DESIGN AND CFD ANALYSIS OF HEAT PIPE WITH DIFFERENT FLUID CONDITIONS

A. Chenna Reddy[1]

[1]Assistant professor, Department of Mechanical Engineering, ABR College of Engineering and Technology, Chinairlapadu Village, Kanigiri, Andhra Pradesh- 523254

Bokka Rajesh[2]**, K. Naveen**[3]**, B. Madhava**[4]**, Ch. Salmanraj**[5]**, K. N Santhosh Kumar**[6]

[2,3,4,5,6] Students, Department of Mechanical Engineering, ABR College of Engineering and Technology, Chinairlapadu Village, Kanigiri, Andhra Pradesh- 523254

Abstract:
Heat Pipes are used in many applications and are similar to thermosyphons in some ways. Since thermosyphon had several limitations, heat pipe was developed. A heat pipe transmits heat with minimal temperature change by evaporation and condensation. A liquid is evaporated in the heat inlet zone (the evaporator) to transfer heat and then condensed in the heat rejection region. Capillary action and bulk forces keep the working fluid in a closed loop. Different coatings can improve the adhesion between the inner wall of the pipe and the working fluid. The number of evaporators and condensers, the choice of the working fluid, and other factors all affect heat pipe performance using both materials like Al+ TIC and SS+TIC. The study utilizes heat pipe design in CAD and CATIA with various geometrical conditions and the Analysis was done by using ANSYS software in CFD with different refrigerant fluids R134a, R214a, and R410a to calculate heat transfer, pressure drop, mass flow rate, and heat transfer coefficient. The fluid analysis calculated the heat transport rate and the spatial distribution of temperatures.

Keywords: Heat Pipe, CFD, Refringent fluids

INTRODUCTION

Heat pipes' largely passive nature has led to their widespread implementation. Heat pipes can carry a lot of heat over a long distance with little to no change in temperature, a high degree of flexibility, low fabrication and control costs, and little to no external pumping power. Uses in aircraft engineering, energy conversion devices, electronic component cooling, and biomedical engineering are just a few examples. As the density and size of microelectronic components continue to shrink, the challenge of keeping them within thermal operating ranges drives the research and development of heat pipes.

Heat Pipe:

Heat pipes are tools for transferring thermal energy. They are small, hollow cylinders filled with a fluid that evaporates to generate heat. This heat is rejected at another end and used in manufacturing. It has many practical uses, including HVAC and refrigeration

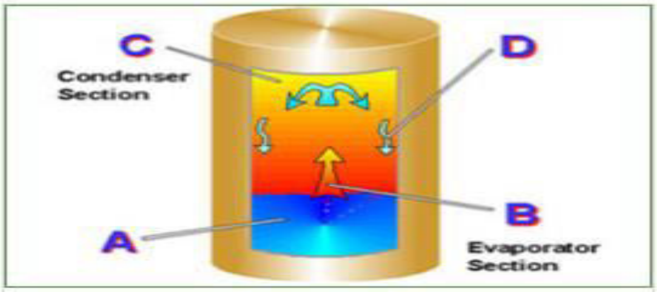

Figure 1: Heat Pipes

The air around us is used to cool or regulate the temperature of everything from power generators like motors and turbines to electrical components like motherboards, IC chips, and programmable chips. In cases when there is no access to liquid water and the air temperature is too high to cool heated surfaces using convection, a heat pipe is a potential technique that can be utilized to maintain thermal equilibrium over 130 kW when the thermal gradient is more than 6-8 kW/K.

Heat pipe working principle:

A heat pipe is a self-heating device that conducts heat from a high-temperature source to a lower-temperature sink, and can also be used to distribute heat within a closed system. When selecting a pipe for use on industrial devices, a number of factors must be considered. Various shapes, including round and flat varieties, are available for production.

Heat Pipe Applications:

- Compact Electronics Enclosures
- Aerospace
- Medical
- Consumer Electronics
- HVAC

Heat Pipe using materials:

- Tube material: Copper/ Aluminum
- Wick structures:

Heat pipe Advantages:

- Operation in passive mode
- Long service life
- The streams of the source and sink are physically separated, so there is no cross contamination
- Low maintenance
- Compact design
- The back pressure is practically zero

Background of the study:

Recently proposed an evaluation of loop heat pipes using flat evaporators. We evaluate the effects of the working fluid and the materials on the performance of a variety of shapes and compare results. A set of recommendations for optimizing the performance of an LHP evaporator was then put forward. For example, between 70 and 100 degrees Celsius, they suggested using a wick material and working fluid of copper and water respectively. Ammonia can be used to bring temperatures down, but only if the material is suitable. They also came to the conclusion that LHPs are of most interest when the distance between the heat source and the heat sink is greater than 200 mm and a loop thermosyphon cannot be used. Having a review like this that can summarize the information found in many different publications is invaluable to the community.

Objectives:

- To study the heat pipe used in different industrial purpose
- Heat pipe was design in done by using CAD/NX12.0 with the materials Aluminum+ TiC and SS +TiC
- The CFD analysis was done by using ANSYS With different fluid conditions (R134a, R214a, or R410a) to determine the heat transfer rate, pressure drop, mass flow rate, and Temperature

2.0 LITERATURE REVIEW

Rahul Royal. Sadey **[1]** Heat pipes are high-efficiency thermal conductance devices that move heat by convection and the expulsion of latent heat. There is now a solid theoretical basis for heat pipes among the scientific community. Cryogenic applications, as well as those running at temperatures up to 2000 degrees Celsius in the development units, show their value throughout a wide temperature range. Aerospace engineering, electronics, and die casting are just a few of the numerous fields that can benefit from these devices. M. Goodarzi, M. R. Safaei **[2]** As energy is transferred and fluids move through the heat pipe system, entropy is created as a result of the thermodynamic principle of irreversibility. A flat heat pipe's efficiency can be maximized by designing it with least entropy production. This effort seeks to identify the flat heat pipe configuration that creates the least entropy given certain constraints on a number of factors. The maximum heat transmission rates achievable by a heat pipe are defined by these constraints. Brian Holley, et al, **[3]** presented By simulating a capillary wick with a continuously changing channel diameter, we investigate the potential for improving heat transfer in a pulsating heat pipe. The model is based on a one-dimensional slug-flow situation, where the momentum equation is solved for discrete slugs of liquid. A simulation's run can result in changes to both the total number of liquid slugs and their overall mass. Sejung Kim, et al, **[4]** investigated how changing the frequency of the pulsing heat pipe affected the temperature, pressure, and oscillatory flow of the vapour plug, as well as the latent and sensible heat transfer. There are regular and unpredictable swings in the temperature of the wall. The standard deviations are indicative of the random component, whereas amplitude and frequency are hallmarks of the periodic component. B.Y Tong, et al, **[5]** Closed-loop PHP used a charge-coupled device for flow visualization (CCD). It was discovered that the working fluid exhibited significant amplitude oscillations at beginning, but that it circulated once the machine reached a steady state of operation. Once circulation is established, the working fluid flows in a consistent direction during the experiment, albeit this direction may shift over time. W. Qu, et al, **[6]** studied the factors that have the greatest impact on the onset of a pulsating heat pipe's operation. Several factors, such as the wall's surface condition, the rate of evaporation in the heating section, the fluid's temperature, the bubble growth rate, and the presence of trapped vapour bubbles in the capillary's inner wall cavities, are found to influence the initiation of oscillating motion in the pulsating heat pipe. Rahul Royal. Sadey **[7]** Considering the growing need of maintaining stable temperatures in electronic components, their potential in both aerial and terrestrial missions has been investigated. Heat pipes, often circular in shape, transfer heat or cold from a central heating or cooling source to an adjacent, typically stationary, cooling system. M. Goodarzi, M. R. Safaei **[8]** to embedded computing and server-type applications are the most popular electrical use cases, with processor die sizes between 10 mm and 30 mm square, power dissipation between 15 W and 150 W, and so on. Due to the fact that the provided requirements may not be applicable in power electronics applications, just those parameters will be discussed. P. Charoensawan, S. Khandekar [9] A heat pipe is used to transfer heat from a high-temperature source to a low-temperature sink across a long distance with a negligible increase in temperature. Very little research has been done on the application of heat pipes in automobile engineering and manufacturing. J. S. Lee and C. J. Kim [10] The usage of a heat pipe allows for the long-distance, efficient transport of heat from a high-temperature source to a low-temperature sink. In spite of their potential benefits, heat pipes have received scant attention from academics and industry professionals in the field of car development and production.

3.0 METHODOLOGY

The heat pipe is one of the most significant technological feats of the twenty-first century, as it allows for the efficient transfer of heat over great distances with minimal loss. Heat pipes have the most potential to reduce energy consumption and carbon emissions. Heat pipes provide an effective thermal solution in applications involving high heat flux, non-uniform heat loading, limited airflow over heat-generating components, and space or weight constraints. The purpose of this chapter is to provide a brief overview of heat pipe technology and its key uses before discussing its passive thermal management features.

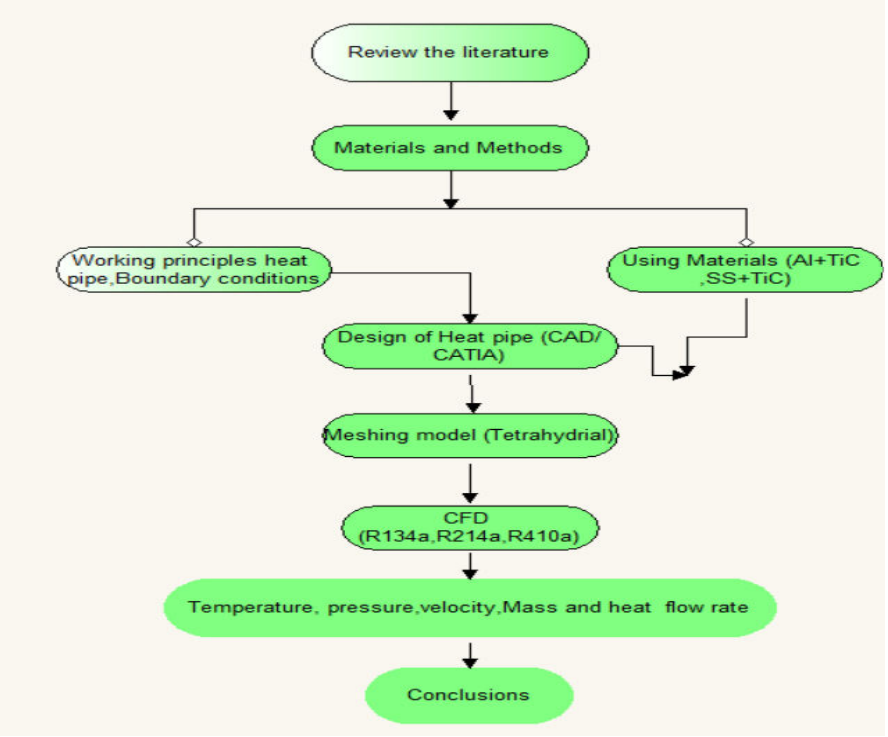

Figure 2: flow chart

COOLING CONDITIONS OF HEAT PIPE:

- The heat pipe's optimal operating temperatures are conditional on several parameters, such as pipe material, size, and coolant.
- As copper (a metal with a high heat conductivity) is used to make most heat pipes, even after it has become extremely hot, it will continue to transfer heat at a rate of around 1/80 of the original flux through the process of conducive convection.
- Heat pipes' optimum operating temperatures are conditional on a wide range of variables, including pipe material, pipe size, and coolant.
- As copper (a highly conductive metal) is used to make most heat pipes, even when it's hot beyond its design point, it will continue to transfer heat at a rate of about 1/8 as much as its initial flux through favorable radiation.

Working Principal of heat Pipe:

The conventional heat pipe is a mechanism for transferring heat that may transport significant thermal loads despite very modest temperature changes. After the tube has been thoroughly cleansed of any foreign matter, the working fluid is added until the wick structure is saturated. Saturation pressure in the pipe is proportional to the temperature in the pipe. Disruption of the equilibrium caused by the introduction of heat to the evaporator causes the generation of somewhat more pressurized and hotter steam. Due to its high pressure, the vapour travels up the tube and eventually condenses at the condenser, where its latent heat of vaporization is released. Because of the capillary processes in the wick, the condensed fluid is then propelled back to the evaporator.

HEAT PIPE DESIGN:

The process of constructing a heat pipe involves many factors. Material compatibility, operating temperature range, heat pipe length and diameter, power limitation, and operating orientation are all of the utmost importance. Yet, by zeroing in on copper/water heat pipes for electronic cooling, a number of design issues can be whittled down to a manageable minimum. In a heat exchange system, the heat pipe's efficiency is of paramount importance. The working fluid's temperature tolerance range is also an important consideration. The vessel material should be suitable for the working fluid in order to prevent corrosion or chemical reaction.

Fluid property Definition:

Density and viscosity, along with other fluid parameters, must be specified. The cell zones must be given complete boundary conditions. Nodes within each cell define the solution to the flow problem, which may include variables like temperature, velocity, pressure, etc. The number of cells in the grid and the grid's fineness control the precision of the CFD solution. Boiling Point -14.9°F or -26.1°C The viscosity of liquid R134a over the temperature range 235 to 343 K and pressures up to 50 MPa. R-214a, R410 has a boiling point of -61.9°F. R410A has a pressure of about 200 psi at normal temperature The solution, the solver in the numerical solution method, is built on three separate streams of information. You can choose from the finite element, finite volume, or finite difference approach. When comparing them, please pay attention to how they handle approximating flow variables and implement them based on them.

Operating Principle of heat pipe:

The copper heat pipe acts as a super-thermal conductor to transfer heat as it facilitates the evaporation and condensation of the working fluid. When the heat pipe's container tube is sealed at a low pressure, the working fluid is in a state of vapour equilibrium with itself. As the exterior of a heat pipe is heated, the working fluid at the surface boils and evaporates. Evaporating the SS+ TiC mixture releases the latent heat of vaporization, which is then absorbed by the SS+ TiC vapor. The excess vapor is transported to a low-temperature, low-pressure zone thanks to pressure gradients inside the heat pipe caused by the rapid evaporation at the surface. After passing through the pipe, the vapor cools down enough to turn back into a liquid, releasing the latent heat it had been holding onto. The heat pump condenser is the part responsible for cooling the incoming air. The cycle finishes after the condensed liquid has been sent back to the evaporator.

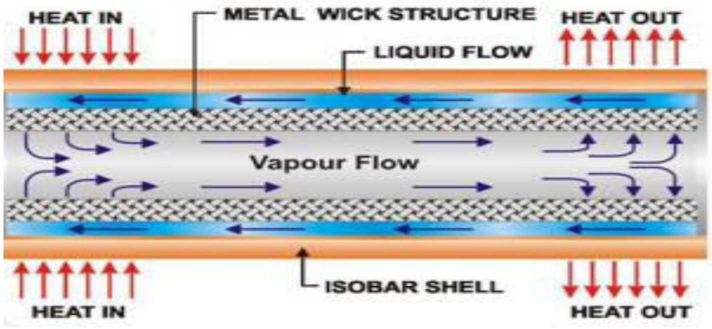

Figure 3: Operating Principle of heat pipe

Convection, radiation, and conduction all play roles in removing heat from the condenser's outer surface. To maintain a constant condensation or evaporation cycle, the heat pipe relies on a capillary pumping force created inside the wick structure that transports the working fluid and forth between the condenser and the evaporator. Heat pipes have a 99% efficiency rate of transfer.

CAD MODELING

Computer-aided design (CAD) refers to the practice of using computer systems to facilitate design-related activities like conceptualization, sketching, revision, and analysis, as well as optimization. CAD software is used to improve the designer's productivity, raise the standard of the design's configuration, smooth over communication breakdowns with thorough documentation, and create an assembly database.

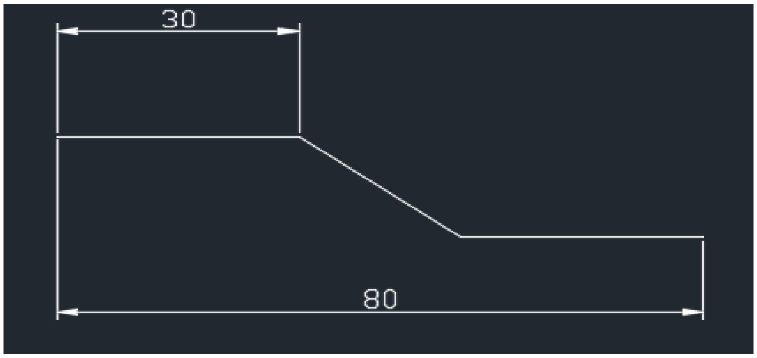

Figure 4: Layout of the lined tube

Two-dimensional shapes have been implemented in the aforementioned sketcher module, and it is now ready to receive commands from a third dimension.

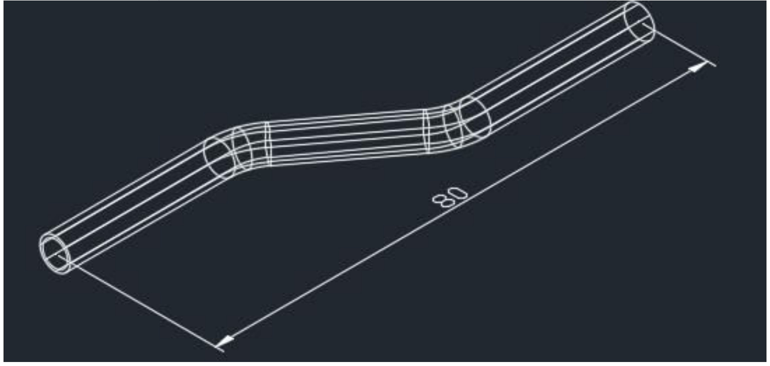

Figure 5: Layout Layer material deposition

Modulus is converting from 2D to 3D models. The STL drawing or three-dimensional depiction that the part modeling Module of NC programs provides is a significant advantage for the program's developer.

Table 1: Mesh object properties definition table for finite mesh

Length X	0.08 m
Length Y	0.0273m
Length Z	0.005m
Volume	$1.746\text{x}10^{-6}\,\text{m}^3$
Nodes	14011
Elements	53157
Analysis Type	3-D

Experimental model:

Tube design: CATIA V5 R20 was used for the tube's 3D modeling, and then the model was exported to the IGES file format so that it could be imported into ANSYS and simulated.

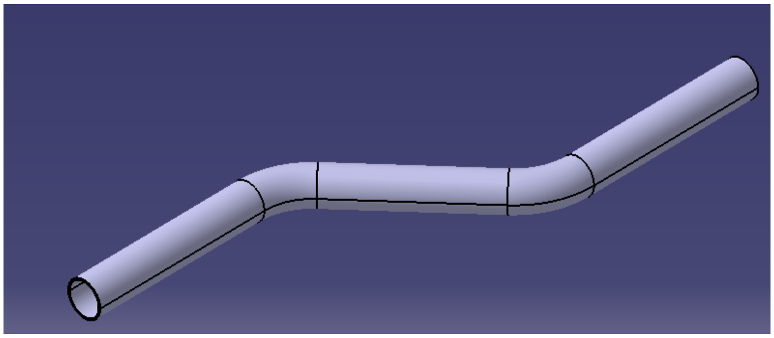

Figure 6: IGES model for ANSYS conversion in CATIA

Explain that the study was thorough by handing over the module to the ANSYS environment. The data in the aforementioned tables allowed for the development of illustrative graphics and useful components.

BOUNDARY CONDITIONS

- The boundary conditions are defined as. The heat flux is very high because the walls are too thin.
- To set up the mass transfer Then, clicking on edit, the saturation temperature, which is the temperature that the liquid starts to turn to vapor and the vapor to liquid, is defined as 35 °C (308 K) (273+35) at a pressure of Pa.

The boundary conditions are introduced to ANSYS. Named selections should be created during the meshing to facilitate this step. After clicking on “Boundary Conditions” a window pops up. The following should be given as inputs.

- Outer evaporator wall: constant heat flux
- Outer condenser wall: convection
- Adiabatic section: zero heat flux
- Inlet: Velocity inlet with a constant velocity of 4 m/s.

Cell Zone Conditions:

- On this section the vacuum inside the pipe is introduced. Clicking on “Cell Zone Conditions” and then on “Operating Conditions” set the “Operating Pressure” as 101325 Pa (0.1 MPa)

K-EPSILON TURBULENCE MODEL:

- K-epsilon (k-ε) turbulence model is the most common model used in Computational Fluid Dynamics (CFD) to simulate mean flow characteristics for turbulent flow conditions.
- the K-epsilon model was to improve the mixing length model, as well as to find an alternative to algebraically prescribing turbulent length scales in moderate to high complexity flows. K-ε model focuses on the mechanisms that affect the turbulent kinetic energy.

4.0 RESULTS AND DISCUSSIONS

In a heat pipe, heat is delivered from the hot end to the cold end with a minimum temperature difference. Metal tubes the size of a pencil conduct heat from one end to the other without the need for a pump. In a heat pipe, fluid vaporizes at the hot end, moves to the slightly cooler end, condenses and then returns to the hot end via a capillary wick.

- Next, click mesh in the left side of the graphic window, select mesh size, and click update.
- The fluent launcher pops up when you double click on set up. Click OK to open the fluent window.
- In solution setup, go to general and select check and report quality. ANSYS now checks the geometry and reports orthogonal quality and aspect ratio.
- Go to models > energy > edit > select on > OK
- Click material: select the fluid or solid material from the fluent database or enter the material manually using the create/edit buttons
- Select cell zone conditions (solid/fluid) and specify them
- To specify boundary conditions, select boundary conditions

PROPERTIES OF FLUENT MATERIALS:

Aluminum+ TIC and stainless steel+ TIC is employed as heat pipe materials, and R134a, R214a, and R410a are the working fluids that are analyzed.

Aluminum+ TIC with R134a fluid

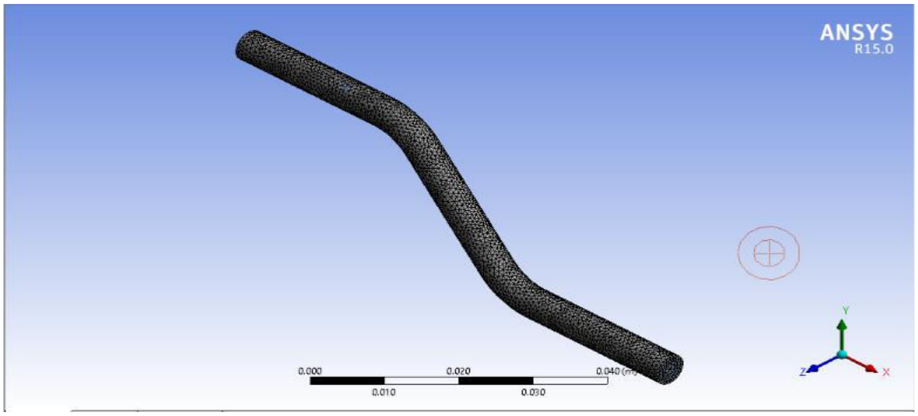

Figure 7: Meshing of the object Aluminum+ TIC

The above diagram illustrates the fluid-like meshing of Aluminum+ TIC R134a. The meshing process is carried out in a way that ensures the pipe experiences uniform load distribution throughout the process, leading to maximum deformation.

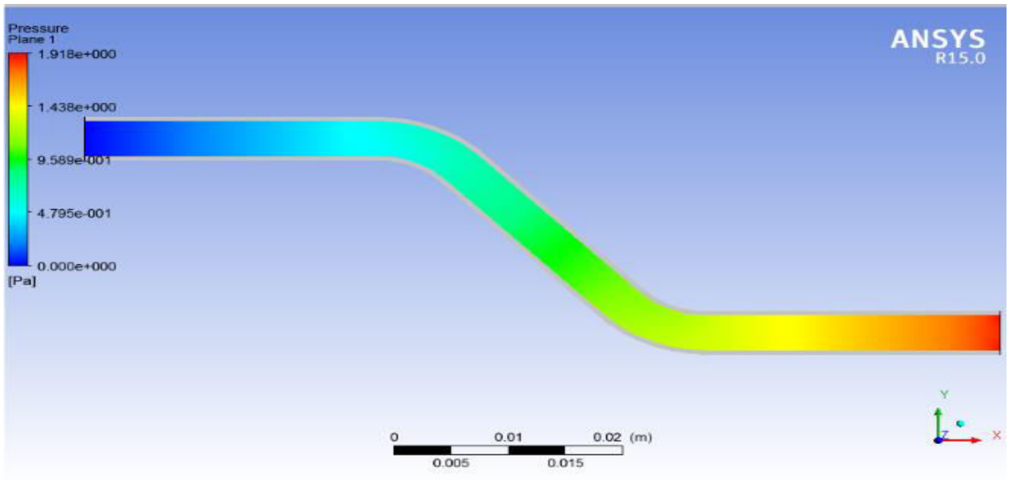

Figure 8: Pressure flow along Aluminum+ TIC tube

The following figure describes the flow of pressure inside of an Aluminum+ Tic tube. The pressure gradient and its fluctuations along the tube can be easily identified.

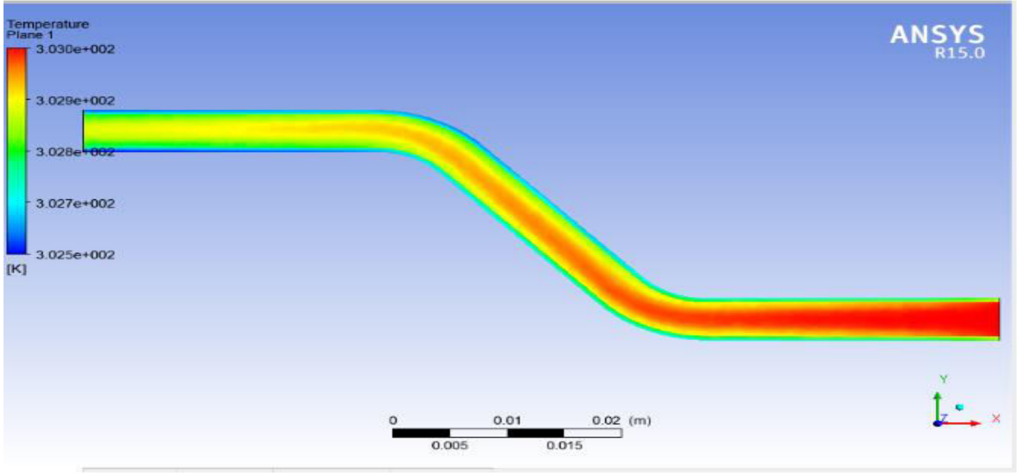

Figure 9: Temperature inlet vector of Aluminum+ TiC tube

Intake temperature via an Aluminum + TiC tube is seen in the above diagram. The temperature is seen to fluctuate at several points and during the flow.

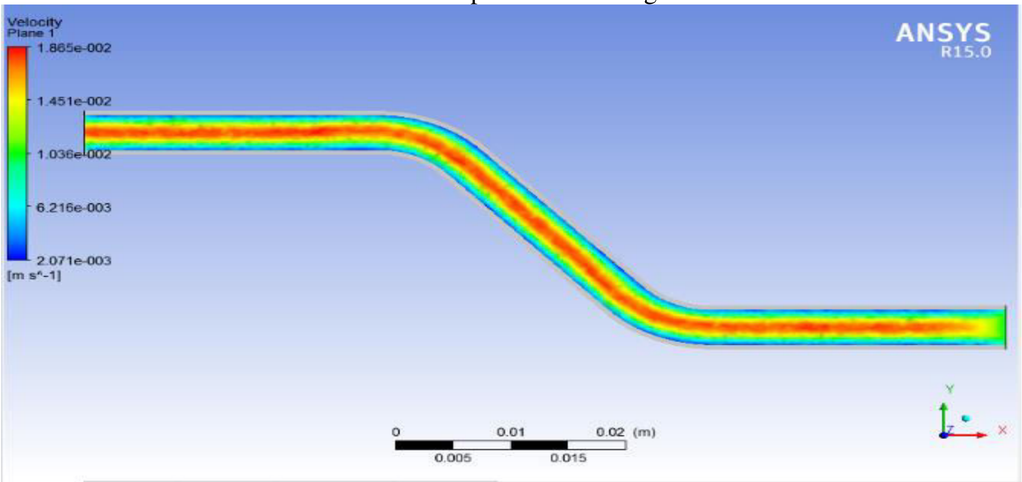

Figure 10: Velocity flow of fluid along Aluminum + Tic tube

Here is a graphic showing the rate at which R134a fluid flows through an Aluminum +TiC tube. Throughout the flow, the velocity is consistent and varies throughout.

Aluminum+ Tic and R214a Fluid:

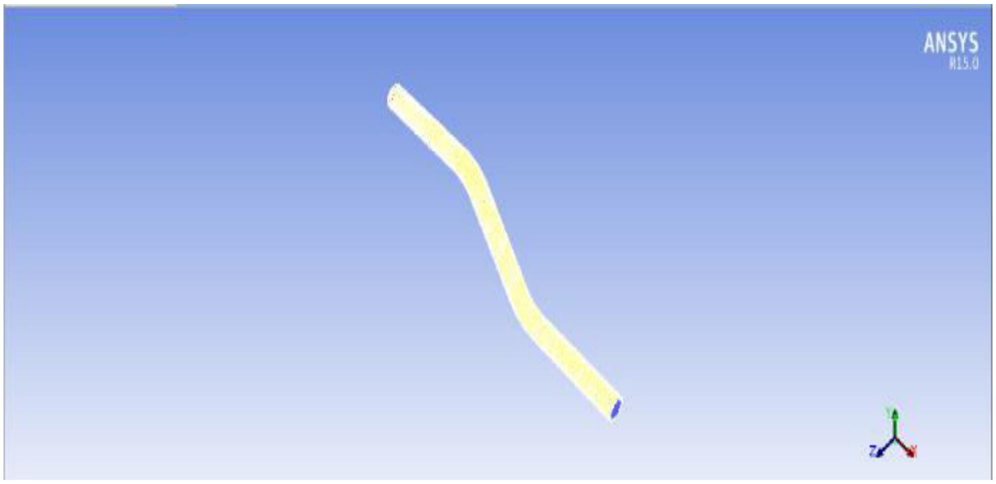

Figure 11: Meshing of Aluminum+ Tic tube

In the image above, Aluminum+ Tic and R214a Fluid have been meshed together. Mesh deformation completely deforms the pipe by distributing the weight over its cross-section.

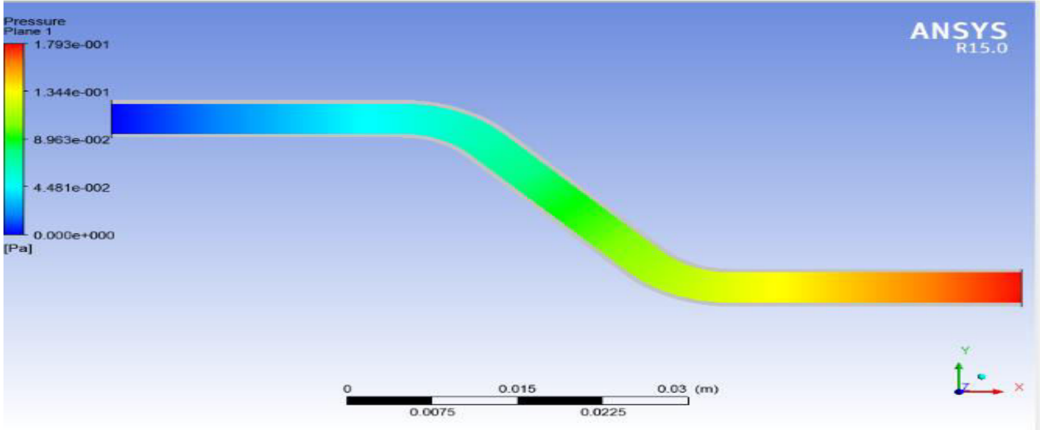

Figure 12: Pressure inlet along x-direction in Aluminum+ Tic tube

This figure shows the flow of pressure along the Aluminum+ Tic tube. The pressure and flow of the tube can be observed.

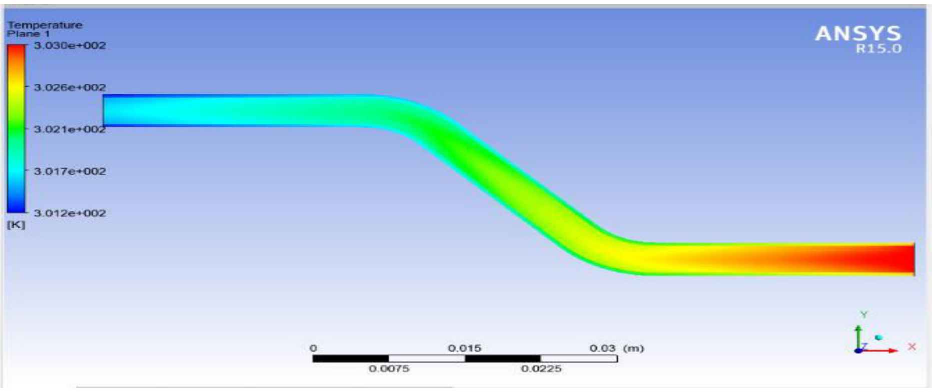

Figure 13: Temperature inlet along x-direction Aluminum+ Tic tube

Temperature inlet R214a fluid along an Aluminum+Tic tube is depicted above. As the flow progresses, the temperature at various points varies and increases.

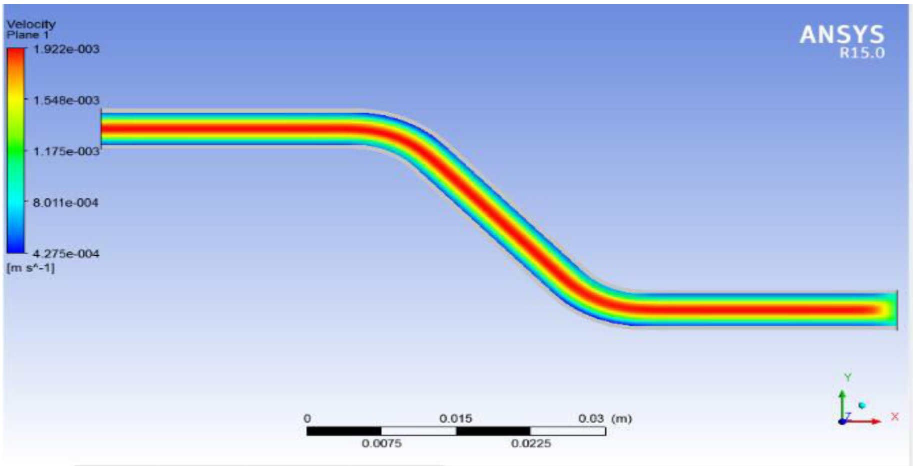

Figure 14: Continuous Velocity along x-direction in Aluminum+ Tic tube

The above diagram depicts the results of a velocity investigation of R214a fluid inside an Aluminum+ TIC tube. In normal conditions, the flow's velocities are uniform along its length and throughout its depths

Heat pipe material Aluminum+ Tic with R410a Fluid:

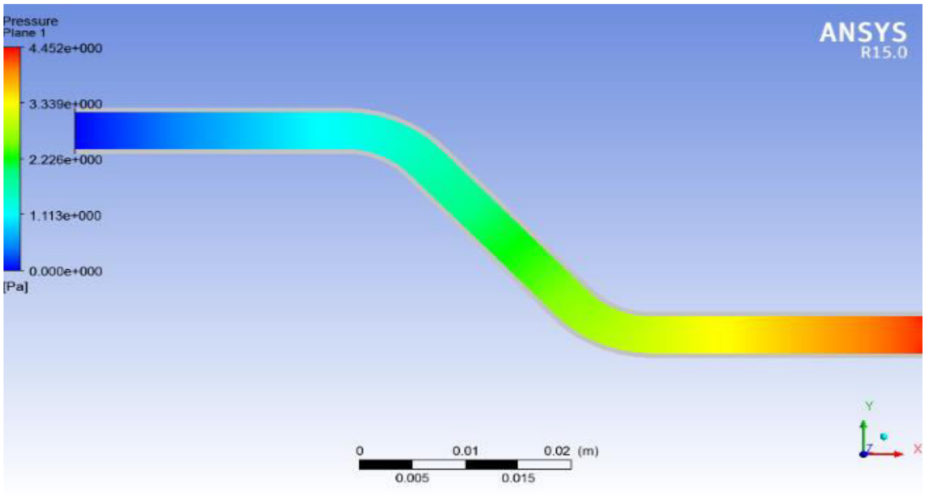

Figure 15: Pressure inlet along x-direction in Aluminum+ Tic tube

Aluminum+ Tic with R410a as fluid is shown in the above figure. During pressure inlet, the load is distributed equally on the pipe.

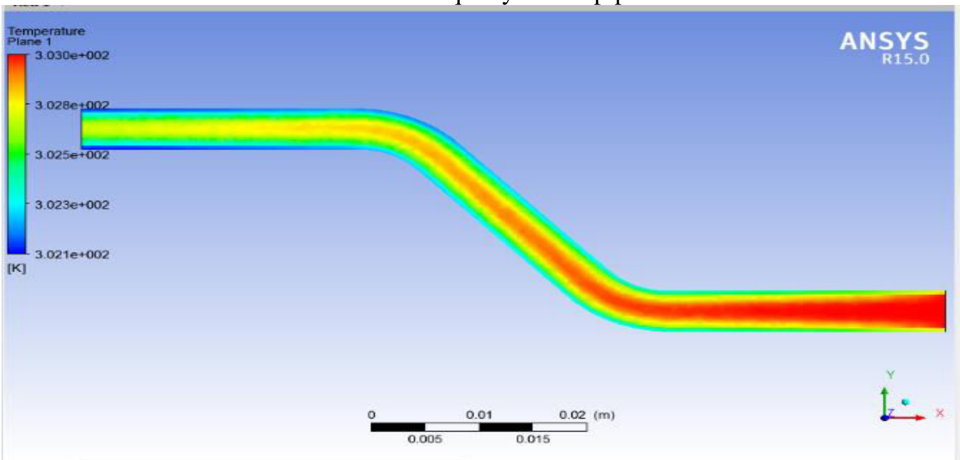

Figure 16: Temperature inlet along x-direction in Aluminum+ Tic tube

According to the above figure, the temperature vector of R410a varies during the flow and is different at each section of the Aluminum+Tic tube.

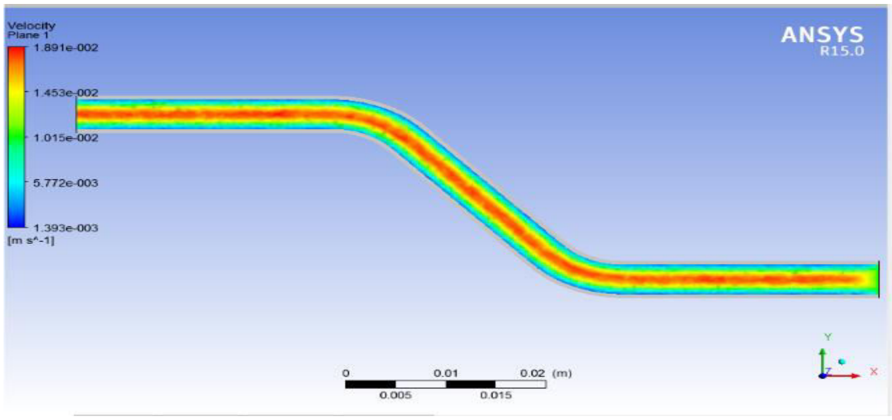

Figure 17: Velocity inlet along x-direction in Aluminum+ Tic tube

The figure above depicts the speed of R410a flowing through the Aluminum+ Tic tube. The velocity is constant throughout the flow and varies at different points in this scenario.

SS+TIC with R134a Fluid:

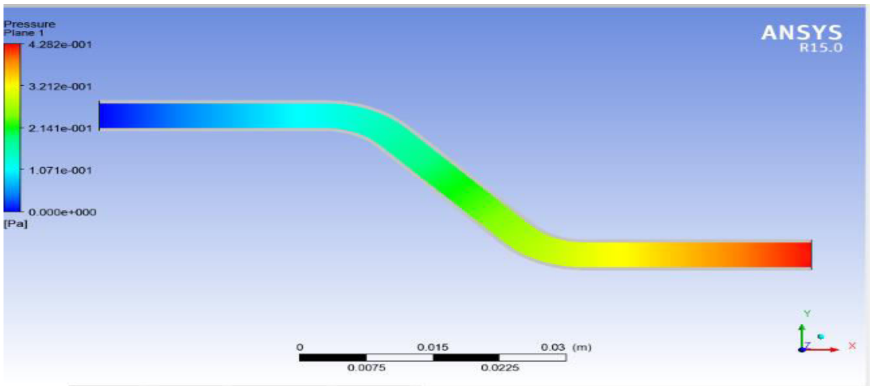

Figure 18: Maximum pressure inlet x- direction in SS+TIC tube

This figure shows the SS+TIC with R134a as the fluid. A maximum inlet pressure of 4.282e-001 N/m2 is obtained by distributing the load equally on the pipe during pressure inlet.

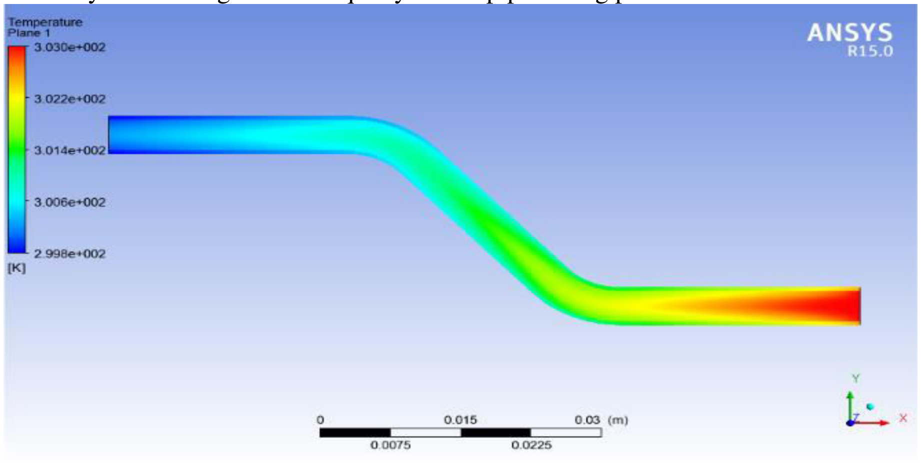

Figure 19: The temperature contours and flow x-direction in SS+TIC tube

The above figure shows the counter flow of the temperature in SS+TIC which is having R134a as fluid and maximum temperature.

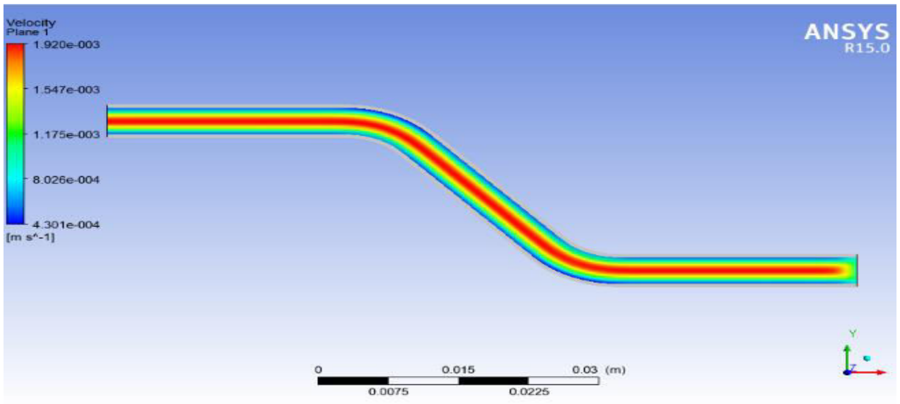

Figure 20: Continuous velocity flow x-direction in SS+TIC tube

The above diagram depicts a steady flow of R134a through an SS+TIC tube at a maximum velocity of 1302 m/s.

SS+TIC with R214a Fluid:

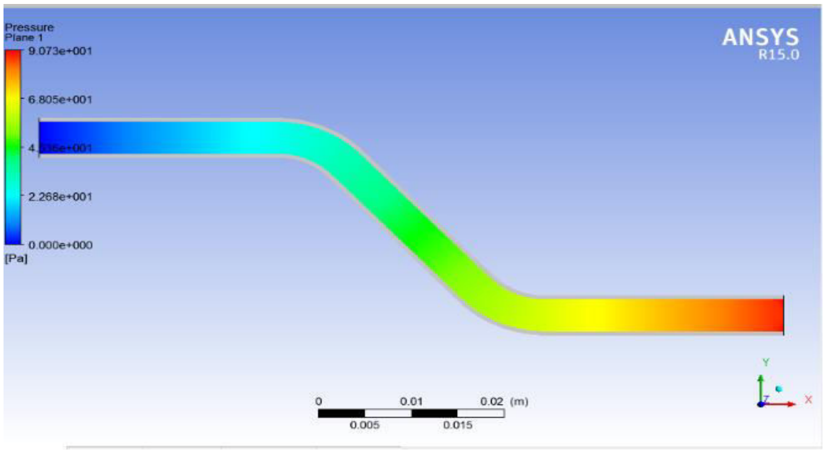

Figure 21: Pressure input SS+TIC tube in x-direction

Pressure differences along the SS+TIC tube is seen in this diagram. The pressure gradient and pressure changes along the tube are clearly visible.

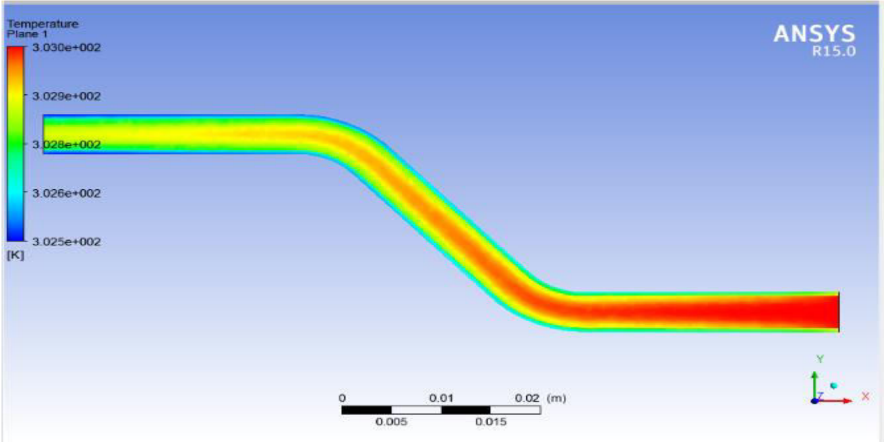

Figure 22: Temperature variations of SS+TIC Tube in x- direction

Temperature inlet R214a along the SS+TIC tube is illustrated above. It has been noted that the velocity of the current varies at different points and changes as it flows.

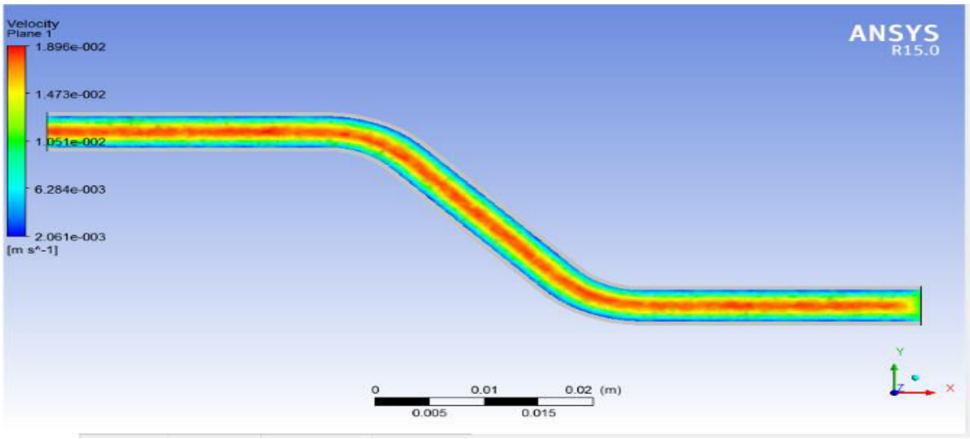

Figure 23: Velocity flow along x- direction in R214a along the SS+TIC tube

R214a along the SS+TIC tube it is can observed that velocity is equal during the flow and varying at all sections.

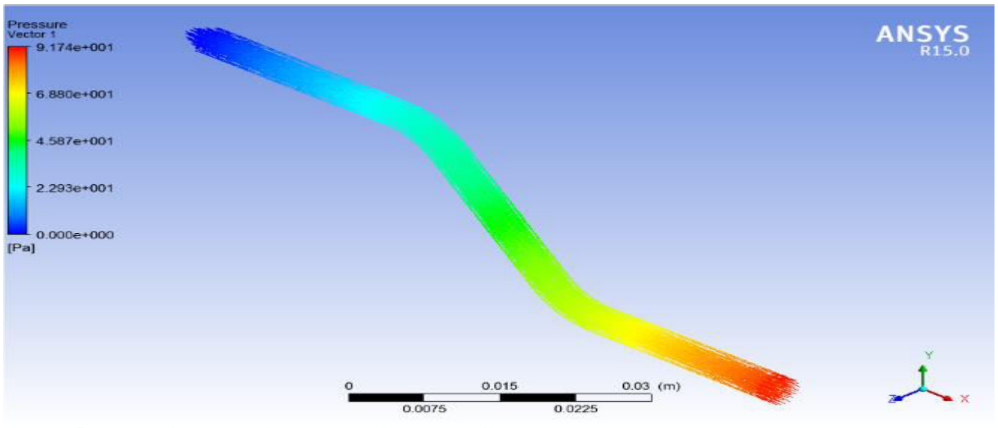

Figure 24: Pressure flow in SS+TIC tube in x- direction

The above diagram depicts the pressure flow of R214a along the SS+TIC tube. It has been determined that the velocity is constant throughout the flow and in all segments.

SS+TIC with R410a Fluid:

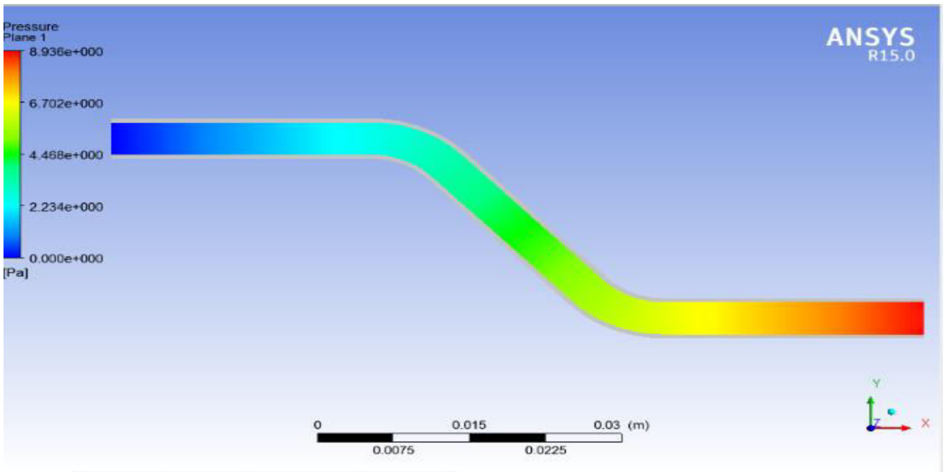

Figure 25: Pressure flow in x-direction in SS+TIC tube

With R410a, the SS+TIC is depicted in the above picture. This is done to ensure that the highest possible inlet pressure is achieved while the strain on the pipe is kept as low as possible.

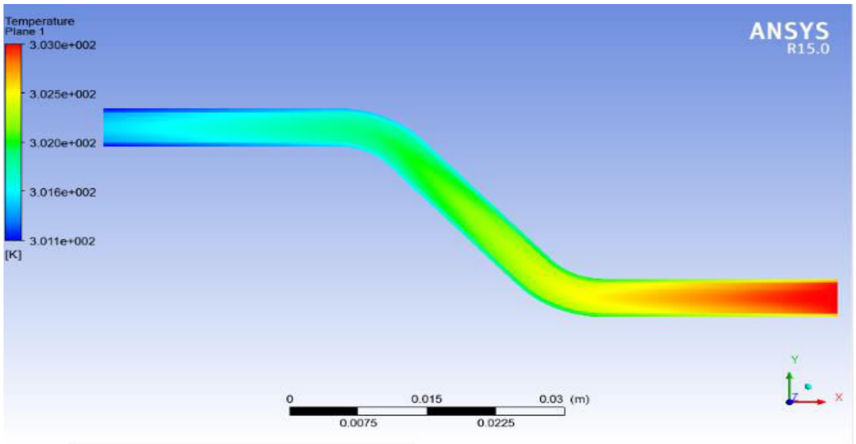

Figure 26: Temperature flow in x-direction in SS+TIC tube

The maximum temperature and reverse temperature flow in a system with R410a as the fluid are shown in the figure above.

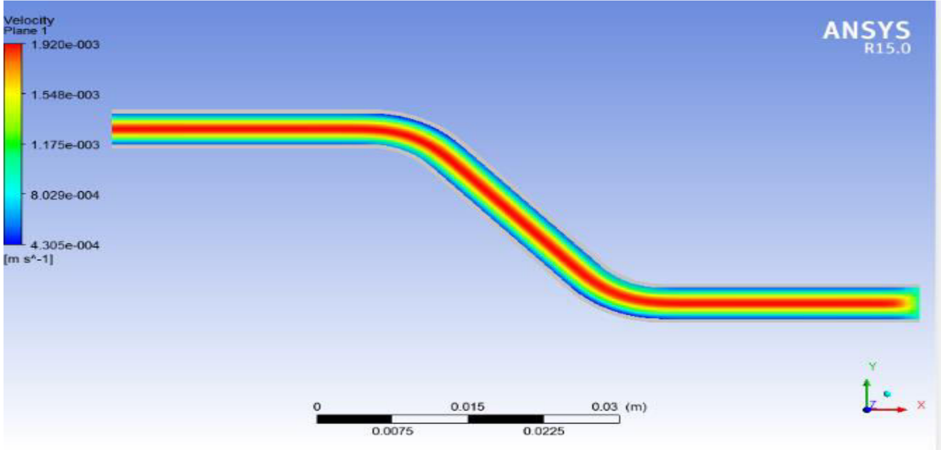

Figure 27: Continuous velocity in x-direction in SS+TIC tube

The above illustration depicts the flow of R410a through an SS+TIC tube at a constant velocity.

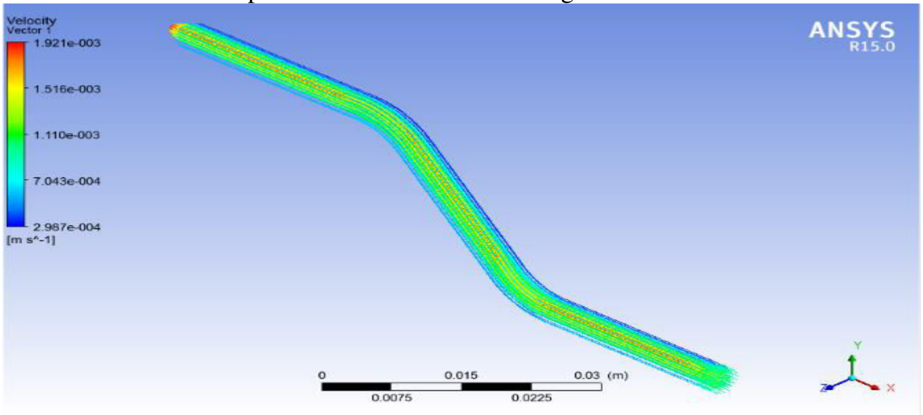

Figure 28: Velocity vectors in x-direction in SS+TIC tube

R410a's velocity vector in the SS+TIC tube is depicted in the image above. Throughout the flow, it is seen that all sections possess the same velocity.

Table 2: Maximum Input and Output Temperatures

S. No	Material	Type of fluid	Maximum temperature input [K]	Outlet Temperature[K]

1	AL+TIC	R134a	303	301
2	AL+TIC	R214a	303	302
3	AL+TIC	R410a	303	302
4	SS+TIC	R134a	303	301
5	SS+TIC	R214a	303	302
6	SS+TIC	R410a	303	302

TABLE 3: CFD ANALYSIS OF HEAT PIPE USING R134A

PARAMETERS	**Al+ TIC**	**SS+TIC**
PRESSURE **[Pa]**	1.91	4.28
VELOCITY **[m/sec]**	1.86	1.92
TEMPERATURE [K]	3.03	3.03
PRESSURE STREAM LINE **[Pa]**	1.91	4.29
VELOCITY STREAM LINE **[m/sec]**	1.78	1.91
TEMPERATURE STREAM LINE [K]	3.03	3.03

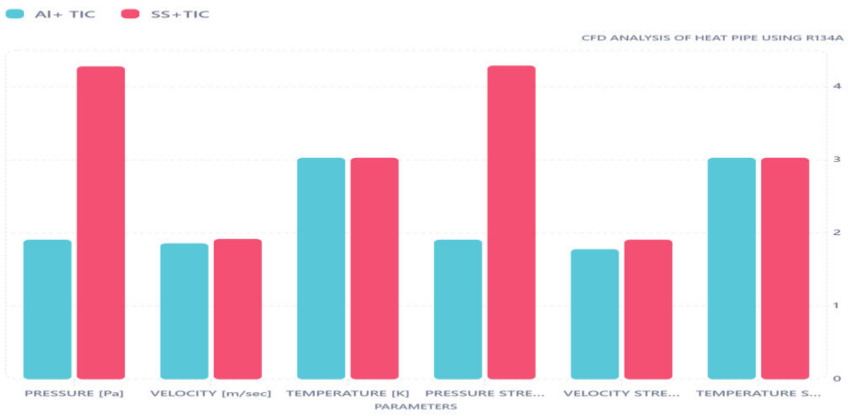

Figure 29: Validation of Heat pipe fluid R134 a with different materials

TABLE 4: CFD ANALYSIS OF HEAT PIPE USING R214 A

PARAMETERS	Al+ TIC	**SS+TIC**
PRESSURE **[Pa]**	1.79	9.07
VELOCITY **[m/sec]**	1.92	1.89
TEMPERATURE [K]	3.03	3.03

PRESSURE STREAM LINE **[Pa]**	1.79	9.11
VELOCITY STREAM LINE **[m/sec]**	1.92	1.8
TEMPERATURE STREAM LINE [K]	3.03	3.03

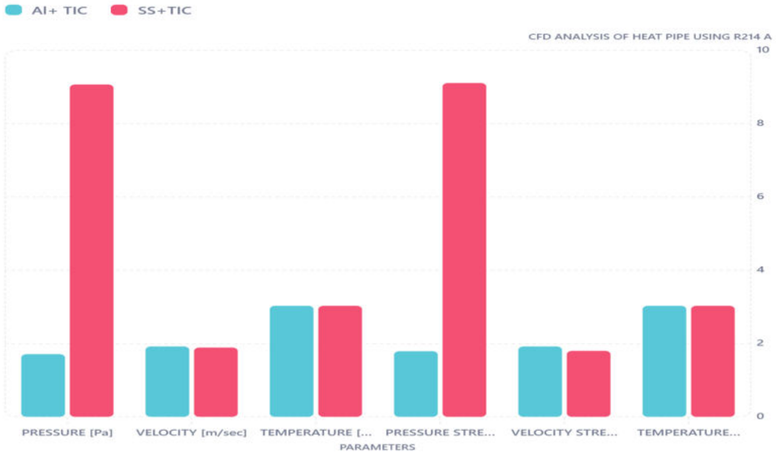

Figure 30: Validation of Heat pipe fluid R214 a with different materials

TABLE 5: CFD ANALYSIS OF HEAT PIPE USING R410 A

PARAMETERS	**Al+ TIC**	**SS+TIC**
PRESSURE **[Pa]**	4.45	8.93
VELOCITY **[m/sec]**	1.89	1.92
TEMPERATURE [K]	3.03	3.03
PRESSURE STREAM LINE **[Pa]**	4.41	8.96
VELOCITY STREAM LINE **[m/sec]**	1.79	1.91
TEMPERATURE STREAM LINE [K]	3.03	3.03

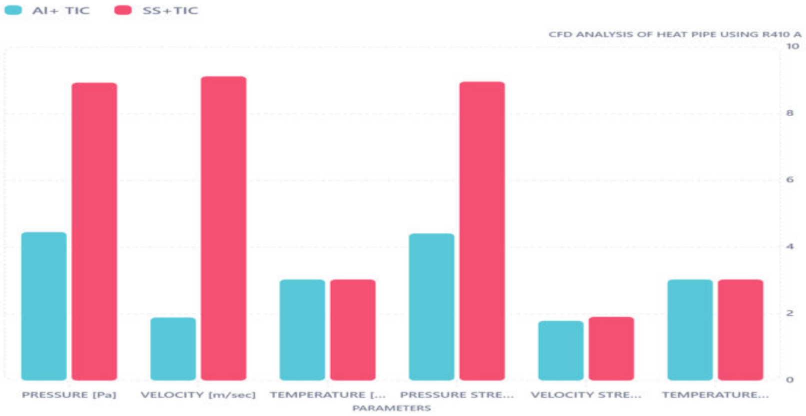

Figure 31: Validation of Heat pipe fluid R410 a with different materials

In the above tabular form, Al+ TiC and SS+TIC maximum intake and output temperatures are displayed for various fluids such as R134a, R214, and R410. All situations have a constant maximum input temperature, while the outlet temperature varies.

CONCLUSION

A heat pipe is a thermomechanical device used to maintain a stable internal temperature in places with a high concentration of electronic components, such as spacecraft, satellites, and other similar structures. Data collected indicate that using multiple evaporators instead of only one increases the efficiency of removing heat from the heating element. Due to the added benefit of removing the fluid's temperature, In the next stage of the propose to change to R134a from R410. As a result, multiple cooling systems supplied with R134a fluid can be used in a configuration that increases a heat pipe's heat transmission rate. Continuous motility of fluids and variations in temperature have been seen in both materials. Al+TiC and SS+Tic materials have been extensively evaluated for various fluids, and the comments are being taken into account for future interface geometry applications.

Finally concluded that in this fluid analysis to determine the heat transfer, pressure drop, mass flow rate, and heat transfer coefficient observed that above results R134a fluid is better than to other fluids (R214a, R410a) and R134a is also a non-flammable, non-toxic fluid with good thermal properties, making it an ideal fluid for refrigeration and cooling applications. Its low viscosity allows it to be more easily pumped, making it more efficient.

REFERENCES:

1. Rahul Royal. Sadey Fabrication and Analysis Of Heat Pipe International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 Vol. 2 Issue 4, April – 2013
2. M. Goodarzi, M. R. Safaei, H. F. Oztop et al., “Numerical study of entropy generation due to coupled laminar and turbulent mixed convection and thermal radiation in an enclosure filled with a semitransparent medium,” The Scientific World Journal, vol. 2014, Article ID 761745, 8 pages, 2014
3. P. Charoensawan, S. Khandekar, M. Groll and P. Terdtoon, ‘Closed loop pulsating heat pipes-Part A: parametric experimental investigations’, Applied Thermal Engineering, 23(16) (2003), 2009–2020
4. T. Kiatsiriroat, A. Nuntaphan and J. Tiansuwan, ‘Thermal performance enhancement of thermosyphon heat pipe with binary working fluids’, Experimental Heat Transfer, 13(2) (2000), 137–152
5. J. S. Lee and C. J. Kim, ‘Heat transfer and internal flow characteristics of a coil-inserted rotating heat pipe’, International Journal of Heat and Mass Transfer, 44(18) (2001), 3543–3551
6. F. J. R. Martinez, M.A.A.-G., Plasencia, E.V. Gomez, F. V. Diez and R. H. Martin, ‘Design and experimental study of mixed energy recovery system, heat pipes and indirect evaporative equipment for air conditioning’, Energy and Buildings, 35(10) (2003), 1021–1030
7. M. J. Rightley, C. P. Tigges, R. C. Givler, C. V. Robino, J. J Mulhall and P. M. Smith ‘Innovative wick design for multi-source, flat plate heat pipes’, Microelectronic Journal, 34(3) (2003), 187–194
8. V. Maziuk, A. Kulakov, M. Rabetsky and L. Vasiliev, ‘Miniature heat pipe thermal performance prediction tool-software development’, Applied Thermal Engineering, 21(5) (2001), 559–571.
9. Xiangdong Liu, Yongping Chen, Mingheng Shi, Dynamic performance analysis on startup of closed-loop pulsating heat pipes, International Journal of Thermal Sciences 65 (2013) 224-233
10. Brian Holley, Amir Faghri, Analysis of pulsating heat pipe with capillary wick and varying channel diameter, Analysis of pulsating heat pipe with capillary wick and varying channel diameter, International Journal of Heat and Mass Transfer 48 (2005) 2635–2651