The paper is written by S. Wellsandt[2]An experimental investigation of in-tube evaporation of R134a has been carried out for a 4 m long herringbone micro fin tube with an outer diameter of 9.53 mm. Measured local heat transfer coefficients and pressure losses are reported for evaporation temperatures between K0.7 and 10.1 8C and mass flow rates between 162 and 366 kg mK2 s K1 . Results from this work are compared to experimental results from literature as well as predicted values from some available helical micro fin correlations. Differences in heat transfer mechanisms between helical and herringbone micro fin tubes are discussed, as heat transfer coefficients in the investigated herringbone tube tend to peak at lower vapour qualities compared to helical micro fins. Correlations developed for helical micro fin tubes generally predict experimental values within G30% for vapour qualities below 50%. However, at higher qualities none of the correlations are able to reflect the early peak of heat transfer coefficients.

The Paper Is Written By Ahmet SelimDalkiliç[6]Heat Transfer Enhancement During Downward Laminar Flow Condensation Of R134a In Vertical Smooth And Microfin Tubes, This paper presents an experimental comparison of the laminar film condensation heat transfer coefficients of R134a in vertical smooth and micro-fin tubes having inner diameters of 7 mm and lengths of 500 mm. Condensation experiments were performed at a mass flux of 29 kg m-2 s -1 . The pressures were between 0.8 and 0.9 MPa.

The original smooth tube heat transfer model was modified by a well-known friction factor to account for the heat transfer enhancement effects due to the presence of micro-fins on the internal wall surface during annular flow regime conditions. Alterations of the local heat transfer coefficient, and condensation rate along the tube length during downward condensing film were determined, considering the effects of the temperature difference between the saturation temperature and the inner wall temperature of the test tubes, and the condensing temperature on these items. The results show that the interfacial shear stress is found to have significance for the laminar condensation heat transfer of R134a under the given conditions due to its better predictive performance than the classical solution neglecting the interfacial shear stress effect.

III. 3D MODELING OF MICRO FIN TUBES

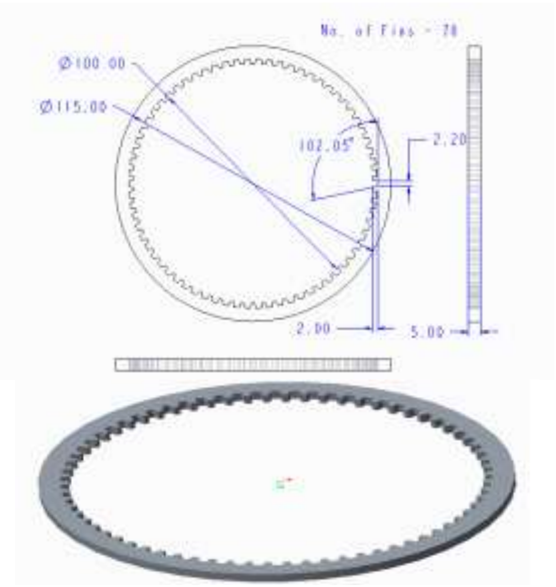
The reference for the modelling and analysis of micro fin tubes is taken from journal paper "G.B. Jiang a, J.T. Tan b, Q.X. Nian a, W.Q. Tao a, Experimental study of boiling heat transfer in smooth/micro-fin tubes of four refrigerants, International Journal of Heat and Mass Transfer 98 (2016) 631–642" specified as [1] in References chapter.

Creo is a family or suite of design software supporting product design for discrete manufacturers and is developed by PTC. The suite consists of apps, each delivering a distinct set of capabilities for a user role within product development.

Creo Elements/Pro can be used to create a complete 3D digital model of manufactured goods. The models consist of 2D and 3D solid model data which can also be used downstream in finite element analysis, rapid prototyping, tooling design, and CNC manufacturing.

PTC Creo is a scalable, interoperable suite of product design software that delivers fast time to value. It helps teams create, analyse, view and leverage product designs downstream utilizing 2D CAD, 3D CAD, parametric & direct modeling.

FIN HEIGHT – 5mm



3D of fin height – 5mm

3D of fin height – 3mm

IV.CFD ANALYSIS OF BOILING HEAT TRANSFER IN MICRO-FIN TUBES

The use of computational fluid dynamics (CFD) in the design and troubleshooting of HRSGs is now well established. However, the large ratio of scales between the overall flow path and the tube bundles themselves means that the bundles must be approximated using "porous media" models, with heat transfer and flow resistance simulated using lumped parameters. The parameters input into these models are taken from the open literature, proprietary data, and/or approximate analytical models. In the case of plain tubes, two-dimensional CFD models have been used to supplement this information. For the finned tubes used in HRSGs, however, 2D models will not suffice and 3D models can quickly become unwieldy.

This work was motivated by a desire to use computational methods to predict the onset of flow-induced vibration (FIV) in the leading superheater tube bundles of heat recovery steam generators (HRSG). These bundles are susceptible to vibration caused by turbulent buffeting as the flow from the gas turbine impinges upon the leading tubes and, to a lesser extent, familiar FIV mechanisms such as fluid-elastic whirl and vortex shedding.

In the case of plain tubes experiencing uniform flow, two-dimensional coupled flow and stiffness models, such as that shown in Figure 1 have been used to successfully simulate FIV. In the case of a HRSG, however, the tubes are typically finned and the approach velocity is far from uniform. Even if we simplify the problem, considering a span over which the approach velocity can be considered to be approximately uniform, we are still left with the problem of modeling the fins. This requires a three-dimensional flow model.

CFD ANALYSIS

CFD analysis is performed in fluent environment by applying the properties of different fluids to determine pressures, heat transfer coefficients and heat transfer rates.

FLUID PROPERTIES

R22

Density: 1409.2 kg/m^3
Cp: 1.090 kj/ (kg-k)
Thermal conductivity: 113.5 W/ (m-k)
Viscosity: 346.0 Pa's

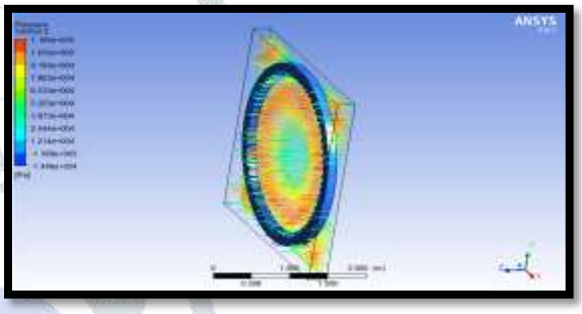
R134A

Density: 1376.7 Kg/m^3
Cp: 1.281 KJ/Kg-K
Thermal conductivity: 103.9 W/m-K
Viscosity: 384.2 Pa's

R407C

Density: 1380.7 Kg/m^3
Cp: 0.787 KJ/Kg-K
Thermal conductivity: 127.9W/m-K
Viscosity: 384.6 Pa's

FLUID - R22

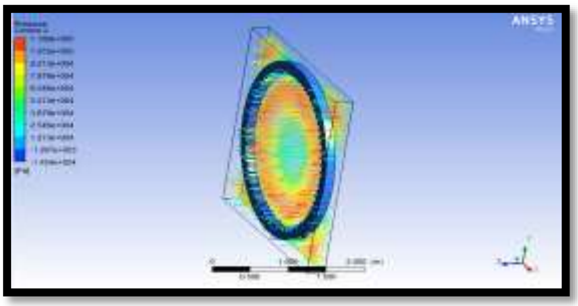


Pressure

Total Heat Transfer Rate	(w)
contact_region-src	0
contact_region-trg	0
inlet	1.1708411e+08
out	-1.1708833e+08
wall-12	0
wall-13	0
wall-7	0.0030730322
wall-7-shadow	0.018572034
wall-solid	0
Net	-4215.9784

Total heat transfer rate

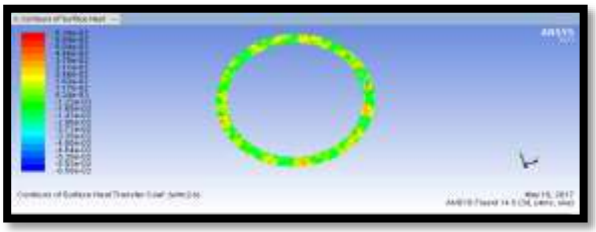
FLUID - R410A



Pressure

Total Heat Transfer Rate	(w)
contact_region-src	0
contact_region-trg	0
inlet	1.4233258e+08
out	-1.4233768e+08
wall-12	0
wall-13	0
wall-7	0.049517076
wall-7-shadow	0.10518756
wall-solid	0
Net	-5103.8453

Total heat transfer rate



Heat transfer coefficient

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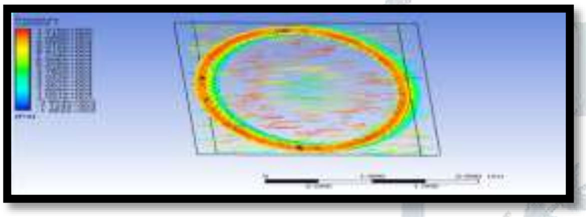
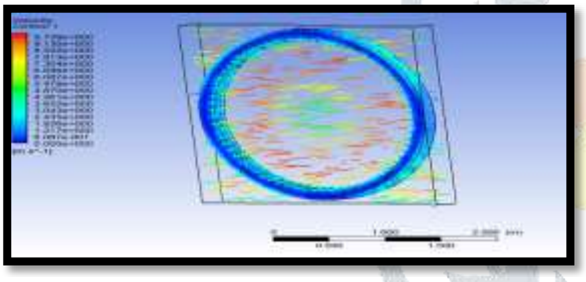
Total Heat Transfer Rate                 (w)
---------------------------- --------------------
       contact_region-src                  0
       contact_region-trg                  0
                    inlet      1.5087818e+08
                   outlet     -1.5088085e+08
                  wall-12                  0
                  wall-13                  0
                   wall-7         0.39060748
            wall-7-shadow         -0.4613454
               wall-solid                  0
         ---------------- --------------------
                      Net         -2672.0707
```

Total heat transfer rate

FLUID - R410A



Pressure



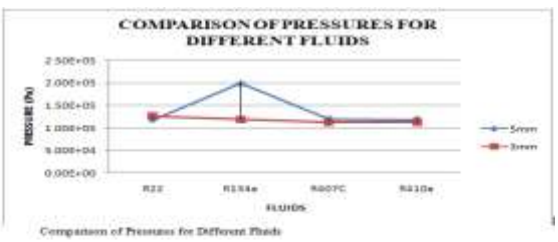
Velocity

TABLE 4.2: Results of FIN HEIGHT – 3mm

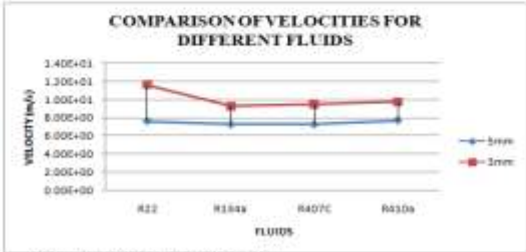
	R22	R134A	R407C	R410A
Pressure(Pa)	1.261E+005	1.188E+005	1.1320E+005	1.126E+005
Velocity(m/s)	1.163E+001	9.299E+000	9.500E+000	9.739E+000
Heat transfer coefficient(w/m^2 K)	8.34E-02	8.56E-02	8.38E-02	8.33E-02
Total heat transfer rate (W)	4215.0784	4184.0398	2608.1967	5600.0791

GRAPHS

Standard volumetric flow rates of a fluid are often used to describe the capacity of a vent or pressure relief device. To determine how this capacity compares for another fluid under different pressure and temperature conditions a conversion must be made on the basis of equivalent pressure loss. This article describes the method for calculating the volumetric flow rate of a gas which will give the equivalent pressure drop to another gas through a fixed restriction such as a vent.



Comparison of Pressures for Different Fluids



Comparison of Velocities for Different Fluids

V. THERMAL ANALYSIS

FIN HEIGHT – 5mm

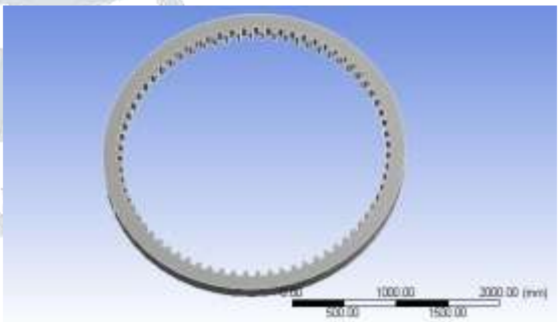
The heat transfer coefficient value for convention is taken of maximum value from CFD analysis (R410A – 5.8e^{-2} W/m^2 K)

MATERIAL - ALUMINUM ALLOY

Save Pro-E Model as .iges format.

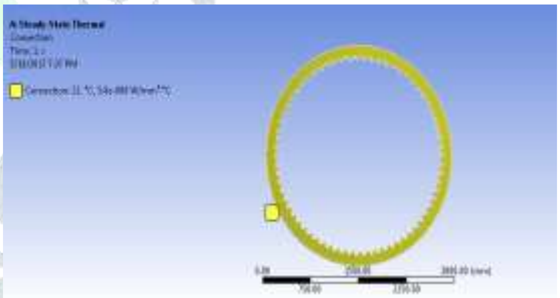
Ansys 14.5 → workbench → select engineering data → edit material properties → return to project → select geometry → right click → import geometry → select required iges file → open

Select model → right click → edit→ other window will be open.



Imported model

Convection



Convection applied on the outer surface

MATERIAL– COPPER ALLOY

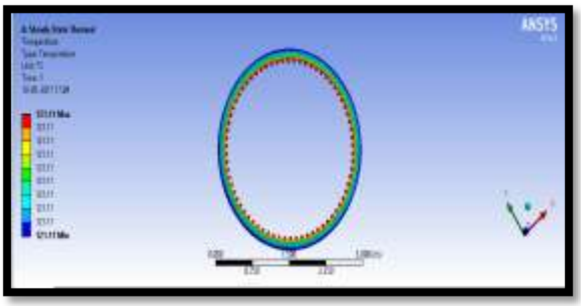
Material properties of Copper

Density – 8300kg/m^3

Young's modulus = 110000Mpa

Poission's ratio = 0.34

Thermal conductivity:401 W/m^{0}C



Temperature

TABLE 5.1: FIN HEIGHT – 5mm

	ALUMINUM ALLOY	COPPER ALLOY	TITANIUM ALLOY
TEMPERATURE(°C)	121.11	121.11	121.11
HEAT FLUX (W/m²)	17.459	17.46	17.45

TABLE 5.2: FIN HEIGHT – 3mm

	ALUMINUM ALLOY	COPPER ALLOY	TITANIUM ALLOY
TEMPERATURE(°C)	121.11	121.11	121.11
HEAT FLUX (W/m²)	37.906	37.91	37.869

VI. CONCLUSION AND FUTURE SCOPE

In this thesis, analytical investigations are performed to determine boiling characteristics in micro-fin tubes for different refrigerants R22, R134a, R407Cand R410A. The performance of the micro fin tubes is determined bychanging fin heights 5mm and 3mm.

CFD is performed on the tube to determine the heat transfer coefficients, pressure drop and heat transfer rates. By observing the results, the heat transfer coefficient for fin height 3mm is more by 25.86% when R22 is used, by 58% when R134A is used, by 36% when R407C is used and by 30% when R410A is used when compared with that of 5mm fin height. The heat transfer rate for fin height 3mm is more by 36.6% when R22 is used, by 28% when R134A is used, by 7.3% when R407C is used and by 8.86% when R410A is used when compared with that of 5mm fin height.

Comparing the results between fluids, the heat transfer coefficient is more when R134A is used and heat transfer rate is when R410A is used.Thermal analysis is performed for different materials Aluminum alloy, Copper alloy and Titanium alloy.By observing the results, the heat flux for fin height 3mm is more by 53% for all materials when compared with that of 5mm fin height. The heat flux is more when Copper alloy is used.

FUTURE SCOPE

Thenanofluid research is in dire need for correlations and modelsto explain and predict the heat transfer phenomena. To cope with it, one should try tounderstand the science of the particle behavior in nanofluids, and to give scientific explanation to the enhancement factor.

The present experimental set up will not serve the purpose for further tests due to its extreme simplicity. To boil liquids at high pressures and thermally isolated conditions, a new test rig needs to be built up. Designing that kind of a system to test

Nanofluids needs extra attention in aspects like the risk of possible particle blockage

In various parts and components in it.

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