Abstract

The latest engineering equipment is increasingly focused on energy transitions that require the rapid transfer of heat. Consequently, there is a growing demand for heat transfer appliances that offer a low cost, a smaller size, and still deliver a high level of performance. It is essential to investigate the performance of these appliances or equipment, as well as the heat transfer rates of these appliances or equipment, in different thermal environments. In addition to the fact that these appliances are used in airplanes, spacecraft, vehicles, nuclear reactors, and many other places. With the use of heat exchangers, the heat energy is exchanged from the hot fluid to the cold fluid simultaneously at a maximum efficiency rate and the minimum operating costs. To design and do a prediction of the performance of a heat exchanger, it is necessary to be able to correlate the total heat transfer to the design parameters of the exchanger. These factors are the overall surface area, the temperature of the inlet and outlet fluid temperatures in the pipe, and the overall heat transfer coefficient of the pipe.

During this project, the stress and thermal analysis of the heat exchanger pipe were performed. In this case, the temperature and heat distribution, rate of thermal conductivity, and properties of the steel materials were all taken into account in order to determine the temperatures and heat distribution. The materials required for designing and analyzing the performance of the heat exchanger pipe have been studied in detail. To reduce the thermal stress of the components, ANSYS has been used to model them and calculate the thermal stress. The thermal stress equation has also been developed. A thermal analysis was conducted on the pipes in the heat exchanger to reduce the thermal stress. In addition, the heat transfer rate and thermal conductivity of the model structure were evaluated. The observations of the deformation, maximum stress, and strain were made and in the end, a conclusion was reached.

Chapter1: Introduction

1.1 Overview

In accordance with the principles of physics, the energy which is driving the system is allowed to make the flow till the equilibrium is obtained. When there is no difference in temperature, heat leaves the warmer body or the hotter liquid and travels to the cooler fluid. This is the main physics behind the heat exchanger. A heat exchanger is equipment used in many industries that allows heat to flow from a hot fluid to a cold fluid. There is a heat exchanger located inside the cylinder that transfers heat between two fluids. There is a certain amount of importance attached to the pipes being as efficient and performing as they can as well as being corrosion resistant and highly wear-resistant. As a result, it is very important that the strength and stiffness of the pipe be kept within the limits so that the heat exchanger system operates as smoothly as possible. The pipe in the heat exchanger has the important role of recovering the heat from air and the fluids present on the heat exchanger. There are some of the factors that need to be considered in order to improve the efficiency of heat exchangers and increase the heat transfer rate among fluids. Mostly finite element analysis is employed to solve the thermal and structural problems. It becomes easier to deploy the smaller grids for simpler geometries but with the rise of complex geometries, finite element analysis becomes easier with the use of numerical methods. A finite element method(FEM) is used to analyze the structural integrity and thermal performance of the components in the system using the finite element method.

1.2 Historical background

First plate heat exchangers appeared in the 1920s. Dr. Richard Seligman 1923 developed a heat exchanger that can heat and cool the liquid without the direct contact in between them. Later, it evolved into various forms. In the 1930s, Sweden produced the first spiral plate heat exchanger. The development of cutting-edge science and space technology in the 1960s necessitated the development of high-efficiency and compact heat exchangers. Examples include the British brazed plate-fin heat exchanger. In conjunction with the development of brazing, sealing, and stamping technologies, the heat exchanger production process has been further optimized, leading to the sudden development and wide range of applications of flat plate surface heat exchangers. In 1990, China exhibited a technology of independent thermal transfer application development, and a large number of enhanced heat transfer elements were introduced. The development of heat pipe heat exchangers was a result of the research and development.

1.3 Problem statement

The main task of the project is to design and analyze the heat exchanger pipe. Temperature distribution inside the heat exchanger pipe has to be analyzed for the better optimization of the system and dissipative heat transfer between the fluids. The proper heat distribution creates better performance and enhances the efficiency of the heat exchangers. For the proper heat distribution, there is a need for optimal design parameters. In some heat exchangers, there is damage due to some kind of fluid which affects the performance of the heat exchanger pipe. The proper flow analysis inside the heat exchangers is much researched. In finite element analysis, the type of model (like RANS, K-Epsilon, K- omega, and many more) required for the flow of liquid has to be determined. The solver model for the flow in the heat exchanger pipe has to be determined. Also, with the advancement of the industries the heating and cooling problem has risen. So, the effective heat exchanger pipe has to be designed for maximum heat flow.

1.4 Objectives

The sole purpose of the project is to design and analyze of heat exchanger pipe.

The secondary objectives of this project are:

- To do modeling and analysis of the components of the heat exchanger system.
- To make the uniform heat distribution around the pipes of heat exchangers.
- To design a safe and more economical heat exchanger pipe.

1.5 Scope

In addition, this project can be applied to the thermal analysis of intercoolers, preheaters, condensers, boilers, and many others. These components can be easily analyzed when it comes to thermal and stress analysis. By analyzing the pipe of the heat exchanger, an optimal design can be made and can affect the overall performance of the heat exchanger. In addition to this, proper heat dissipation can also be a means of making the production of industries continuous. The efficient pipe design of heat exchange helps in the efficient transfer of heat. It is also easier to dismantle and maintain due to the efficient pipe design of heat exchange. Furthermore, the analysis of the stress and deformation of the heat exchangers can also determine the number of plates that will be needed to add to the heat exchangers. Further, the operating temperature and pressure of the system can also be adjusted to ensure that the heat exchangers are operating at maximum efficiency.

1.6 Methodology

As part of this project, the main objective is to design and analyze the pipe of the heat exchanger. Several articles and research studies have analyzed the design parameters and the conditions that need to be evaluated. The material properties of the pipes are also sorted out. Aluminum and stainless steel are the most commonly used materials. Both of these materials have some pros and some cons. In terms of weight and thermal conductivity, aluminum is lighter and more conductive. For the pipe of the heat exchanger, stainless steel is selected as the most suitable material, as it is corrosion-resistant. For the modeling of the components, SolidWorks is the software of choice. In order to conduct thermal and structural analyses of the components, ANSYS is used. With ANSYS, a finite element problem is by the boundary conditions and the multiple iterations. As a result of the analysis, the values are obtained until the optimal value for the analysis cannot be achieved. It is necessary to obtain the thermal stress, the heat transfer conductivity, the deformation, the stress, and the strain of the heat exchanger pipe in order to evaluate the overall performance of the heat exchanger pipe.

Chapter 2: Literature review

Based on the thermal dissipation rate, the heat exchanger's thermal resistance was calculated by measuring the irrevocable of transfer of heat during the time of heating and cooling of a material.. Additionally, the relationship between thermal effectiveness and thermal resistance has been established. As a result, the performance of the heat exchanger was compared with different flow arrangements. Moreover, such arrangements close a gap between the irreversibility of heat exchangers and their efficiency.

https://www.sciencedirect.com/science/article/abs/pii/S0017931010000669

A new type of grid plate was presented in this paper which improves the heat-dissipating rate of pipe. With the use of heat transfer and energy conservation law and the application of the finite element method, the steady-state heat transfer analysis of pipe was done. The distribution of temperature and stress was analyzed in the model so the material selection and optimized radius of the grid plate were obtained.

https://www.scientific.net/AMR.532-533.417

The exhaust gas recirculation (ERG) system had been used in diesel engines to reduce pollutants produced by vehicles. ERG coolers, however, are generally inefficient in terms of heat exchange efficiency. An analysis of dimple-type ERG coolers is presented in this paper. It was determined that the dimples on the surface of this type of cooler allowed for heat transfer to occur. A 3D finite element method was employed to determine the structural rigidity of this type of cooler which undergoes thermal and pressure stress. At the end of the experiment, a dimple-type model was built and its high heat exchange efficiency was analyzed experimentally.

https://link.springer.com/article/10.1007/s12541-012-0023-5

The thermal fatigue in the exhaust manifold of the engine could affect the performance and service life. ANSYS was used for finite element analysis to model the working environment and calculate the state temperature distribution under a thermal field at a steady state. Also, the critical locations where the thermal stress generates were identified. Also, the failure analysis and fatigue analysis were carried out which provided better results for the optimization of the exhaust manifold. Also, the thermal fatigue failure of exhaust manifolds improved the stability of the structure.

https://www.scientific.net/amr17-218.1531

This paper was about the temperature, stress, and strain analysis of heat transfer in jet plugs in a hot blast furnace where the parts have high stress with the uniform stress and strain distribution. The finite element method was used to study the temperature field. The maximum temperature was not found on the thermal stress but in the region where the temperature difference was higher and the causes were discussed. The main conclusion of this paper provided the enhancement of machines and optimized the design of the structure.

https://www.scientific.net/AMR.396-398.1856

The temperature distribution and the thermal stress caused by a temperature difference in silicon carbide were examined in this project. This study was performed by applying the finite element method to the temperature and stress fields. In this paper, based on the results of the finite element method, the non-axial heat transfer coefficient is discussed, as well as the calculation of thermal stress and difference in temperature. In this study, the FEM technique was found to be applicable for the analysis of thermal and structural problems of similar meaning.

https://www.sciencedirect.com/science/article/abs/pii/S0261306904000184

This article presents numerical results of the transient response of thermal stress within a pressurized water reactor which is utilizing internal thermal stratification. In order to conduct a stress analysis of a piping system with a finite wall thickness, an analysis of the numerical method of the unsteady heat transfer is conducted, which gives the transient temperature distribution. This study sought to investigate the effect of surge flow direction on the distribution of stress on surge walls, specifically to determine the stress distribution on surge walls. With the use of the K-Epsilon turbulence model, the current numerical analysis was able to simulate

thermal and outburst turbulence in the pipeline. An unsteady heat transfer analysis was implemented in a finite volume code which was based on a mesh arrangement. ANSYS was used to calculate the non-dimensional stress distributions at the pipe wall which are dependent on time and temperature in the thermal stress analysis.
https://www.kns.org/files/pre_paper/22/310%EC%B5%9C%EC%98%81%ED%99%98.pdf

A FEM is applied to analyze thermal stress in radiant tube by applying the finite element analysis. In this paper, a steel alloy was analyzed as an important factor influencing the strength of heat exchanger pipes. As the linear temperature gradient occurs in the axial direction, it was found that thermal stress exists in this direction. Thermal stress in the circumferential direction is calculated by evaluating the thermal stress at various angular positions. Radial thermal stress is also calculated by analyzing the difference between the pipe's inner and outer radii and the thermal stress was also calculated by evaluating the difference between the inner and outer radii.

http://www.thenucleuspak.org.pk/index.php/Nucleus/article/view/432

There has been developed a mathematical analysis that will check the heat transfer in the heat pipe. The model explains the flow of liquid inside the heat pipe, as well as the thermal characteristics that influence the change in temperature of the liquids. The flow of liquid in the triangular corners is considered for the change in facial shear stresses due to solid and liquid interaction. The analysis results have been validated against the test results.

https://asmedigitalcollection.asme.org/heattransfer/article-abstract/116/1/189/415473/Thermal-Analysis-of-a-Micro-Heat-Pipe

Chapter 3 – Terms, Terminologies, and components

Thermal analysis, Structural analysis, Stainless steel, Aluminum, Finite element analysis, Mesh

- Thermal analysis

Thermal analysis is a general term that refers to a way of measuring the time and nature of the physical changes that occur when heat or cold are applied to a material. Each thermal analysis method is characterized by the types of physical changes that it evaluates. As part of Thermal Analysis, several different methods are used to measure the sample properties while the sample temperature is pre-programmed.

- Structural analysis

The objective of structural analysis or experiment is to investigate how an object or part of an object will respond to a specific set of excitations mainly forces or thrusts. The method involves calculating internal forces like the shear force, axial force, bending force, stress, strain, deflection, etc., associated with an object or part.

- Stainless steel

While stainless steel of consists at least 10.5% chromium, the exact components and ratios will depend on the grade and purpose of the steel. Stainless steel has many desirable properties that have led to its widespread application in many industrial sectors. Because of its high chromium content, it is extremely corrosion resistant.

- Aluminum

In general, aluminum has good formability and excellent corrosion resistance; its thermal conductivity is 237 W/mK and it is also very cost-effective. Aluminum is lightweight, flexible, and well malleable, so it is used as a heat exchanger material. Also, it has lower resistance so the problem of deformation is more.

- Finite element analysis

With the use of the finite element method, a computer can analyze how a product will act in the real world. It is possible to construct an approximation for the equations by discretizing them. It is possible to approximate the PDEs numerically by using numerical method equations. As a result, the numerical model equations approximate the solution to the PDEs. To compute these estimates, finite elements are used.

- Mesh

  It is the method to split geometry into the multiple numbers of nodes and elements at which the optimal solution is obtained. Meshes are networks of cells and points. Partial Differential Equations (PDE) can have almost any shape in any size and can be solved with them. The mesh consists of individual cells that, when combined, result in a total solution for the whole network.

Chapter 4 Design and Calculation

4.1 Material selection

Material selection is done for the pipe of the heat exchanger for its model design and analysis. A study of different materials is conducted along with their thermal properties for heat exchanger pipes. Aluminum and stainless steel are the best materials to be used for heat exchanger pipes. On the other hand, aluminum has a higher risk of damage if the appropriate fluid is not applied. On the other hand, stainless steel does not require the use of fluids of this kind. It is known that aluminum has a thermal conductivity of 237W/ (m. K). Therefore, it is the most effective and most cost-effective material in terms of thermal conductivity. In terms of specific heat, it has a specific heat of 0.44 J/g °C). In addition, it is also flexible and malleable. On the other hand, stainless steel does not require the use of fluids of this kind. As a result, stainless steel was found to be an appropriate material for the model. Steel has a coefficient of expansion of 6.56*10*6/c, a modulus of elasticity of 1.72*10*5MPa, and the Poisson's ratio of 0.3. A stainless steel plate (11% chromium) has good thermal properties as well as heat-resistance characteristics. In addition to this, it is also capable of resisting corrosion and fatigue loads. Furthermore, it has the good heat transfer performance required for the pipe. Moreover, it reduces the number of limestone deposits as well as other ingredients that are present in the fluid. The product is durable and can withstand high temperatures and pressure.

4.2 Parameters selection

When designing pipes for heat exchangers, three parameters must be taken into account: the cross-sectional area of the pipe, the temperature of the inlet and outlet fluids, and the overall heat transfer coefficient. It is essential to analyze the designed temperature, the designed pressure, and the allowable pressure drop before designing the heat exchanger pipes. As well, the value of the inlet flow rate of liquid, the inlet and outlet temperatures as well as the flow rate will depend on the heat exchanger pipe design. It is assumed that the temperature difference is about the mean logarithmic value. The diameter and measurement of the cross-section of the pipe are determined. To determine the thermal stress, it is necessary to determine the thermal strain. In order to solve the node displacement, it is necessary to use the initial strain due to thermal deformation, which is obtained by the nodal loads. In this way, multiple stresses are caused by the combination of multiple loads and thermal loads. As a result, the temperature strain value can be obtained. Assuming a three-dimensional problem, the virtual displacement caused by thermal loads, surface loads, and point loads will be assumed, and with a coefficient of thermal expansion, the value of thermal strain and finally, the value of thermal stress will be determined.

4.3 Modeling

The modeling is carried out in SolidWorks. It is possible to set up the units and design parameters within the computer program. In order to draw a sketch, you need to draw lines, circles, trim, copy, etc. The pipe is designed by first drawing a circle that represents the inner diameter of the pipe, then extruding the circle which corresponds to the outside diameter of the pipe, which completes the pipe design. On top of the sketch, a second circle is drawn, with a diameter equal to the internal diameter of the pipe, and then the feature extrude-cut is applied. In order to make the external socket, the planes at the ends of the pipe are defined, and subsequently a rectangle is drawn. SolidWorks has an extrusion boss feature that allows you to extrude the sketch rectangle using the extrude boss feature. The materials are assigned accordingly. In this way, modeling of pipe of heat exchanger is done.

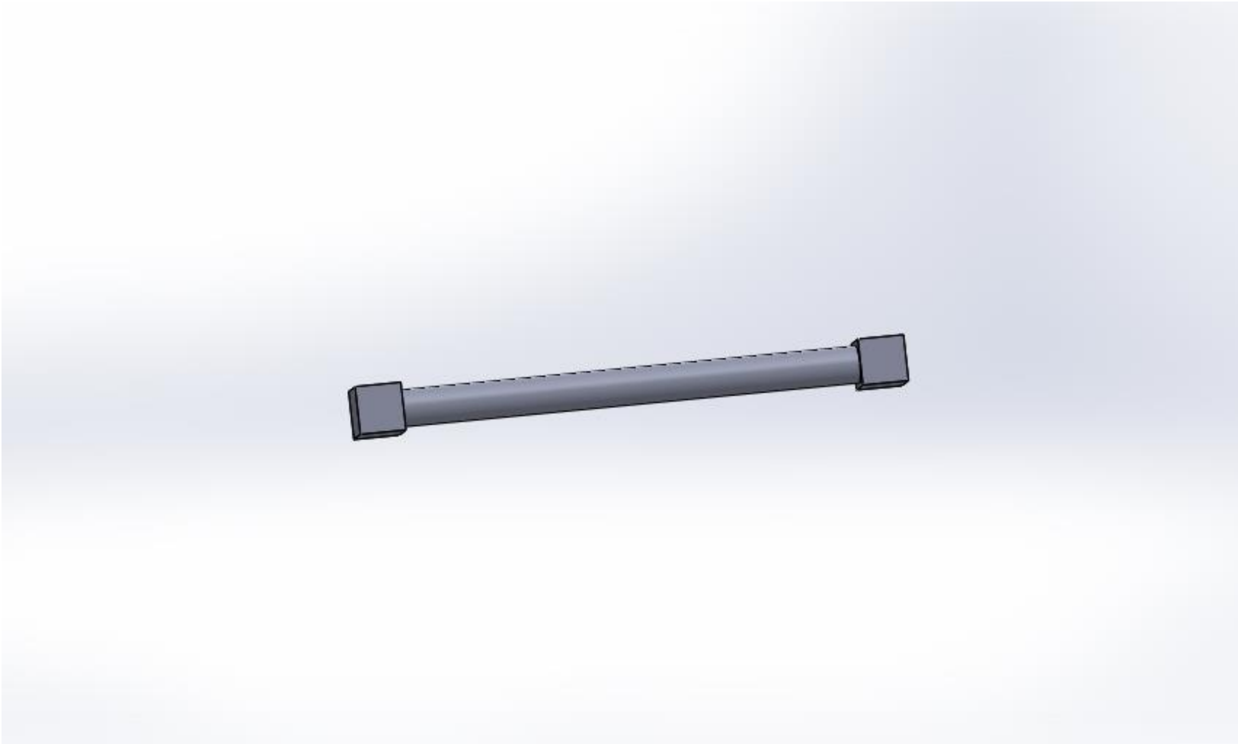

Fig 1: Model

Chapter 5 Analysis, Results, and Discussion

5.1 Analysis

Following the design of the heat exchanger pipe in SolidWorks, the designs are imported into the ANSYS (thermal stress and strain analysis software) for analysis. There are several material properties that are assigned to stainless steel from the Engineering data. The thermal analysis is to be done in steady-state thermal and the structural analysis is to be done in ANSYS structural. The steady-state thermal analysis involves the equilibrium state of a system under the same thermal loads and surrounding factors. These properties are the expansion coefficient, the Poisson's ratio, the elastic modulus, and the thermal conductivity. The liquids used in the exchanger are too defined. The physical properties of such liquids and their thermal conductivity is defined. Mesh is to be generated for the analysis because it is able to break down the bulky geometry into smaller elements, with each smaller element being considered as geometry and making the problem resolvable. The mesh is generated by discretizing the model into several nodes and arrays by dividing the elements into nodes. The fine mesh is made by specifying the element size and the body and face sizes. In addition, the mesh quality is checked under mesh skewness. From the elements of the stiffness matrix as a whole, the stiffness matrix is found. There are various thermal properties such as heat transfer coefficient, thermal conductivity, specific heat, heat capacity, and thermal expansion which are used as the boundary conditions. The mesh generated at steady-state thermal is imported to ANSYS structural where the structural analysis is to be done. The solver used in the thermal analysis was the thermal solver at transient mode. The minimum and maximum time steps are presumed at the solver. The simulation is performed. After some time, under the results tab, the results are displayed.

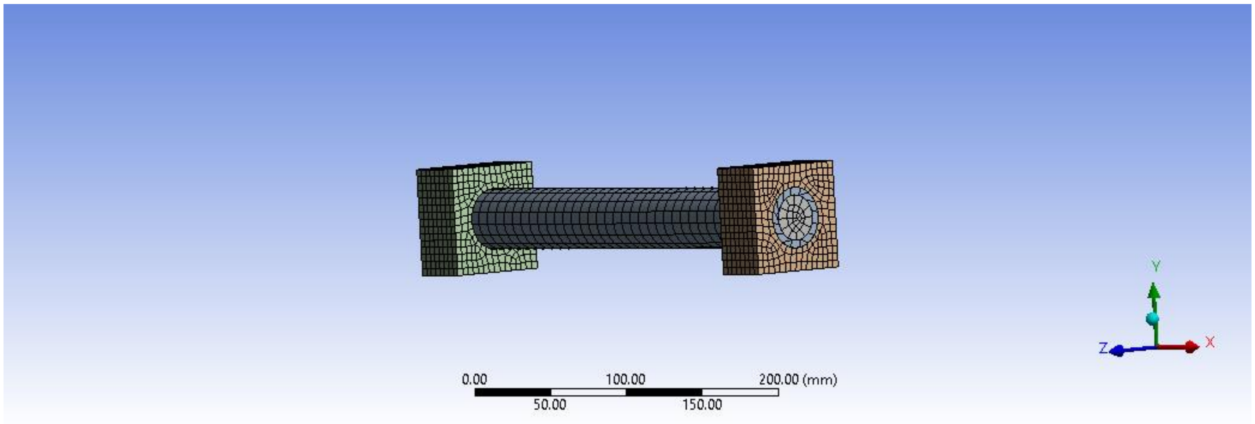

Fig 2: Mesh

5.2 Results

After the simulation, the results of ANSYS are analyzed. The model was interpreted from the analysis and found the different values of stress, strain, and deformation. The total deformation on the pipe is found to be 0.004139mm. The maximum value of stress is evaluated from the stress diagrams. The maximum is 329.01 MPa and the maximum value of strain is 0.0016451. Also, from the thermal analysis, the values of directional heat flux, total heat flux, and the maximum temperature are found. The directional heat flux is found to be 5.3627E+5 W/m². Also, the maximum temperature is 253.88˚c. The temperature along the length of the pipe is found to be 208.33 degrees Celcius. Finally, the total heat flux is 1.7847 E+6 W/m^2. The values are validated against the trial results. After that, the conclusion is drawn accordingly for the analysis of the heat exchanger pipe's performance and effectiveness.

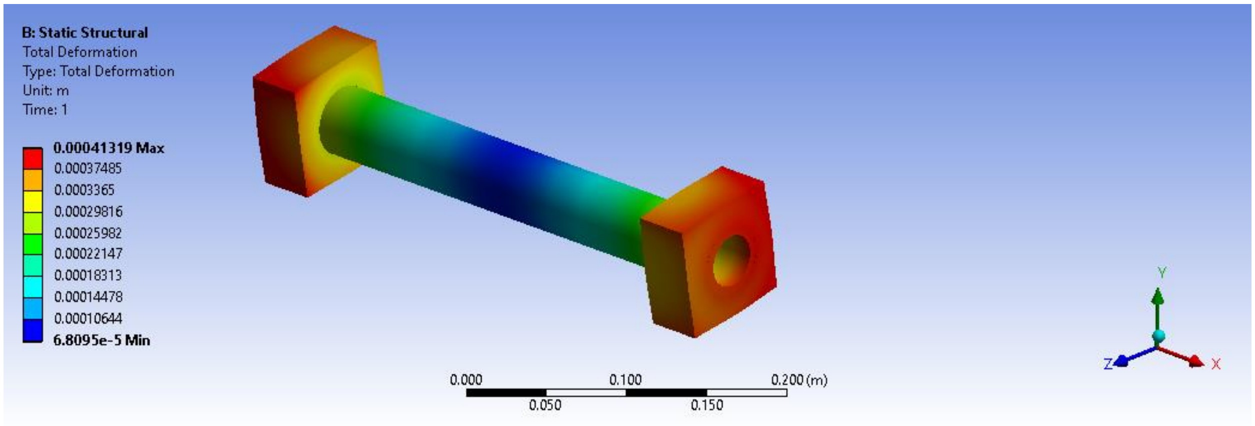

Fig 3: Deformation

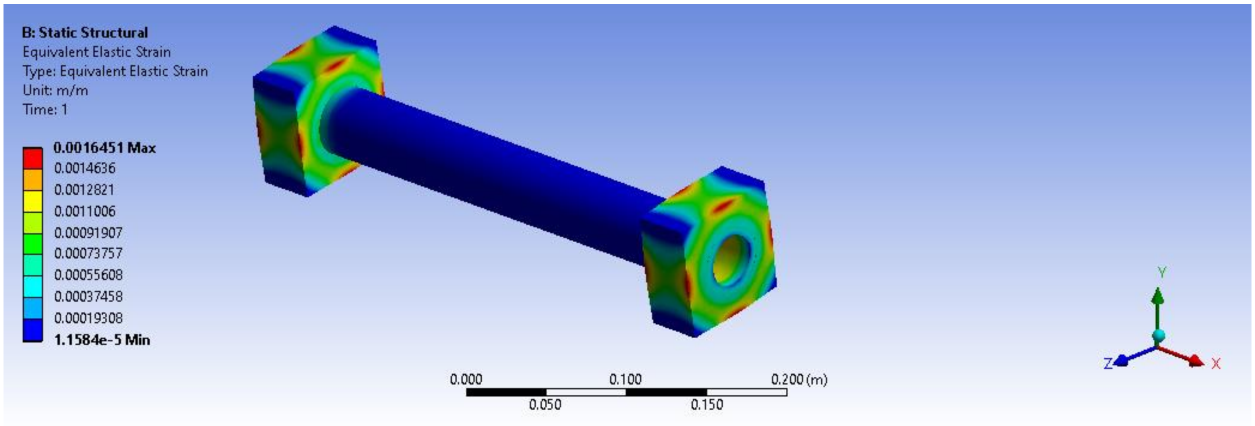

Fig 4: Stain

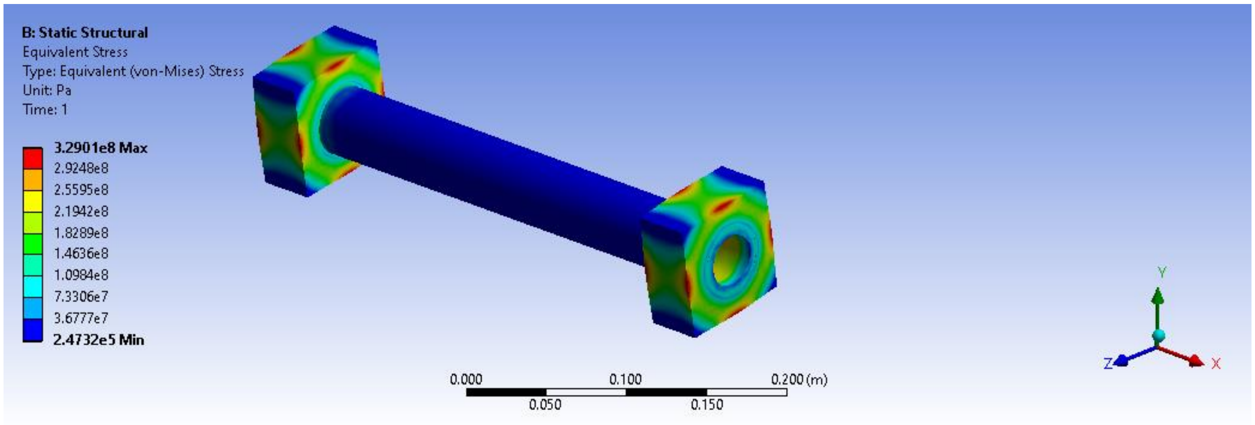

Fig 5: Stress

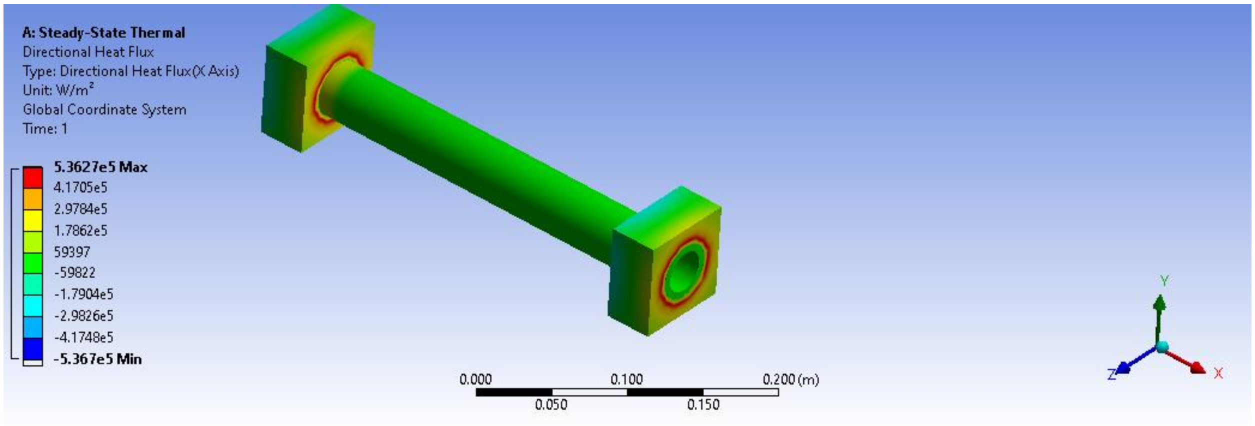

Fig 6: Directional heat flux

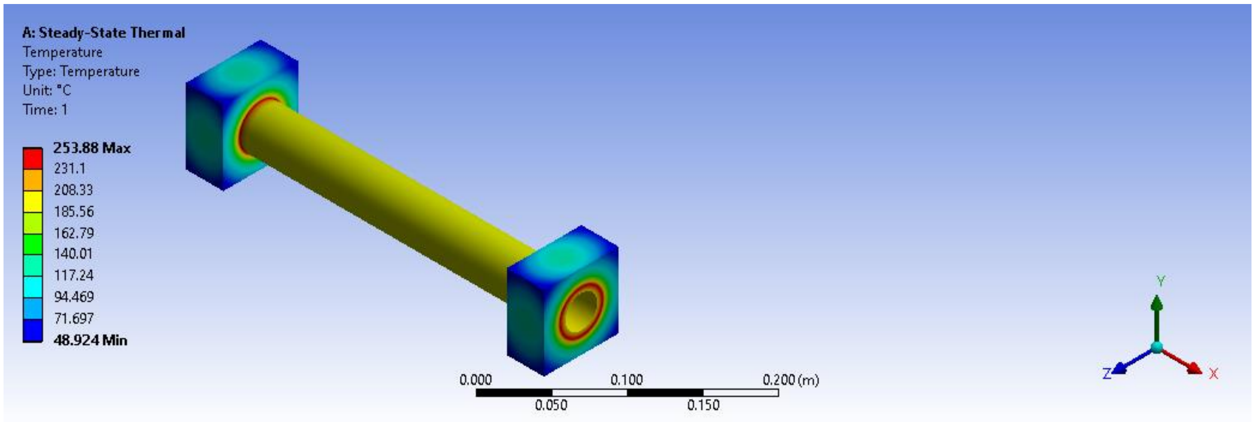

Fig 7: Temperature

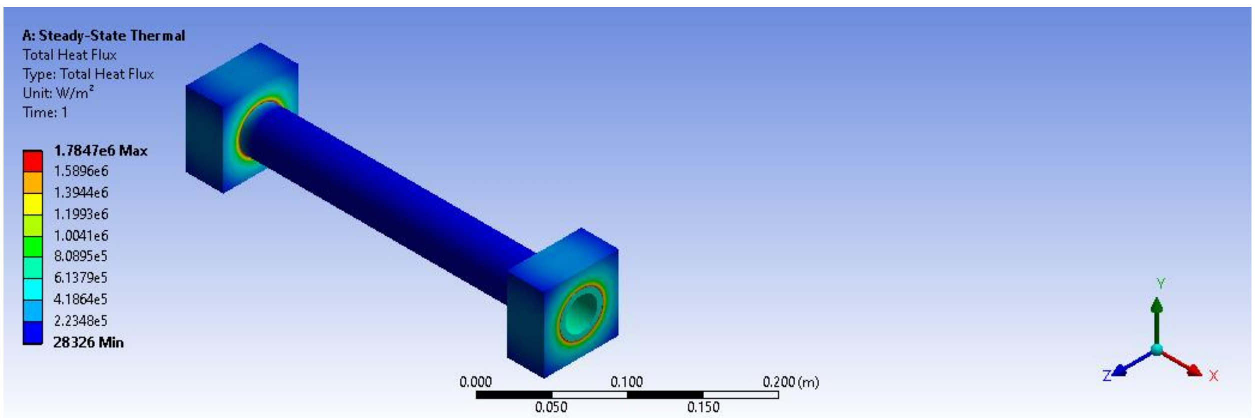

Fig 8: Total heat flux

5.3 Discussion

During the project, the value of the stress, the deformation, and the strain is determined. The determination of thermal stress and structural stress is necessary to evaluate the overall performance of the heat exchangers. It is seen in the figure the maximum deformation is seen at the end of the pipes i.e. at the sockets. Due to the deformation at the socket, the value of strain is also seen maximum there. The value of equivalent stress is also seen at maximum at the sockets and minimum along the length of the pipe. The temperature is seen at maximum at the inlet of the pipe and the minimum at the top of the socket. A review of the ICS 77.140.75 code is carried out with regard to the steel pipe design and the tubes used in the design of heat exchange pipes. In addition, the ICS 24.010 code is used for the energy and heat transfer in pipes Also, the value of heat transfer rate as well as the maximum temperature is analyzed. The material properties used in the heat exchanger pipe are analyzed and their thermal conductivity is noted down. The obtained stress value was within the limit of the ultimate strength of the material. Based on the analysis, it was found that the heat generated in the pipe is exceeding the permissible range, which could result in the pipe being destroyed. By assigning a hinge constraint at any point at the end of the pipe, the axial displacement will be equal to 0. Also, there is a higher value of dimensions and thickness of the model to resist the deformation applied in the pipe as a result of linear strain applied to it. However, the values of thermal stress and heat generation are within the acceptable range. As a result, all the stress and strain values, deformation values, and heat generation rate values are found to be within safe limits.

Chapter 6 Conclusion

6.1 Conclusion

As part of the project, the design and analysis of the heat exchanger pipe are done. Through this, performance parameters are determined, and a mathematical model is developed. The modeling is carried out using SolidWorks software using specialized tools. The material stainless steel is chosen because of its high thermal and heat resistance properties. By using the IGES file format, ANSYS is used as an analysis tool by importing the model into the program. During the analysis, the models are discretized into several arrays or nodes and the analysis is then performed. Based on the finite element analysis method, the model is analyzed until the values of the stress, strain, deformation, and heat generation rate was under the limit. It is observed from the results that the optimized diameter and the geometry of the heat exchanger pipe can withstand the thermal and operating pressure at the walls of the pipe. The standard codes are too reviewed accordingly to carry out the design of the system. The proper heat distribution through the pipe can increase the productivity of the heat exchanger pipe and the overall entire system. The heat flow inside the pipe can easily increase and decrease the fluid temperatures and has a great heat dissipation rate. This analysis is important for the design engineers and the manufacturers regarding the design and the material selection for the heat exchanger design. The liquid that can be used in the system and the effect of that liquid on the heat exchanger pipe can be determined.

6.2 Advantage

The advantage of this project are:

- Analyzing the heat exchanger pipe with ANSYS is the easiest way to analyze its performance.
- Using the ANSYS heat exchanger pipe analysis tool, it is easier to find the best materials for the performance of the heat exchanger pipe.

- To do the efficient design of heat exchanger pipes, the finite element method is the most appropriate method to take into consideration the performance parameters of the exchanger pipes.
- Depending on the optimal design of the heat exchanger pipe, the number of plates that should be added to the heat exchangers in order to get proper distribution of heat energy between the liquids can be determined.
- With the proper design of the heat exchanger pipe, reverse engineering of the heat exchanger model can be done.

6.3 Limitations

The limitations of this project are:

- It is difficult to get correct values of stress, strain, and deformation without the precise calculations and proper assignment of boundary conditions.
- The heat flow analysis of the entire heat exchanger system is difficult because of the higher computational time.
- The fabrication of the optimized model is difficult.

6.4 Future works

The design and modelling of the pipes of the heat exchanger can be carried out. Due to these properties, stainless steel is the best material to use in the case of the heat exchanger pipe used in this project, although aluminum can also be used as a good option due to its lightweight properties and ability to conduct heat efficiently. There is only one part of the heat exchanger that is being looked at here, and that part is the pipe portion. It is possible to analyze various heat exchanger components as part of a comprehensive analysis of the heat exchanger system. An analysis of the heat exchanger pipe can be carried out at different sections of the pipe in different cross-sections of the pipe. Depending on the results of the analysis, a comparison of results from the analysis with those from the experiment can be made. When the two different sets of data are compared, it is possible to determine both the optimal dimensions of heat exchanger pipes as well as the optimal dimensions of the entire system by comparing the two different sets of data. It is also possible to analyze both laminar and turbulent flow in the pipe simultaneously. Different types of metal alloys can be used for the analysis of the system, and their performance can be determined as well. It is also possible to use copper metal as the pipe material of the heat exchanger due to its performance. As heat is transferred along the length of a heat exchanger, many plates are deployed where the heat is transferred. In order to determine the number of plates to be used in the system, it is necessary to assess the heat exchanger's performance and effectiveness. Different codes can be reviewed for the design of pipes and the system. From the codes, proper optimal design can be produced. By performing the pressure test of the system, we can determine if there are any leakage sections in the heat exchanger pipe. By doing so, the thickness of such a critical region can be increased. Furthermore, it is also possible to perform a flow analysis of the fluid inside the heat exchanger pipe by using ANSYS Fluent to calculate the flow of liquid and the velocity of the fluid inside the pipe.