Analysis of Effect of Varying Cross-Section on Thermal Efficiency of a Heat Pipe Heat Exchanger Using CFD

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Abstract- **The heat transfer enhancement technology (HTET) has been developed and widely applied to heat exchanger applications over last decade, such as refrigeration, auto motives, process industry, nuclear reactors, and solar water heaters. Till date, there have been many attempts to reduce the sizes and the costs of the heat exchangers and their energy consumption with the most influential factors being heat transfer coefficients and pressure drops, which generally lead to the incurring of less capital costs.**

Heat pipes are two-phase heat transfer devices with high effective thermal conductivity. Due to the high heat transport capacity, heat exchanger with heat pipes has become much smaller than traditional heat exchangers in handling high heat fluxes. With the working fluid in a heat pipe, heat can be absorbed on the evaporator region and transported to the condenser region where the vapor condenses releasing the heat to the cooling media.

The primary aim is to evaluate the effect of different varying diameter ratio on entrance on heat transfer. Increasing diameter ratio on entrance leads to enhancement of heat transfer coefficient. In the present, work attempts are made to enhance the heat transfer rate in heat pipe heat exchangers. A heat pipe heat exchanger with different varying section modeling is done using ANSYS. The CFD simulated results are compared with previous work. Based on the results, increasing diameter ratio on entrance causes the increment of overall heat transfer coefficient which results in the enhancement of heat transfer rate of heat exchanger.

Index Terms- Heat pipe heat exchanger, Diameter ratio, Heat transfer, ANSYS 14.5, Overall heat transfer coefficient, CFD, Fluent.

I. INTRODUCTION

1.1 HEAT EXCHANGER

Heat exchanger is defined as a device which is use to transfer energy between two fluid which are at different temperature with maximum rate and minimum cost.

1.2 HEAT PIPE

Heat pipe is device that transfers heat using the principles of both thermal conductivity & phase transition so that heat can transfer effectively between two interfaces. Heat pipe is a self-contained passive energy recovery device. A heat pipe can transfer up to 1000 times more thermal energy, than copper, the best known conductor; that too with less than 57°C/mtr temperature drop. One of the amazing features of the heat pipes is that they have no moving parts and hence require minimum maintenance. They are completely silent and reversible in operation and require no external energy other than the thermal energy they transfer. Heat pipes are ruggedly built and can withstand a lot of abuse.

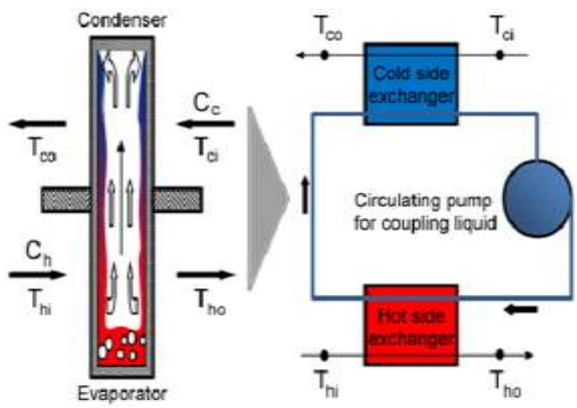

Figure 1 Single heat pipe heat exchanger.

The Heat Pipe functions as follows:

- Heat is absorbed in the evaporating section.
- Fluid boils to vapor phase.
- Heat is released from the upper part of cylinder to the environment; vapor condenses to liquid phase.
- Liquid returns by gravity to the lower part of cylinder (evaporating section).

When heat is added to the evaporator section, the working fluid boils and converts into vapor absorbing latent heat.

After reaching the condenser section, due to partial pressure build up, the vapor transforms back into liquid thus releasing latent heat. From the condenser section, heat is taken away by means of water cooling / air cooling with fins etc. The liquid condensate returns to the original position through the capillary return mechanism, completing the cycle. Due to very high latent heat of vaporization a large quantity of heat can be transferred.

1.2.1 TYPES OF HEAT PIPE HEAT EXCHANGER

(i) Hot Gas to Air Heat Pipe Exchanger

Typical finned Hot Gas to air Heat Pipe heat exchanger comprise of number of tubular gravity assisted finned Heat Pipes arranged in staggered pitch, depending upon the application. One of the advantages of the Heat Pipe Heat Exchanger is its ability to operate without cross contamination between the two streams.

(ii) Hot Gas to Liquid Heat Pipe Exchanger

This heat exchanger resembles Air to Air unit, only difference is liquid/water tank is provided at the condensation section to preheat liquid / water.

Manor heat pipe heat exchanger can recover up to 85% of exhausted thermal energy. However under ideal conditions the thermal efficiency of an economic system ranges between 55 to 70% and saves millions of BTUs year after year.

Manor heat pipe heat exchanger as standard is suitable for air-to air heat recovery for a temperature range of - 10℃ to + 260℃. With special materials of construction for the tube, the exchanger can be designed to extend the range to 427℃ to 482℃

(iii) Heat Pipe Panel Cooler (HPPC)

Electrical and electronics control panels are normally made air tight to protect costly electronic and electrical components from dust. Inside components get overheated which leads to failure or mal-function. Control panel coolers extract heat from inside the panel without disturbing inside environment of panel.

(iv) Heat Pipe Dehumidifier (HPD)

In an air conditioning system, additional moisture is condensed out, as the air becomes colder and colder. The heat pipe is designed to have one section in the warm incoming stream and the other in the cold outgoing stream. By transferring the heat from the warm return/incoming air to the cold outgoing supply air, the heat pipes create the double effect of pre-cooling the air before it goes to the evaporator and then re-heating it immediately. This lowers the cooling load, evaporating temperature and heating load. Activated by temperature difference and therefore consuming no energy, the heat pipe, due to its pre-cooling effect, allows the evaporator coil to operate at a lower temperature, increasing the moisture removal capability of the air conditioning system by 50-100%.

With lower relative humidity, indoor comfort can be achieved at higher thermostat settings, which results in net energy savings. Generally, for each 1℃ rise in thermostat setting, there is a 3% savings in electricity cost. In addition, the pre-cooling effect of the heat pipe allows the use of a smaller compressor.

1.2.2 APPLICATIONS OF HEAT PIPE

- Waste Heat Recovery from Air Conditioners
- Heat Pipe Air Preheater for Boilers
- Waste Heat Boilers to Recovery Heat
- Heat Recovery at the Kiln Furnace
- Spray Drying

II. LITERATURE REVIEW

The performance of a heat pipe is critical, and is often judged in part by the amount of heat a unit length of the heat pipe can transport under a uniform heat load. Many investigations have been performed concerning heat pipe operating limits, heat pipe applications and design modifications to improve the heat pipe performance. In the present work, a detailed review has been made on the various research works carried out experimentally and theoretically on the operating limits, start-up considerations and various design parametric considerations.

Jang et al (1991) mathematically developed a model, to predict the start-up behavior of the heat pipe from the frozen state condition. A parametric study is performed to examine the effects of the boundary specification at the surface of the outer wall on the successful start-up from the frozen state.

Ivan Catton and Stroes (2002) analytically predicted the wetted length capillary limit in inclined triangular grooves for a variety of operating conditions. The concept of the accommodation theory is introduced to account for the change in the radius of curvature of the liquid – vapor interface between the liquid – reservoir and the groove.

Stephane Launay et al (2007) discusses the operating limits of a loop heat pipe with various choices of the working fluid, the fill charge ratio, the porous wick geometry and thermal properties, the sink and ambient temperature levels, the design of the evaporator and compensation chamber, the elevation and tilt, the presence of non – condensable gases, and the pressure drop of the fluid along the loop.

Pruzan et al (2008) analytically predicted the steady state heat flux limits in a sintered wick heat pipe, with various geometrical parameters in the wick structure such as the wick thickness, effective capillary radius of curvature, porosity and heated wire diameter. The analytical results are compared with the experimental results. They concluded that the dry out heat flux increases with the increase in all geometrical parameters in the wick structure, except in the tilt angle. The dry out heat flux decreases with an increase in the tilt angle.

Sugumar and Tio (2009) experimentally investigated the effect of the thermo physical properties of the working fluid on the performance of a micro heat pipe with a triangular cross section. The different working fluids are water, heptane, ammonia, methanol and ethanol for operating temperatures ranging from 20 ^{0}C to 100 ^{0}C.

Zhu and Vafai (2012) analytically predicted the vapor and liquid velocity and pressure distribution, the steady state vapor and wall temperature for a given input heat load in the evaporator region. They also described a convective boundary condition in the condenser section and the effects of the liquid – vapor interfacial hydrodynamic coupling and non – Darcian transport through the porous wick.

Lanchao Lin et al (2015) experimentally investigated the thermal performance of a miniature heat pipe with different capillary structures of the heat pipe, such as partially and fully opened grooves, and different fill amounts of the working fluid, and different modes of heat source in the evaporator section.

M. H. Saber et al (2017) heat pipe heat exchanger (HPHE) is considered and computational fluid dynamics (CFD) is used to analyses its evaporator's performance and based on it, will be try to increase the thermal efficiency. Use of baffles is a very effective role for appropriate development of flow and temperature's profiles. The results show that using an imperfect cone with 1/5 diameter ratio, can optimizes performance of HPHE very well.

III.METHODOLOGY

The geometry of Heat pipe heat exchanger performing the simulation study is taken form one of the research scholar's M H Saber et al. (2017) paper with exact dimension. The part of model was designed in ANSYS (Fluent) workbench14.5 software. The geometric dimension of the heat pipe heat exchanger is shown in figures. It was made a specific geometry for the HPHE in dimensions of 150*180*150 (cm*cm*cm) that is based on the basic design.

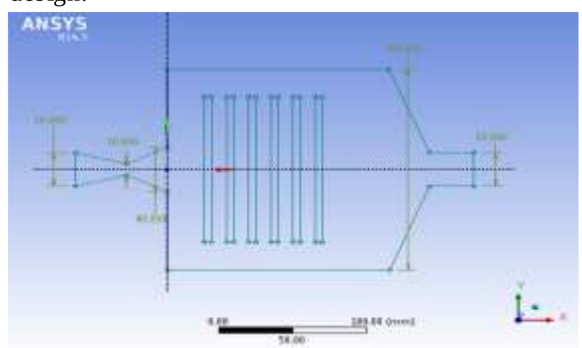

Figure 2 Geometrical dimension of an imperfect cone with 1/4 diameter ratio

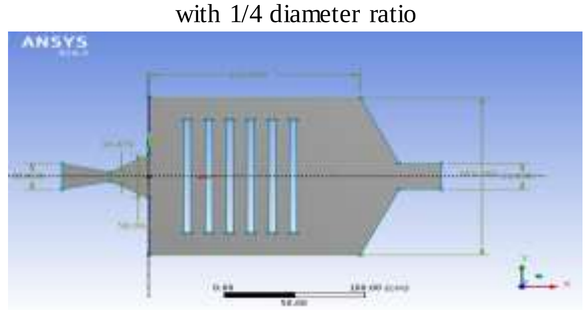

Figure 3 Geometrical dimension of an imperfect cone with 1/5 diameter ratio.

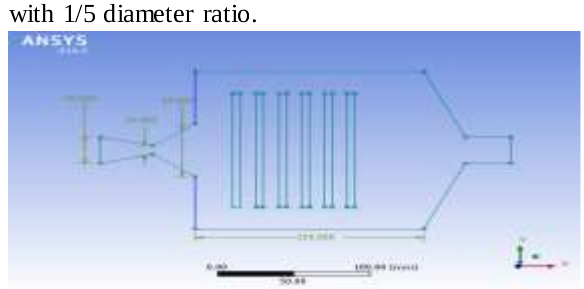

Figure 4 Geometrical dimension of an imperfect cone with 1/5 diameter ratio.

MESHING

By using ANSYS software in meshing edge sizing has been done. Inflation also makes for proper contact mesh.

For ¼ diameter ratio

Meshing Type - Quardcore

Number of nodes - 29825

Number of elements -28600

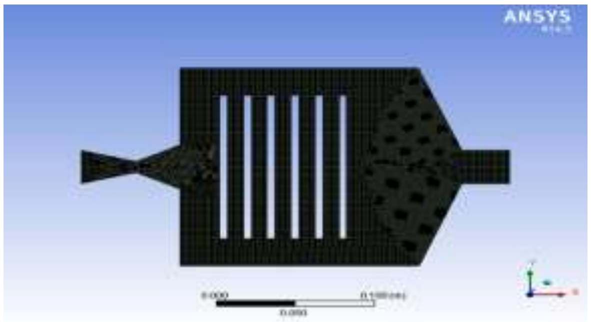

Figure 5 Meshing of an imperfect cone with 1/4 diameter ratio.

For 1/5 diameter ratio

Meshing Type - Quadcore

Number of nodes - 29887

Number of elements -28665

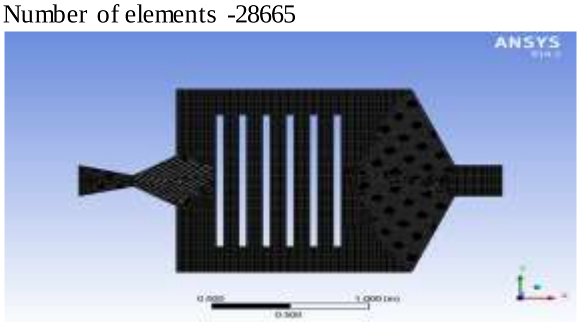

Figure 6 Meshing of an imperfect cone with 1/5 diameter ratio.

For 1/6 diameter ratio

Meshing Type - Quadcore

Number of nodes - 29960

Number of elements -28739

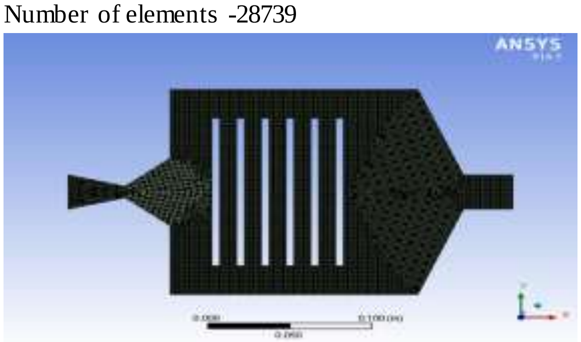

Figure 7 Meshing of an imperfect cone with 1/6 diameter ratio.

NAME SELECTION

A different part of Heat pipe heat exchanger is selected and the names are given to them so that boundary conditions can be applied on different boundary. The name selection remains same for substrate different diameter entry ratio which is as follows:

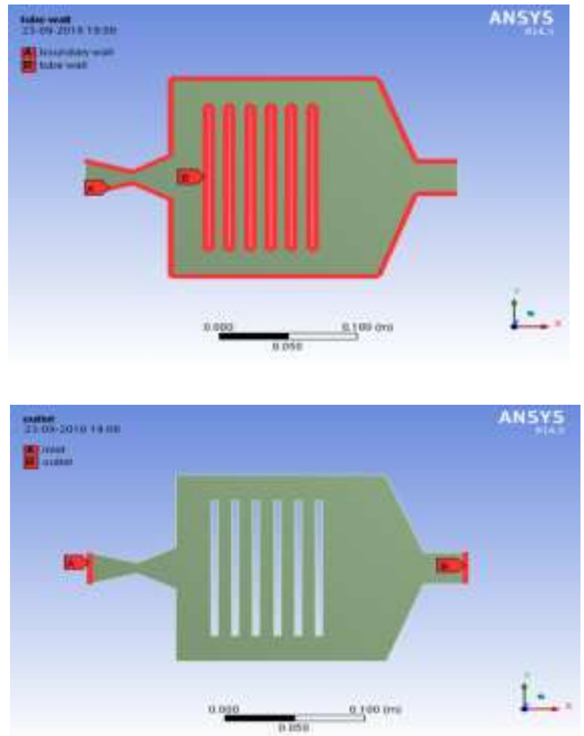

Figure 8 Name selections for heat pipe heat exchanger

FLUENT SETUP

The mesh is properly checked and fine mesh is obtained.. The problem type is 2D and type of solver pressure-based solver. The Velocity is change to absolute velocity and gravity is set y = -9.81 m/s

MODEL SELECTION

In model selection only three parameters are selected. Remaining parameter are remained as default. The three parameters are:-

Species, Energy – on and Viscous -Turbulent k-e standard wall Function, Solution method-Presto.

BOUNDARY CONDITION

Table 1 Physical specification of combustion gases for CFD modelling

Physical Parameter	Values
Temperature(K)	793
Mass flow rate(Kg/s)	3.75

Viscosity(Kg/m-s)	$2*10^{-5}$
Density(Kg/m^3)	0.88
Heat Conduction(W/m-K)	95

IV. RESULTS AND DISCUSSIONS

After putting the boundary conditions, the solution is initialized and then iteration is applied so that the values of all parameters can be seen in a curve or line graph. After the iteration gets completed final result could be seen.

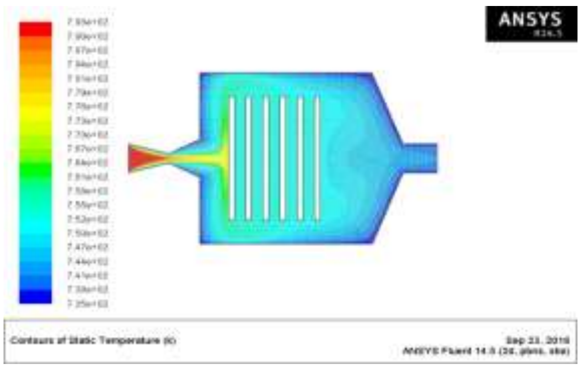

Figure 9 Static Temperature contour of an imperfect cone with 1/4 diameter ratio.

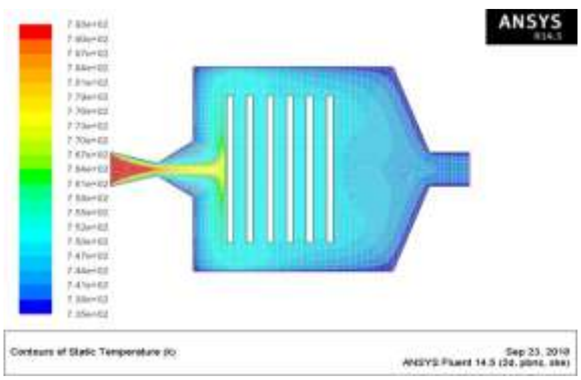

Figure 10 Static Temperature contour of an imperfect cone with 1/5 diameter ratio.

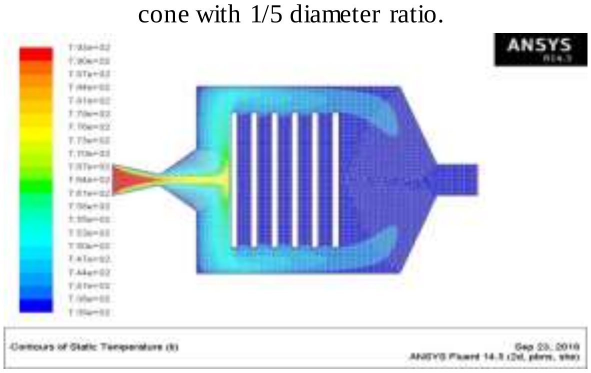

Figure 11 Static Temperature contour of an imperfect cone with 1/6 diameter ratio.

Finally, for a convenient comparison, table 2 is given that reports average of outlet flow temperature and temperature difference (ΔT). Inlet flow temperature is 793K for all of them.

Table 2 Outlet temperature and temperature difference for all of cases

Inlet Diameter Ratio	T_{out}(K)	ΔT(K)
1/4th	739.52	53.48
1/5th	738	55
1/6th	736	57

So that is realizable from table 2, case with 1/5th diameter ratio with imperfect cone baffle has highest rate of temperature change that causes the highest heat transfer and heat recovery between these cases. Therefore, it could be state that type of the flow's distribution is effective parameter in HPHE's rate of heat transfer and consequently in heat recovery quantity of it.

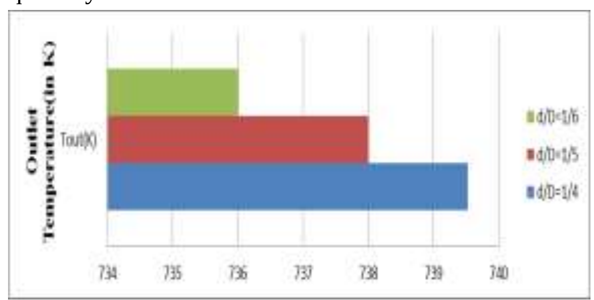

Figure 12 Outlet Temperature for an imperfect cone with different diameter ratio.

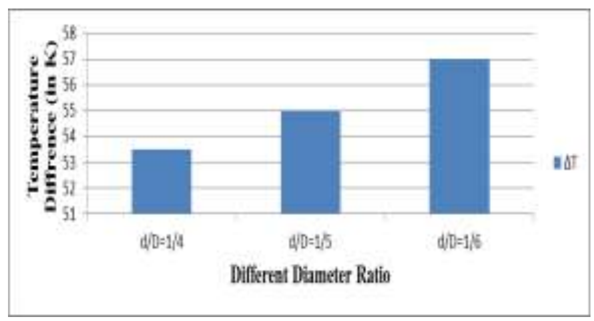

Figure 13 Temperature Difference for an imperfect cone with different diameter ratio.

V. CONCLUSIONS

From the simulation results it is observed that:

- Use of baffles is a very effective role for appropriate development of flow and temperature's profiles. The results show that using an imperfect cone with 1/6 diameter ratio, can optimizes performance of HPHE very well.
- There is a difference of 2 K as compared for an imperfect cone with 1/5 diameter ratio.

- There is a difference of 3.52 K as compared for an imperfect cone with 1/6 diameter ratio.
- For imperfect cone with 1/6 diameter ratio, the best distribution of flow and temperature with minimum pressure drop will be reached and so operation cost may decreases.

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