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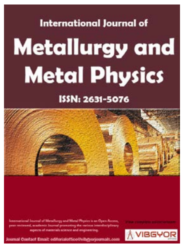
A Fundamental Study on Physical Properties of Optimized Sintered Wick Structured Heat Pipe Using Computational Fluid Dynamics Analysis Method



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Abstract

This paper reports the evaluation of physical properties for optimized sintered wick structured heat pipe. The structural design of the heat pipe was executed using CATIA V5 computer aided design software. Upon designing, finite element analysis conducted to evaluate performance of heat pipe were evaluated using ANSYS R19 computer aided manufacturing software. The physical properties of heat pipe evaluated according to physical parameters such as Temperature, Pressure and Velocity. The results obtained achieved the objectives. A low cost solution identified for the problem stated.

Keywords

Heat transfer, Physical properties, Finite element method, Computational fluid dynamics

Introduction

Introduction to aluminium and heat pipe

Aluminium Alloy has highly opted for structural applications. 7075 grade has been a mutual choice of raw material selection for heavy-duty manufacturing sectors and construction industries. The advantages are low density, highest tensile strength, ductile and huge fatigue resistant [1].

Heat pipes known as passive equipment. It affords the capacity to transform heat efficiently from one point to another with minimum scale in temperature. A heat pipe is a "double phase" heat transfer mechanism with extremely huge "effective" thermal conductivity. A thin walled pipe with an internal wick structure allows boiling and condensing to occur within the pipe resulting in heat transfer from the hot end to the cooled end [2] Figure 1.0.

Wick structure

It is a porous structure made of materials like steel, aluminium, nickel or copper in various ranges of porous sizes. The prime purpose of the wick is to generate capillary pressure to transport the working fluid from the condenser to the evaporator. It must also be able to distribute the liquid around the evaporator section at any area where heat is likely to be received by the heat pipe [2] Figure 1.1.

Literature Review

Simulation and CFD analysis of heat pipe with different wick geometry using CFX

Miniature cylindrical metal powder sintered wick heat pipe (sintered heat pipe) undoubtedly a unique component with extreme thermal efficiency for high heat flux electronics cooling. This paper reports about Heat pipe designed using Wick ge-

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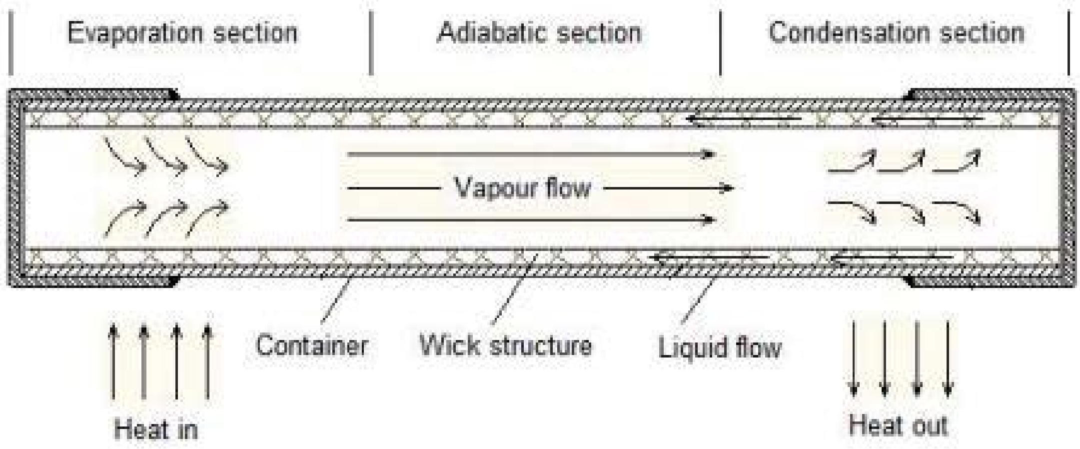

Figure 1.0: Shows the cross-section of heat pipe [2].

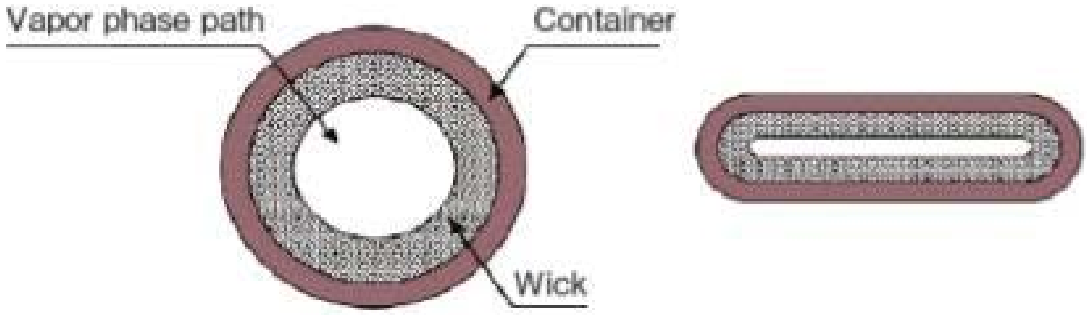

Figure 1.1: Shows the fundamental sintered wick structure design heat pipe [2].

ometry 0.5 mm, 0.75 mm, 1 mm. The shapes involved are Sintered, V- Groove, and Screen Groove.

For the Heat pipe, the material chosen was silica material. Furthermore, nickel alloy nisil (nickel + silicon) applied as a wick material. Water, Methanol, Aqueous Methanol applied as working fluids. Numerical evaluations accomplished using CFX (the CFD solver program).

Results provided in graphical representation. Main objective of this research is to study the difference between temperature gradient vs. heat transfer coefficient with different wick's, wick shapes and different working fluids [3] Figure 1.2.

CFD analysis of axially wicked heat pipe

Compared with conventional heat pipes, huge heat transfer rates with improved cooling possibly achieved by Axial Wicked Heat Pipes (AWHP). This exists due to increase in heat transfer area. Experiments conducted to examine the effect of variation in heat input and inclination angle during performance of AWHP. SS304 opted as the material for container and water as the working fluid for AWHP. Interior phase of the outer pipe covered with single layer of screen mesh wick. Surface and vapour temperatures were determined for various heat inputs and inclination angles at steady state conditions and isothermal characteristics of AWHP considering uniform heating application identified. Results proves that increase in heat input, the vapor temperature difference between the evaporator and condenser section decreases for all inclination angles of AWHP. The temperature difference between the evaporator and condenser end in axial direction is the least for vertical position of AWHP at all levels of heat input. This depicts the isothermal characteristic of concentric annular heat pipe. Thermal resistance decreased possibly due to enhancement in nucleate boiling activity and this improved the heat transfer with increase in heat input. Least thermal resistance found at vertical position of AWHP [4].

Problem Statement and Objectives

Problem statement

Producing an optimized heat pipe prototype

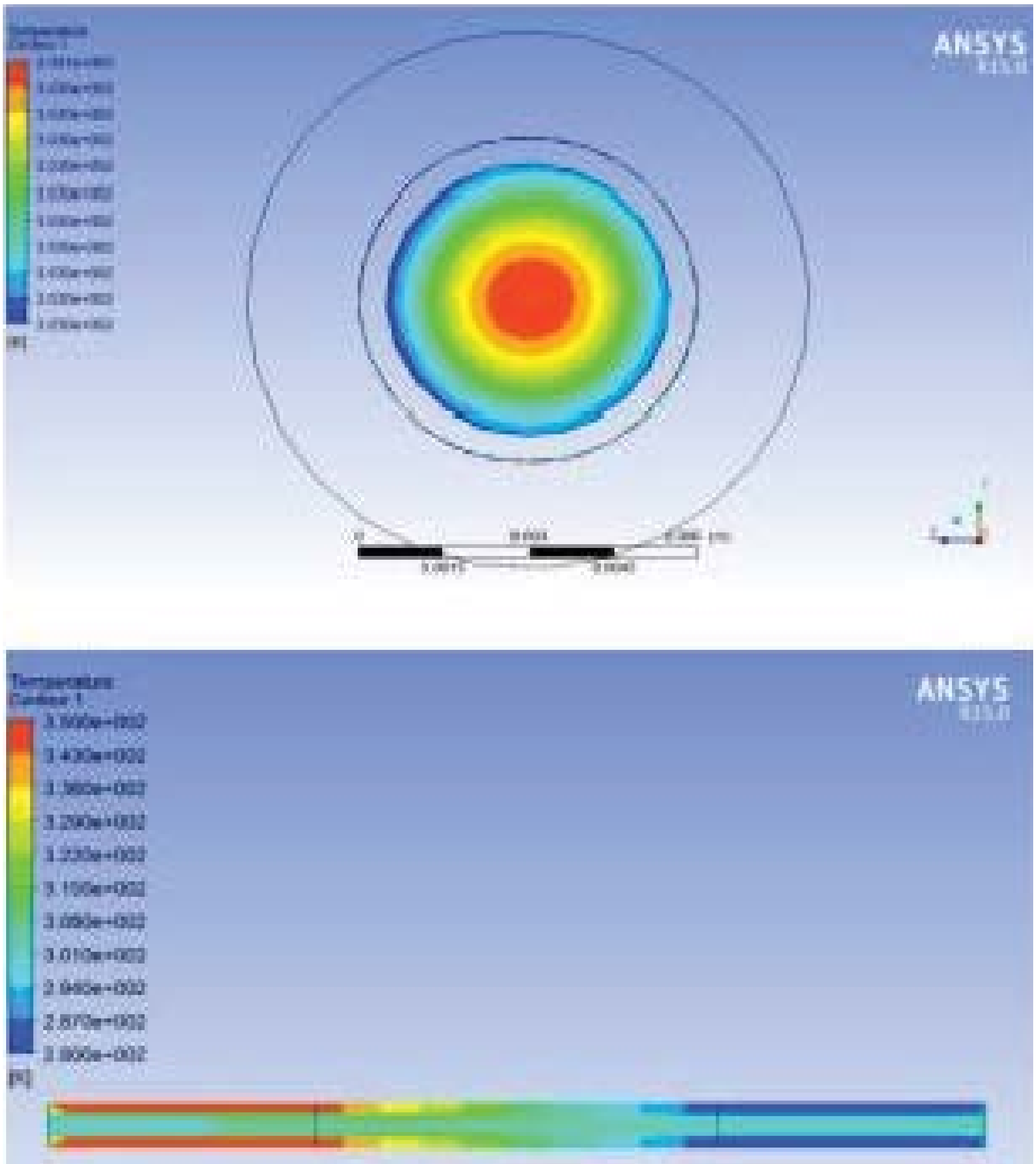

Figure 1.2: Contours of sintered wick heat pipe using CFD method [3].

Figure 1.3: Reference of 3-Dimensional basic sintered wicked heat pipe [3].

conventionally leads to high cost in terms of fabrication and features installation. Conventional testing method to analyze the physical properties turns challenging to obtain accurate and precise results in short period according to finite element method.

Research objectives

i. To design an optimized sintered wicked 3-Dimensional heat pipe using CAD Software.

ii. To analyze the physical properties of the designed heat pipe using finite element method with simulation software to prevent from spending huge cost.

iii. To conduct simulation study the impacts of physical properties such as Temperature, Pressure and Velocity of the optimized heat pipe.

Methodology

Design of sintered wicked heat pipe

To achieve the first objective, an optimized sintered wicked heat pipe designed using CatiaV5 software. Figure 1.3 was referred to design. The designed heat pipe consist numerous chamfers and curves due to ensure a smooth flow of fluid and pressure Table 1.0, Figure 1.4 and Figure 1.5.

Chronology of finite element analysis

To achieve the second objective, finite element analysis conducted using ANSYS R19 software. Flu-

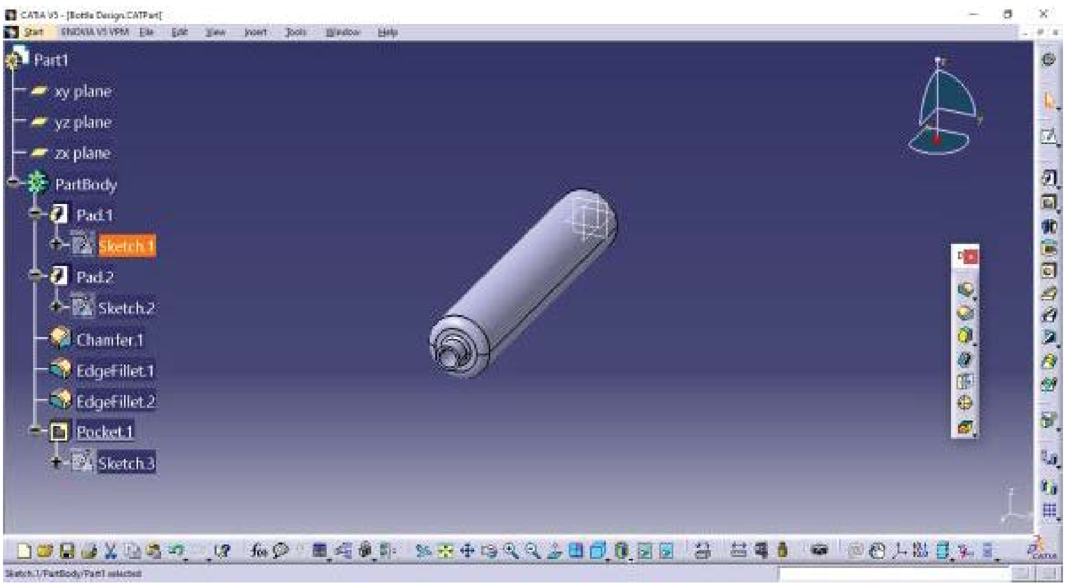

Figure 1.4: Isometric view of optimized sintered wick heat pipe.

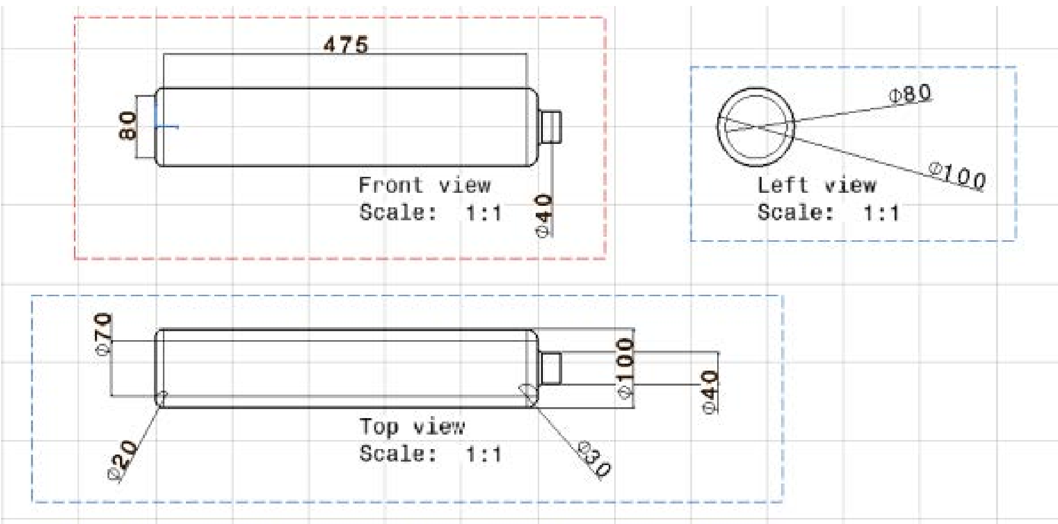

Figure 1.5: 3-Dimensional views of designed heat pipe.

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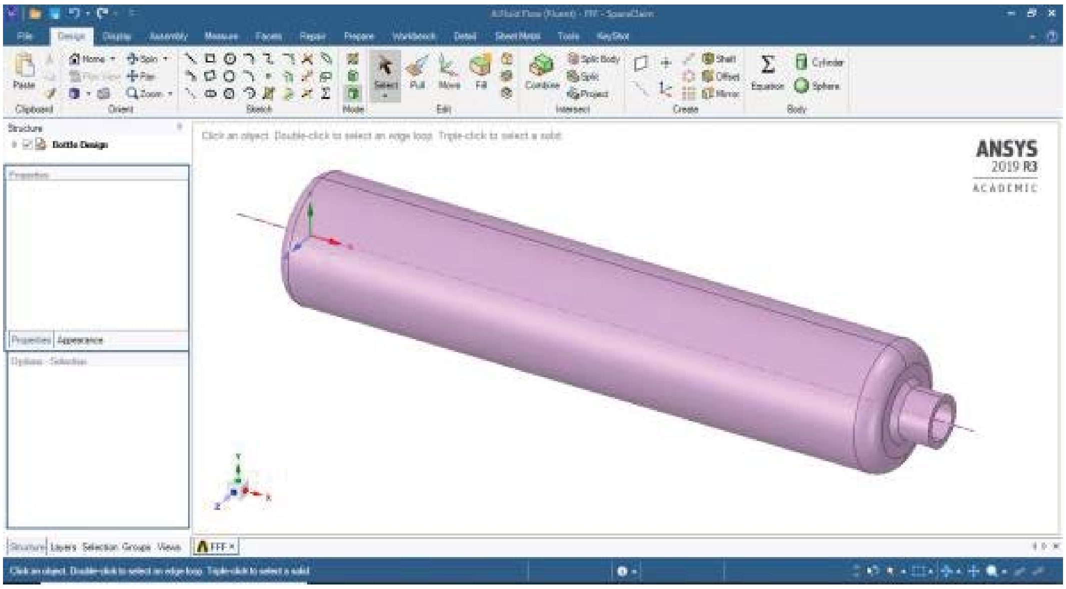

Figure 1.6: Heat pipe design in geometry database.

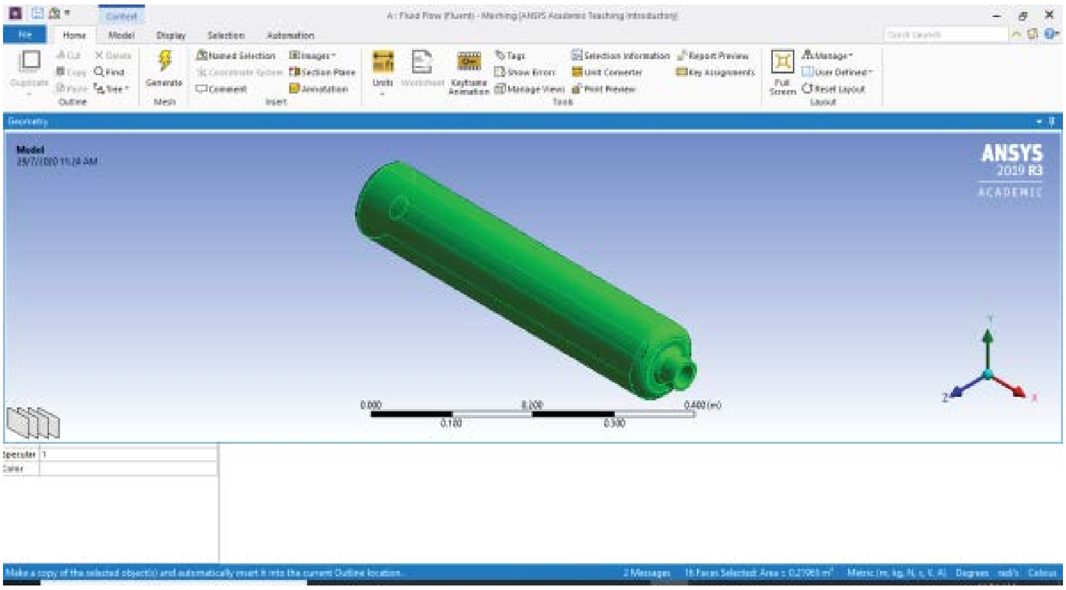

Figure 1.7: Surface capturing and labelling at mesh database.

Table 1.0: Tabulation of dimensions for designed sintered heat pipe.

Parameters	**Dimensions**
Total length	530 mm
Total thickness	100 mm
Inlet diameter	40 mm
External diameter	60 mm
Wick thickness	5 mm

ent analysis method chosen to proceed the analysis.

Initially, the design were loaded in the geometry database. Upon loading, the data updated Figure 1.6.

Table 1.1: Tabulation of specifications for heat pipe.

Material name	**Aluminium**
Applied density	2719 kg/m^3
Applied specific heat	1871 J/kg-k
Applied thermal conductivity	100 °C/373 K

Meshing process generated to capture entire elements involved in evaluation. In prior of meshing, the elements were labelled as Inlet and Surface Figure 1.7.

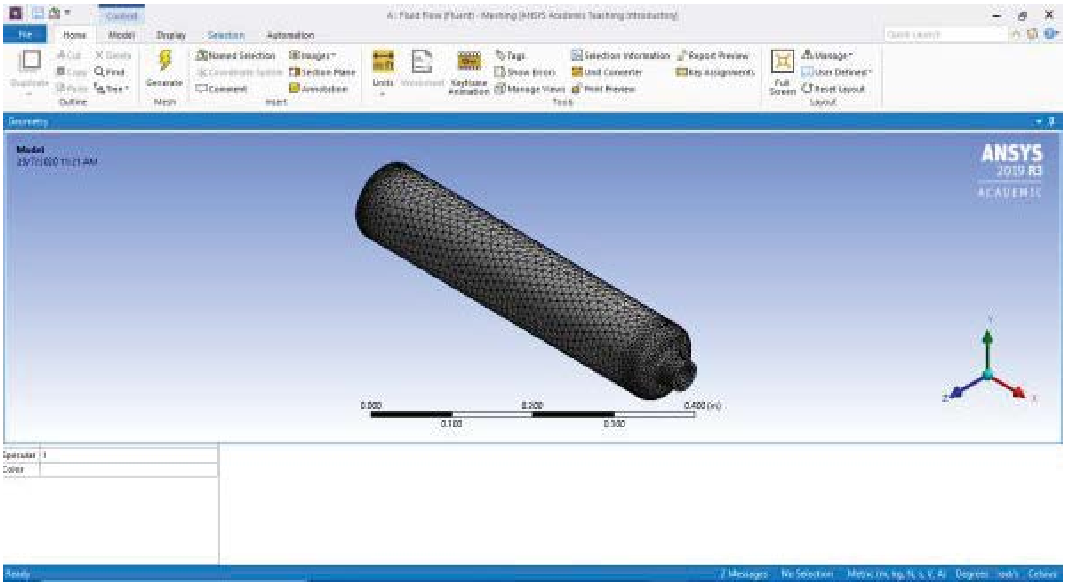

Figure 1.8: Meshing process successful.

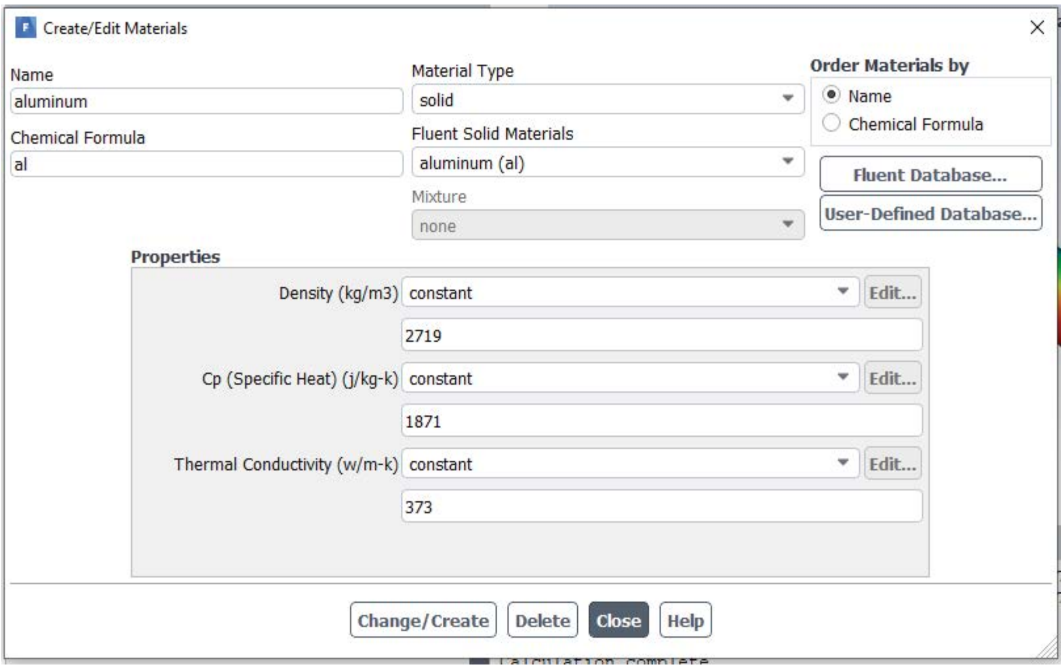

Figure 1.9: Database of Create/Edit materials with specifications for heat pipe surface.

Table 1.2: Tabulation of applied specifications for fluid properties.

Material type	Fluid
Applied density	1500 kg/m^3
Applied specific heat	1006.43 J/kg-k
Applied thermal conductivity	2.0242 w/m-k
Applied viscosity	Constant

Table 1.3: Tabulation of specifications for external wall surface of heat pipe.

Surface	Wall
Applied temperature	100 °C/373 K
Wall thickness	0.01 m

Table 1.4: Tabulation of maximum temperature at Inlet.

Surface	Velocity Inlet
Max temperature	300 °C/573 K

Meshing process successfully accomplished whereby entire finite elements are captured and eligible for evaluation Figure 1.8.

At setup database, Energy icon activated. At create and edit materials icon selected the desired materials for the applied geometry design. Aluminum (al) was selected. Converted the material type to solid and followed by filling the properties column according to given data Table 1.1, Table 1.2, Table 1.3, Table 1.4, Table 1.5, Figure 1.9, Figure 2.0, Figure 2.1, Figure 2.2 and Figure 2.3.

Analysis method

Upon completion of data applications, proceeded to solution process to evaluate. Determined the level of iterations at 480 to evaluate the computational fluid dynamics solutions. As per increase in iterations well noticed the changes occurs in simulation of graph during the calculations in progress. As the calculations accomplished, clicked the contours icon to view the 3-Dimensional results upon simulation. Selected the named surfaces and click Save/Display to obtain the output Figure 2.4.

Results and Discussion

Velocity impact in heat pipe

According to my third research objective, the analysis conducted to test the thermal characteristics of heat pipe Figure 2.5. The velocity rate at 100 m/s has resulted as per Figure 2.6 below. From observation, I noticed that concentration of heat is high at the bottom surface known as Evaporation section. The simulation result at vapour phase path is reddish contour at evaporation section and finally changes into blue at the condensing section.

Therefore, it's understood that the velocity applied at the bottom vapour phase path increased the pressure of hot air at the evaporation section and performs the heat distribution slowly from evaporation stage to medium cooled stage at adiabatic section which is green contour and finally to blue contour at condensing section.

Finally, the blue contour states that the hot fluid has become cold as per the role of heat pipe Figure 2.5 and Figure 2.6.

Pressure impact in heat pipe

As per observation from Figure 2.7, the overall pressure contour concludes that, the heat is uniformly distributed. Because the contour at evaporation section is green and slowly turns, light blue at adiabatic section and finally becomes dark blue contour at the condensing section.

As the surface area of container is larger compared to vapour phase path, the air particles col-

Table 1.5: Tabulation of applied velocity at Inlet.

Surface	Inlet
Velocity magnitude	100 m/s

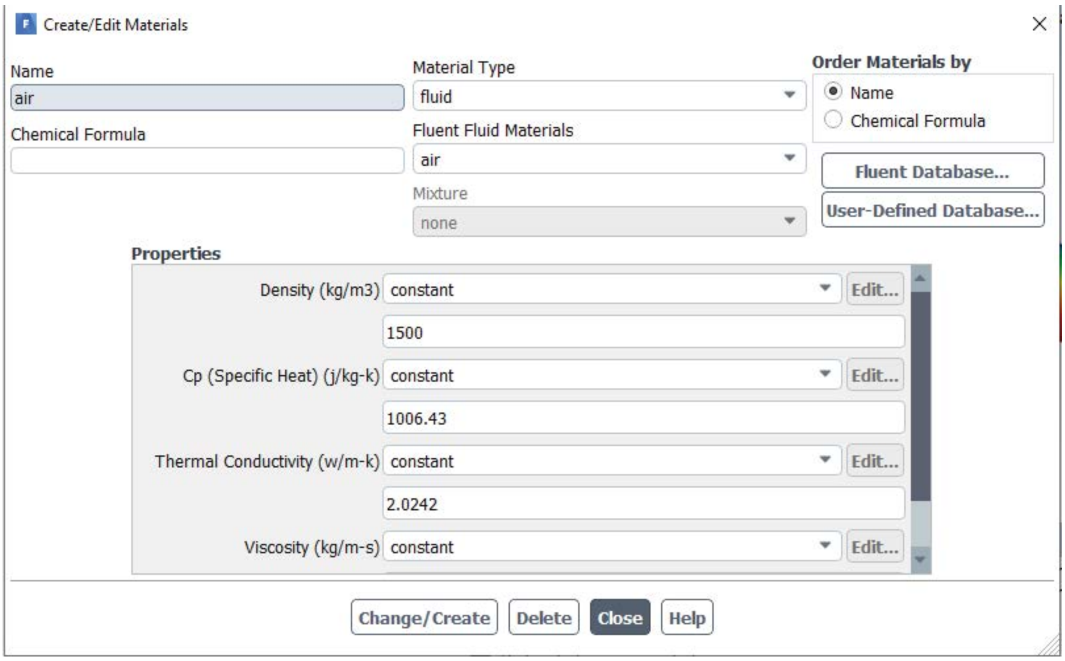

Figure 2.0: Database of Create/Edit materials with specifications for fluid.

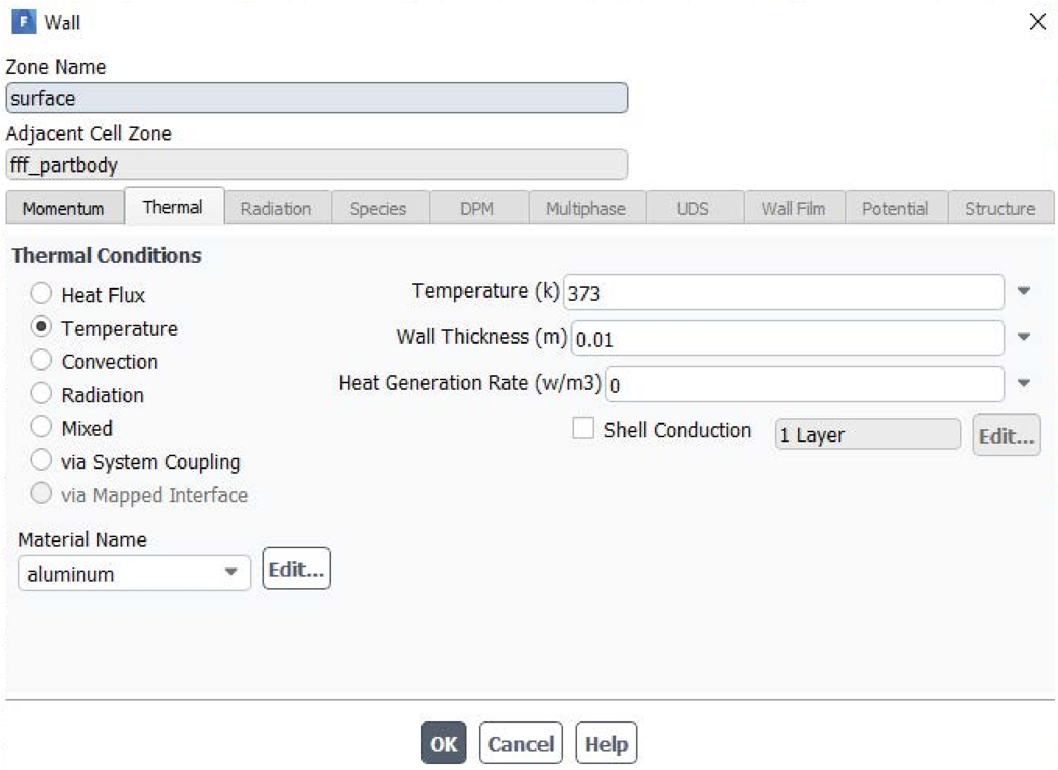

Figure 2.1: Database of Create/Edit materials with specifications for external wall.

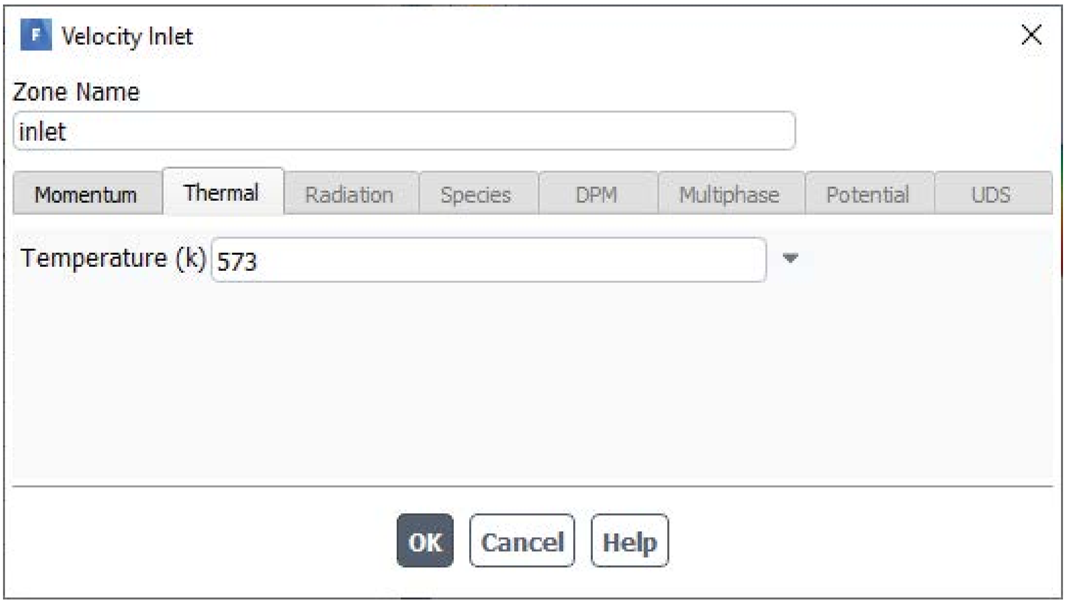

Figure 2.2: Database of velocity Inlet.

lides smoothly. This shows the atmosphere is warm at the interior surface of container even though the vapour path is still hot.

As the pressure level is not harmful, it prevents the structure from cracking or fractured Figure 2.7.

Temperature distribution in heat pipe

According to temperature distribution analysis in Figure 2.8, the heat pipe has successfully transferred the hot vapour to condensed fluid. The statement a thin walled pipe with an internal wick structure allows boiling and condensing to occur within the pipe resulting in heat transfer from the hot end to the cooled end proved again in this simulation [2,5].

The distribution of heat is smooth as witnessed

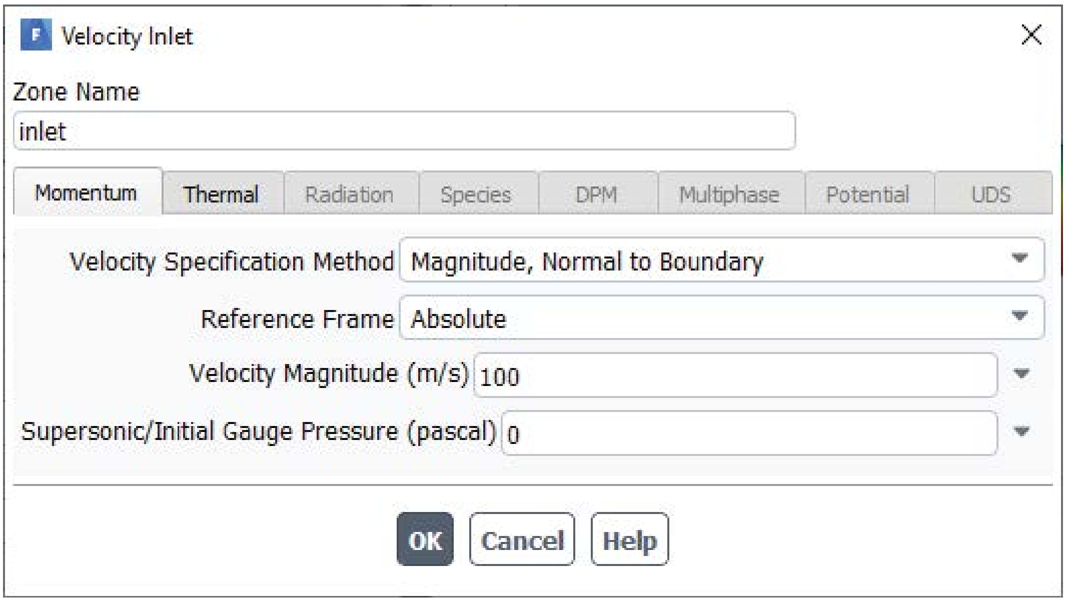

Figure 2.3: Database of Inlet.

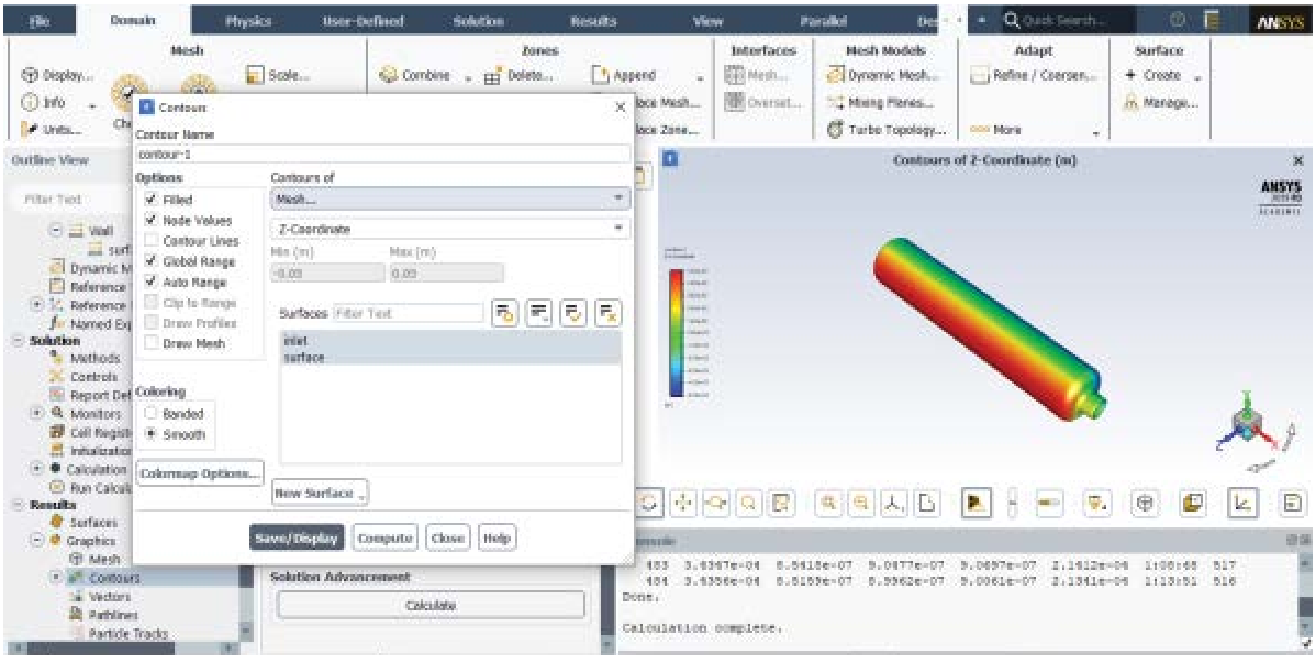

Figure 2.4: Result of mesh contour upon analysis.

clearly. It shows the vapour phase path carries good thermal conductivity, which results in good thermal efficiency.

The adiabatic process turns successful, by compressing the heat at adiabatic section and convert it to condensed air turned fluid. Aluminium material been a right choice for the pipe construction due to prove its tendency to withstand the applied temperatures from 100 °C/373 K until 300 °C/573 K.

Conclusion

Predominantly, I would confidently mention that the research objectives achieved without any technical flaw. Computational Fluid Dynamics (CFD) method to conduct Finite Element Analysis turned successful. Results obtained for optimized heat pipe are according to standard specifications and parameters. Through the results, I witnessed that the tendency of physical properties such as

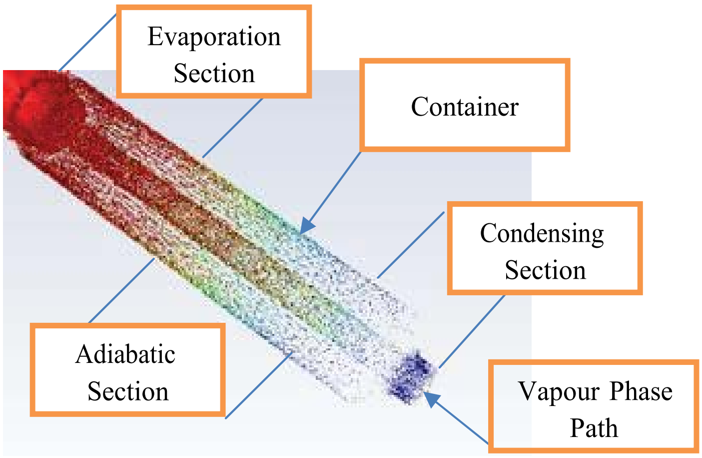

Figure 2.5: Shows the cross-section of resultant heat pipe [2].

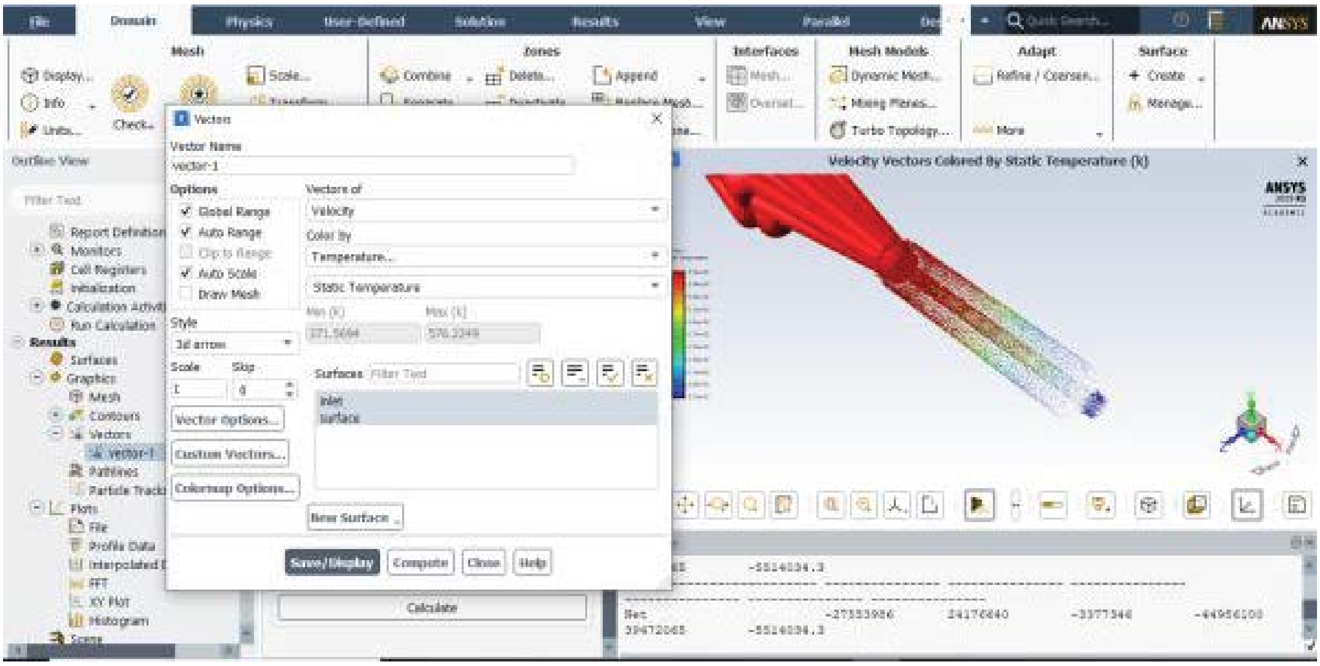

Figure 2.6: Contour result of applied velocity rate.

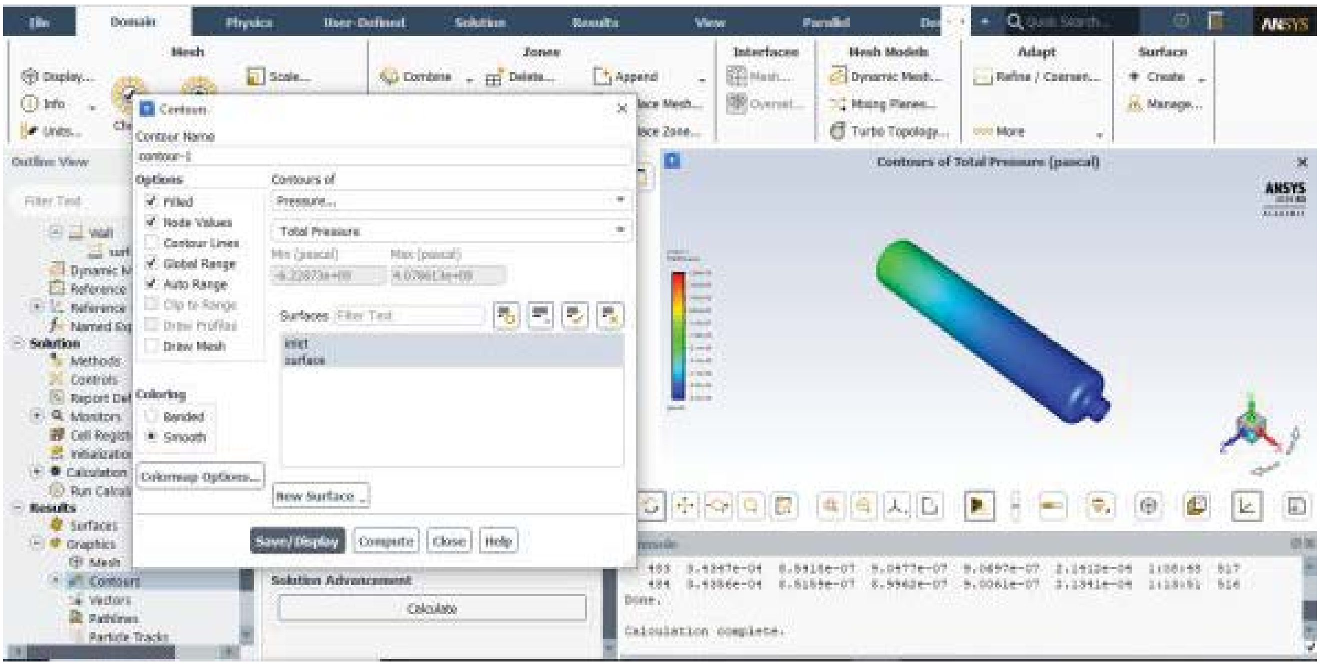

Figure 2.7: Contour result of pressure flow in heat pipe.

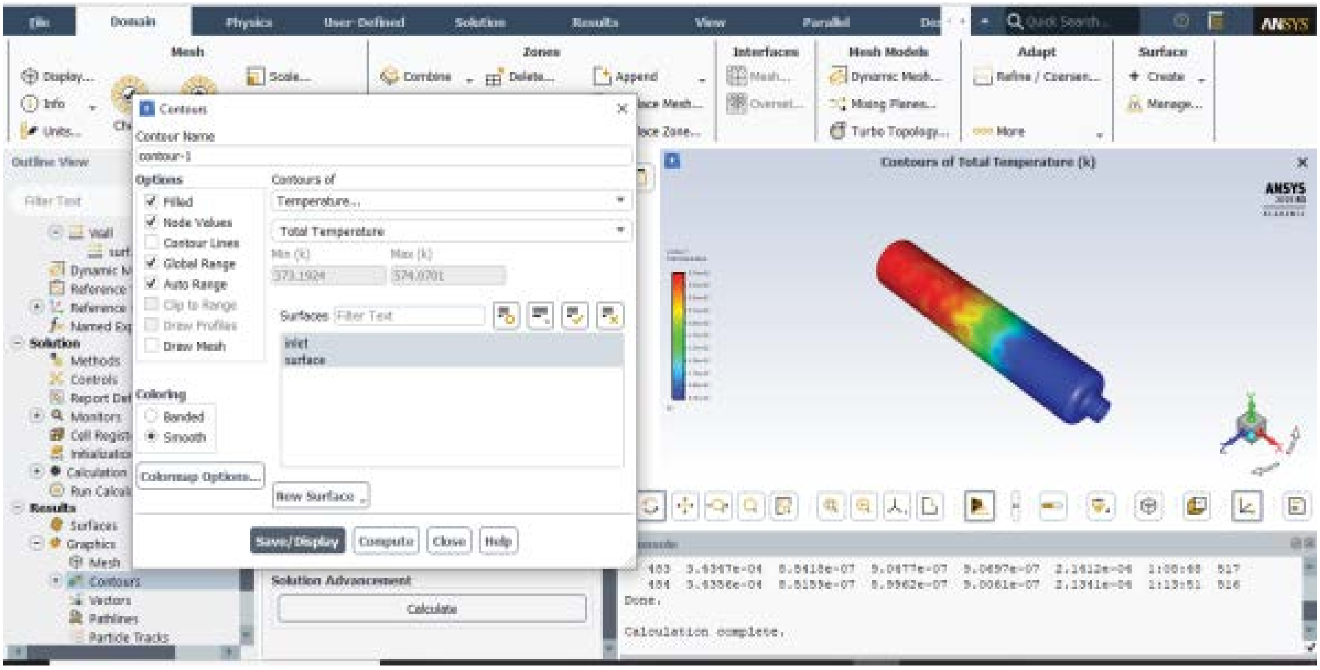

Figure 2.8: Contour result of temperature distribution in heat pipe.

Temperature, Pressure and Velocity precisely evaluated in numerical values using CFD method. The references in literature reviews helped more in conducting the methodology. The output of simulations proved that CFD simulations are unique and reliable to explain the performance of prototypes applies thermodynamics theories and applications.

To conclude my research, I endorse that heat pipe is unique invention to learn thermal characteristics of a heat transfer mechanisms. The effect of core elements during heat transfer such as conduction, convection and condensation are well investigative, through simulations of heat pipe under different conditions. These measures provides more advantages to improve the sustainability of a heat pipes in future with more added features.

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