THERMAL DESIGN ANALYSIS OF SERVER CHASSIS MANIFOLDS FOR LIQUID COOLED SERVERS USING CFD

By

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May 05, 2021

Abstract

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Direct-to-chip liquid cooling is one of the most popular methods in data center thermal management when it comes to cooling high chip power densities. A cold plate-based liquid cooling system contains various components such as pumps, data center room, and rack-level manifolds, and server chassis-level manifold. Efficient coolant distribution to the heat-dissipating cold plates plays an important role in both the thermal and hydraulic performance of the server. It is, thus, very important to design and manufacture server chassis manifold geometry that can perform efficiently under the anticipated heat loads and coolant flow rates. In the present thesis, two such server chassis manifolds from two different vendors were characterized using CFD for various coolant inlet temperatures and flow rates. A gird independence study was carried out to select the best possible grid size for accurate results. Temperature-dependent properties of 25% propylene glycol were used to determine the pressure drops at different flow rates and inlet

temperatures. The baseline results of manifold pressure drop were also validated with experimental results. Furthermore, the impact of kinks and bends in server manifold connecting pipes on the system pressure drop was also explored. Lastly, the fillet was added on the corners of manifold to see the difference between the pressure drop.

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Introduction

1.1 Data Centers and Computers

The data center is a dedicated space that houses various computer systems and its related components. Data centers house the most critical systems of networks to ensure continuity in daily operations. [1], [2]. Data centers are increasing every year by the increase of demands for digital technology by causing year 2020 by chip shortage year. Microsoft is planning to build 100 new data centers by next year. Many companies like tesla, google, amazon, etc, have large demands for data centers. This increase in demand has its own disadvantages by consuming more power it ends up generating more heat in servers of data centers. Data center components are to be kept under required temperature range. Hence to maintain these temperatures is the biggest concerns of all time. There are different methods for cooling of data centers. Safety, reliability, cost, working conditions and few more factors are taken into consideration before deciding any particular method for cooling.[3],[4].

These methods are the most commonly used methods for data center cooling:

1. Air Cooling.
2. Liquid Cooling.

1.2 Air Cooling of data servers

Initially, there was just one cooling solution which was air cooling using heat sinks and fans to keep the data centers to required temperatures. Heat sink which was aluminum and copper material was used. Here, air is the cooling medium for cooling the heat generated. Fan is used to generate the airflow. The convection mode of heat transfer is performed to dissipate the generated heat by GPU's/CPU's by passing air over heat sinks with forced convection method. The air flows from the inlet to the outlet throught the servers by cooling the servers down, this hot air then comes out of the outlet of the server to the hot aisle which then rises above to pass on to the Computer Room Air Conditioning (CRAC) unit where air is cooled down to the basic temperature needed. This cooled air is then passed back into the cold aisle to reenter the hot servers to cool it down as mentioned in the figure. Air having low specific heat capacity and less thermal conductivity causes limitations for cooling data center with high temperatures. For cooling high temperature data centers there will be a need of large number of heatsink fins covering greater area which would not only increase the size and cost of the cooling process but also, make the structure more complex.[3]-[5].

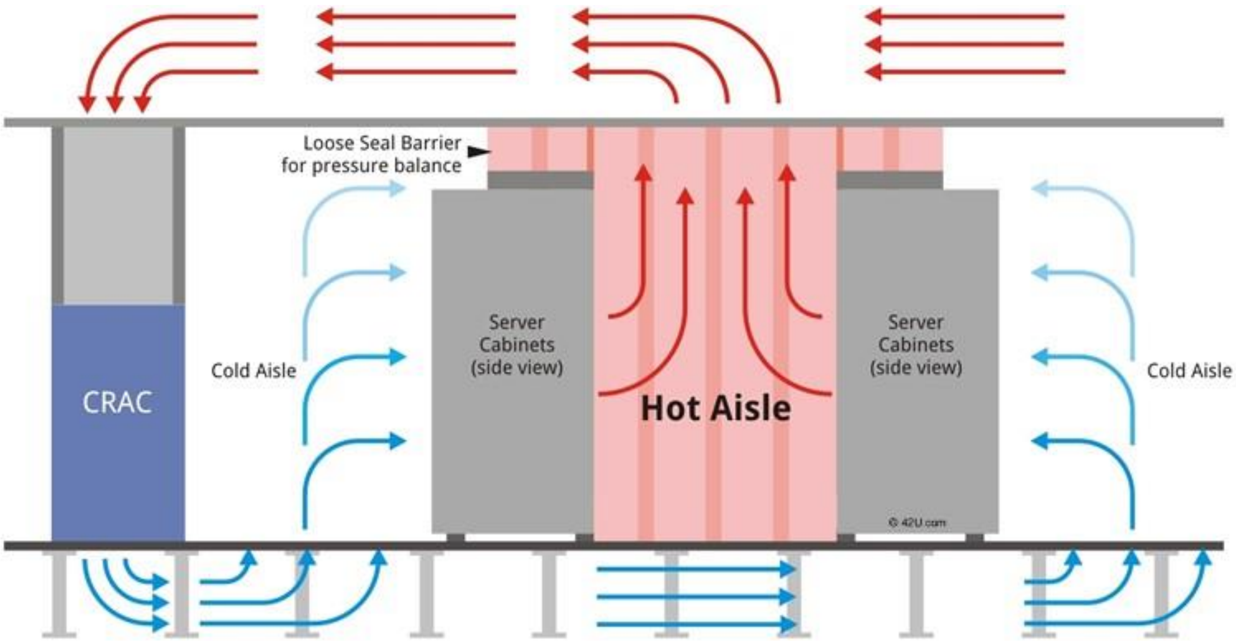

Figure 1Air cooled data center

1.3 Liquid Cooling of data servers

By keeping all the limitations of air cooling in mind to overcome those limitations it is necessary to adopt more efficient way for data center cooling. The liquid cooling is more efficient and effective way of cooling data center than air cooling method. As the liquids used in liquid cooling have more thermal conductivity and specific heat than air used in air cooling. Liquid cooling setup is also compact when compared with air cooling setup, as, axial fans , economizer are taken off in liquid cooling also making it more smoother with less noise in operation. Being more efficient and compact than air cooling for removing heat, liquid cooling is used to meet the increasing cooling demand. Heat sinks are replaced with cold plates and fans are replaced with pumps in liquid cooling.[6]-[13].

Liquid cooling Data center generally have 6 major parts:-

i. Cooling Distribution Unit- CDU
ii. Supply and Return Manifolds
iii. Server
iv. Server Manifolds
v. Cold Plates

i. Cooling Distribution Unit – CDU :- The function of CDU is to pump cool liquid in supply manifold and to cool the hot received from return manifold. Cooling of hot liquid received from return manifold can either be done by liquid-to-liquid cooling or by liquid-to-air cooling. CDU does face some challenges which can be space available for setting up or CDU material and cooling liquid compatibility. Material compatibility plays an important role in the long term to avoid issues arising in the long term such as corrosion.[13].

ii. Manifolds:- There are different types of manifolds fitted in the system which are supply and return manifolds from CDU to server and supply and return server manifolds inside the server to cold plates. Manifolds supply and return the cooling fluid from CDU to cooling unit and from cooling unit back to CDU. Manifolds can be of different size, flow rates, pressure drops, and flow rates depending on the parameters needed. ASHRAE recommends to keep the maximum velocity of the cooling fluid less than 1.8m/s to avoid erosion issues in the loop. [14],[13].

iii. Server :- Server holds the supply and return server manifolds attached to the cold plates which are fitted on the heat dissipating units GPU's or CPU's. There may or may not be the server manifolds present in the server but there are always pipes that are connected to the cold plates.[13]

iv. Cold Plates:- Cold plates are a device that provide localized cooling of GPU's/CPU's by transferring heat from hot device to cooling fluid that flows to a remote heat exchanger and dissipates into either the ambient or to another liquid in a secondary cooling system.Thermal path is provided between heat dissipating CPU's/GPU's and cooling fluid in cold plates. Cold plates can be of metal design which are attached to these hot units through a thermal interface material (TIM).[13]

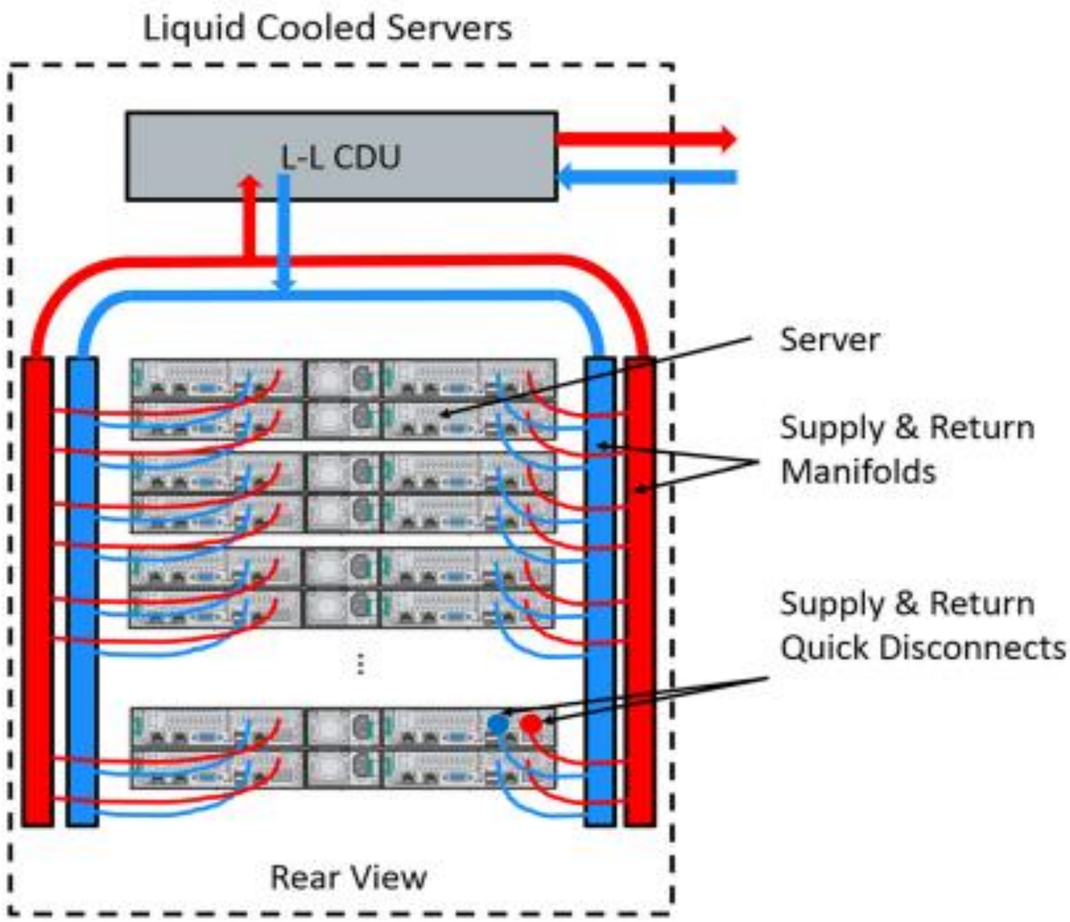

Figure 2Example of a fluid loop from CDU to server[14]

Since computing and communication devices are converging with improvement of the functionally which creates complexity of circuit interconnections for 2-D devices. It becomes a limitation for performance and also drives up power dissipation [15]. Computational modeling is often used in the design and optimization of electronic packages for performance and reliability. The accuracy of material properties is one of the factors that influences the accuracy of computational models. Sensors in microelectromechanical systems are often highly sensitive to even minor changes in the package's material properties [16]. Different failure modes are caused by factors such as temperature cycling, mechanical stresses, and humidity, making electronic package reliability a major concern [17].

OBJECTIVE

Hydraulic characterization of two different liquid cooled server manifold designs using CFD is done. Hydraulic performance of both the designs were compared. Operational issues on the server manifold was considered such as adding pipe kinks and curvature to the manifold pipes to determine the variation of hydraulic performances.

GEOMETRY AND METHODS

1.3 Server Manifold

The server manifolds are fitted in the server. Inlet of the supply server manifold is attached to the outlet of the supply manifold which takes in the cooling fluid and passes through the supply manifold to the outlet which is attached to the cold plates fitted on top of heat dissipating units in the server. On the other side of the cold plates the inlet of the return server manifold is attached which passes the hot fluid through it to the return manifold from its outlet which is attached to the inlet of the return manifold. Server Manifolds consists of multiple ports, in which fluid enters the manifold and then branches out or fluid branches in and exit the manifold. Server Manifold is considered to be one of the most essential elements in liquid cooling as it carries the coolant to heat dissipating GPU’s/CPU’s

Here in the thesis 2 different types of server manifold were taken into consideration.

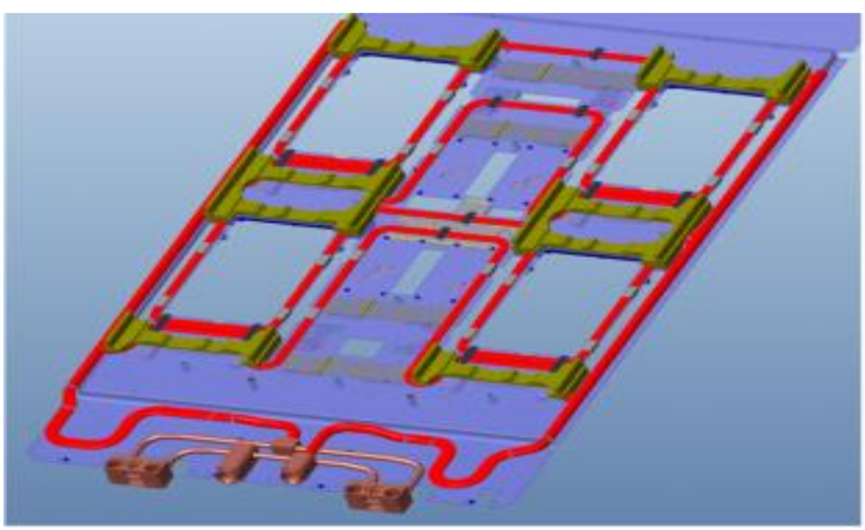

Figure 3 Server Manifold

1.4 Methodology

There were two server manifolds model taken into considerations which were named Manifold A and Manifold B. These server manifolds were designed using solid works and later inserted in ANSYS Fluent for further CFD simulations. The gird independence test was performed on both the server manifolds. For both the server manifold model 2 separate supply and return manifolds were considered for further calculations with different flow rates and inlet temperatures. The cooling fluid used in the setup was propylene glycol at different temperatures 35^{o}C and 45^{o}C. After all the meshing and setup, the solutions for pressure drop was calculated for each cases. Analysis of all the cases of server manifolds was done.

1.5 Cooling Fluid

Cooling fluid use in this setup was propylene glycol. Propylene glycol 25% was considered under two different temperatures at $35^{o}C$ and $45^{o}C$.

Propylene glycol at $35^{o}C$ inlet temperature.

Density :- 1026.6 kg/m^3

Viscosity:- 0.00161 kg/ms

Propylene glycol at $45^{o}C$ inlet temperature.

Density :- 1021.45 kg/m^3

Viscosity:- 0.001245 kg/ms

1.6 Grid Independence Test

Grid independence test was performed on both the server manifolds. Grid independence test is performed to find the least number of elements which can be used to perform the calculations without having much effects on pressure drop to save lot of time for future calculations. The figure 4 below shows the gird independence test for server manifold. We can see from the graph that after certain number of elements pressure drop almost remains constant. We can observe from the graph the pressure drop of the first value is much higher than rest which is 5673.36Pa at number of elements 18782. While, the second point shows the pressure drop of 3154.56Pa at 91389 number of elements. The third point which was finalized for the calculation shows the pressure drop of 3034.73Pa at 227131 number of elements. Lastly, the fourth point shows the increase of just 2% with the third point by showing pressure drop of 3100.99Pa at 1131826 number of elements which were a lot more compared with third point.

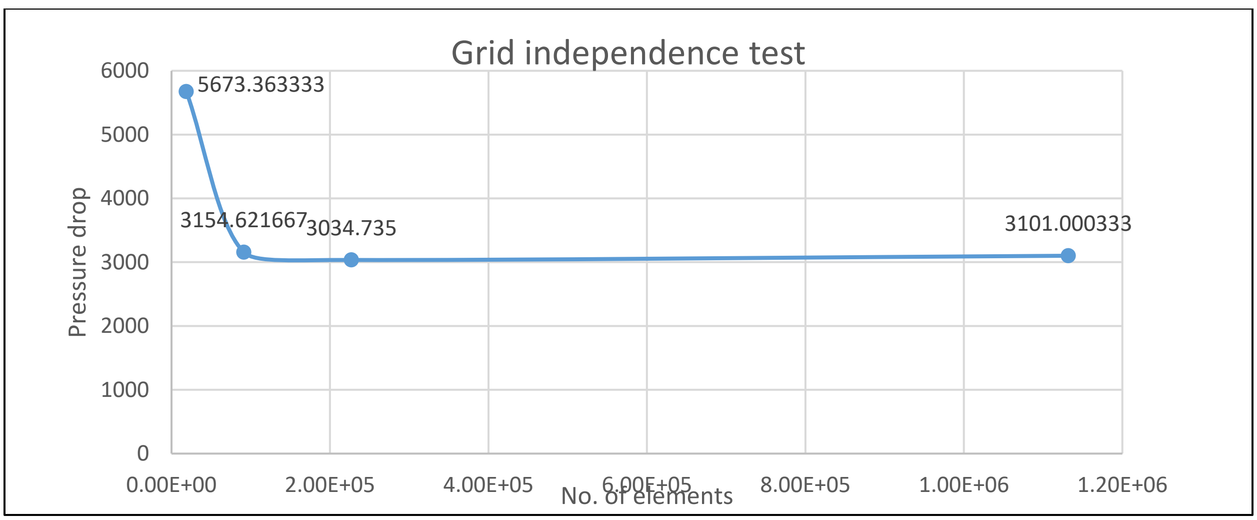

Figure 4Grid independence test.

1.7 Server Manifold A

Server Manifold A consists of two different manifolds namely supply and return server manifold A. Figure 5. shows the meshing of the manifold which clearly shows the inflation of 10 layers of element size 0.002 and maximum thickness of 0.000143 at inlet and outlet pipes of server manifold. Figure 6 shows the design of server manifold A supply while Figure 7 shows the design of server manifold A return. Here in Figure 6 the one single pipe shown is named as the inlet of server manifold A supply which takes in the cooling fluid from supply manifold through the rest 6 pipes on the other side are named as the outlet of server Manifold A supply which are attached to the cold plates fitted in server. Calculations for pressure drop across the manifold was done on different flow rates of 4lpm, 6lpm and 8lpm at two different inlet temperatures 35^{o}C and 45^{o}C. The hot fluid which escapes the cold plates is then entered in the return server manifold from 6 pipes shown in figure 7, which passes through the server manifold from 1 pipe outlet shown in the figure 7 Calculations for pressure drop across the manifold was done at 8lpm flow rates at two different inlet temperatures 35^{o}C and 45^{o}C.

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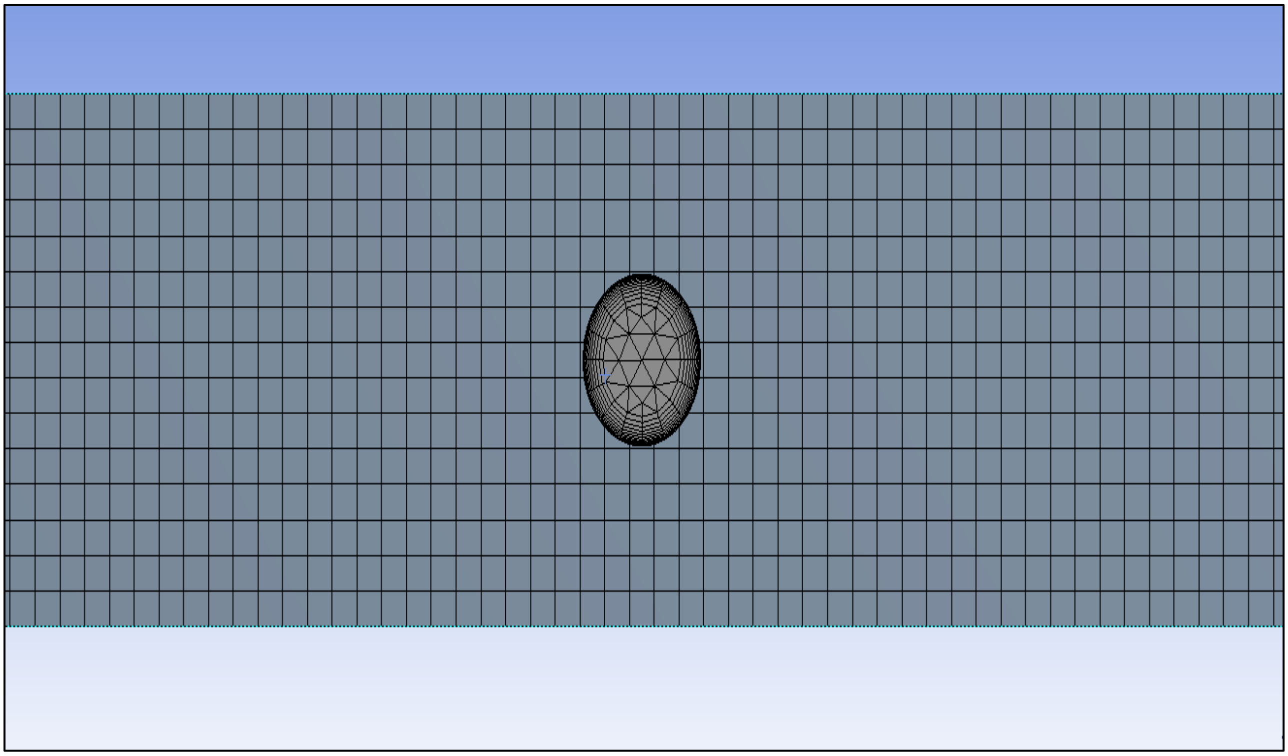

Figure 5 Meshing of Server Manifold A to show inflation.

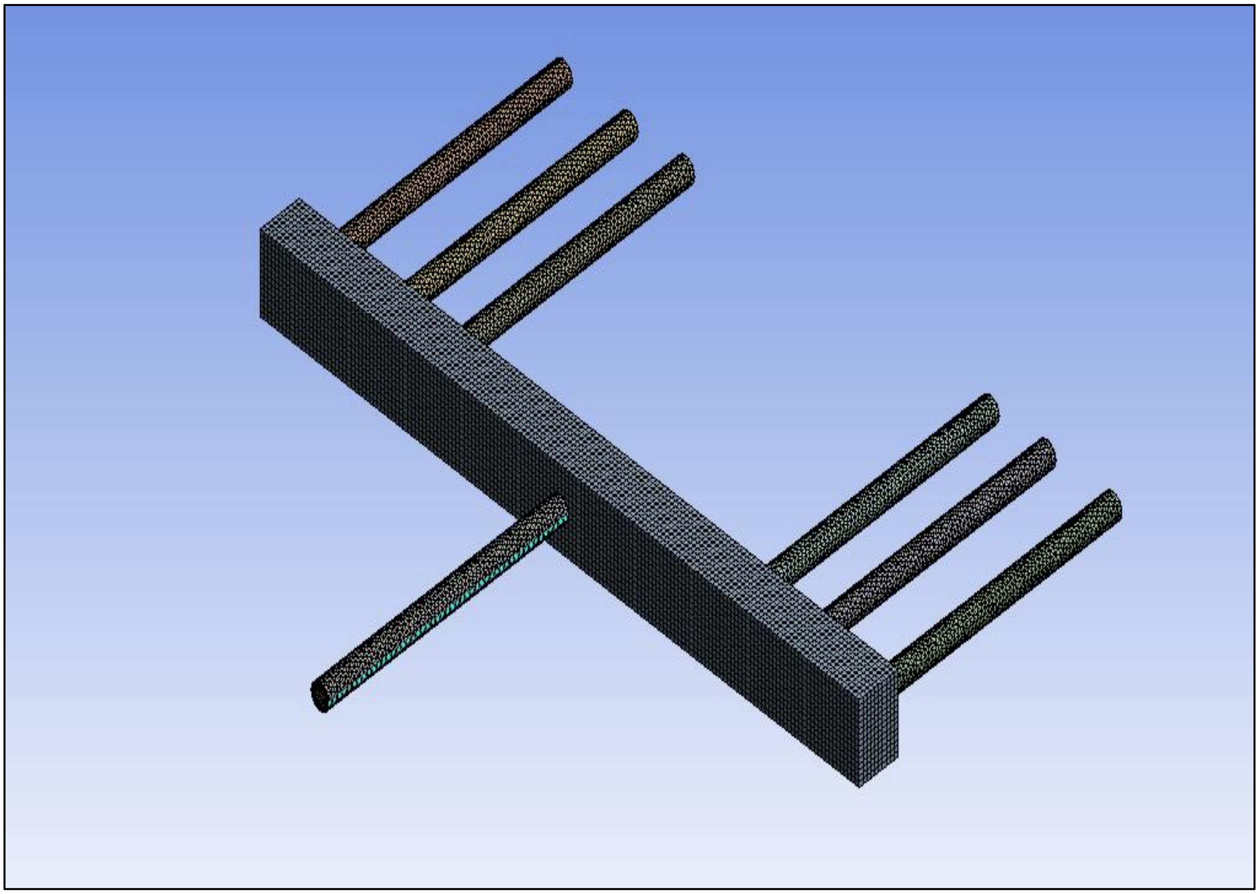

Figure 6 Supply Server Manifold A

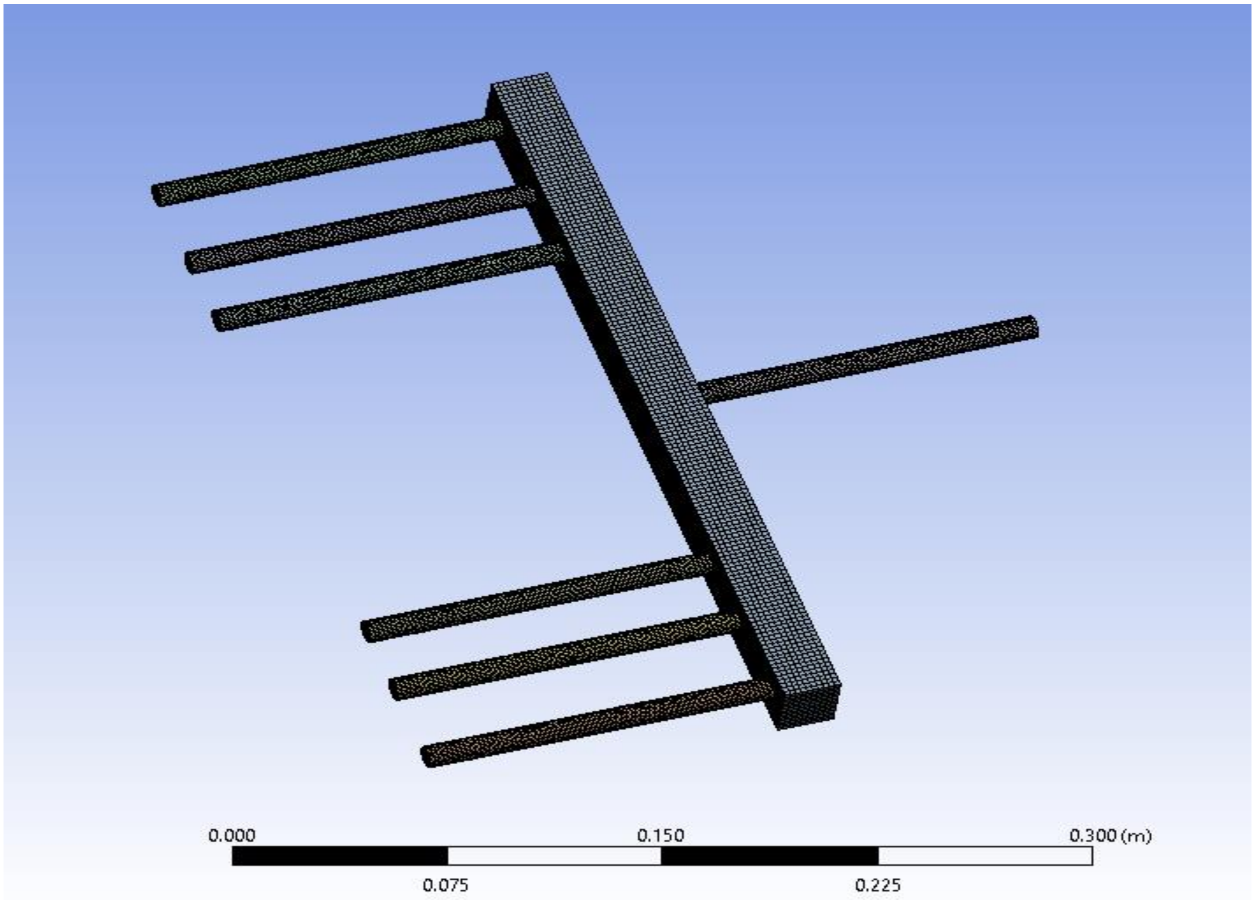

Figure 7 Return Server Manifold A

1.8 Server Manifold A with pipe kinks

Server Manifold pipes are not always straight when fitted in the servers. Sometimes it undergoes kinks in pipe which we have considered in this part. Outlet pipes of supply server manifold A and inlet pipes of return server manifold A were given kinks in the center. Figure 8 shows the kinks given on the pipes. Here same procedure was repeated as in Server Manifold A to calculate the pressure drop across supply and return server manifolds with kinks at two different temperatures 35^{o}C and 45^{o}C and flow rate 4lpm,6lpm, and 8lpm for supply server manifold A with kinks and total flow rate of 8lpm for inlet of return server manifold A with kinks. Figure 8 is meshing of server manifold A supply with kinks while figure 9 resembles the meshing of server manifold A return with kinks.

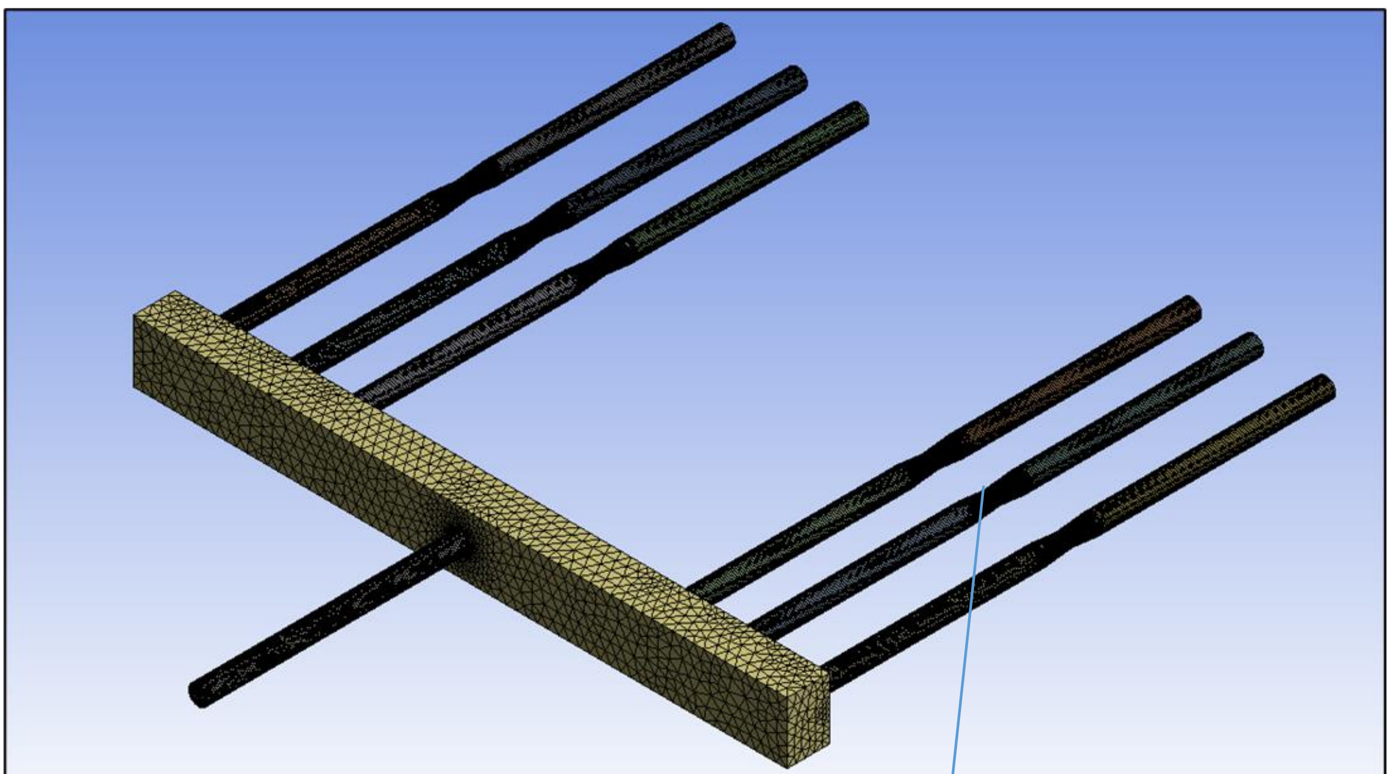

Figure 8:- Server Manifold A supply with pipe kinks.

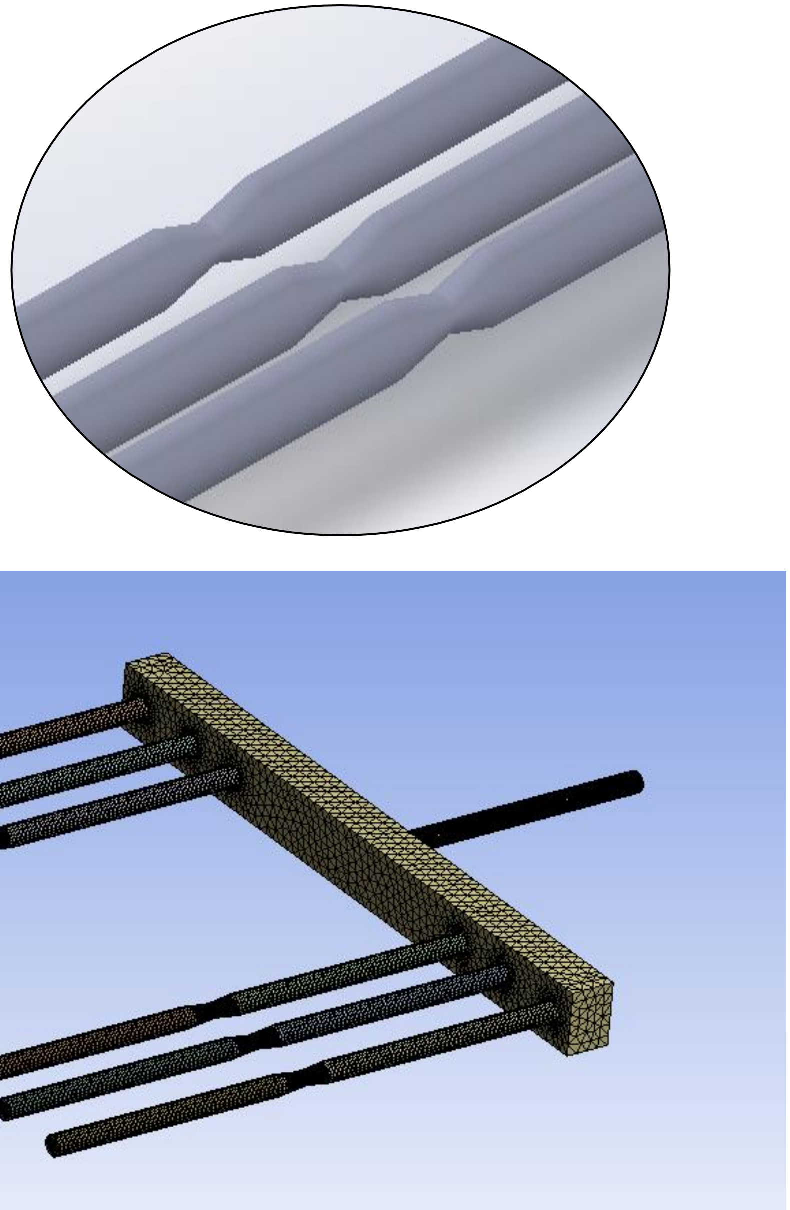

Figure 9:- Server Manifold A return with pipe kinks.

1.9 Server Manifold A with pipe curvature

Server Manifold pipes are not always straight or just undergo with kinks in pipe when fitted in the servers. Sometimes it undergoes with pipe curvature which we have considered in this part. Outlet pipes of supply server manifold A and inlet pipes of return server manifold A were given same curvature throughout the pipe. Figure shows the curvature given on the pipes. Here same procedure was repeated as in Server Manifold A to calculate the pressure drop across supply and return server manifolds with curvature at two different temperatures 35^{o}C and 45^{o}C and flow rate 4lpm,6lpm, and 8lpm for supply server manifold A with curvature and total flow rate of 8lpm for inlet of return server manifold A with curvature. . Figure 10 is meshing of server manifold A supply with curvature while figure 11 resembles the meshing of server manifold A return with curvature.

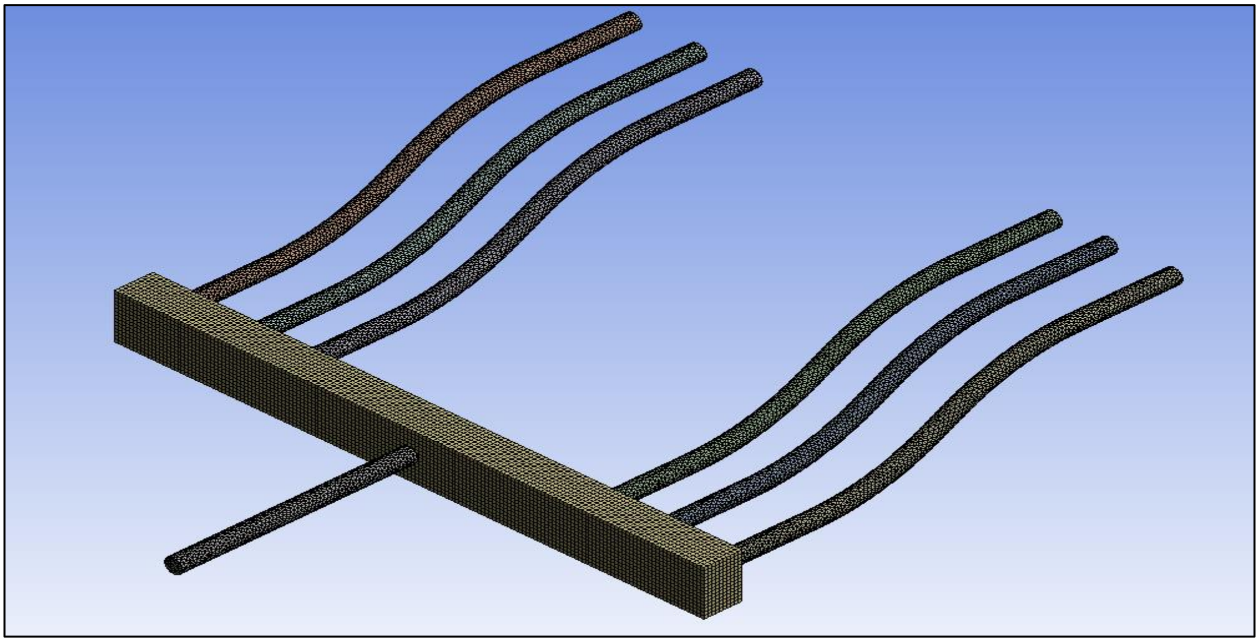

Figure 10:- Server Manifold A supply with curvature.

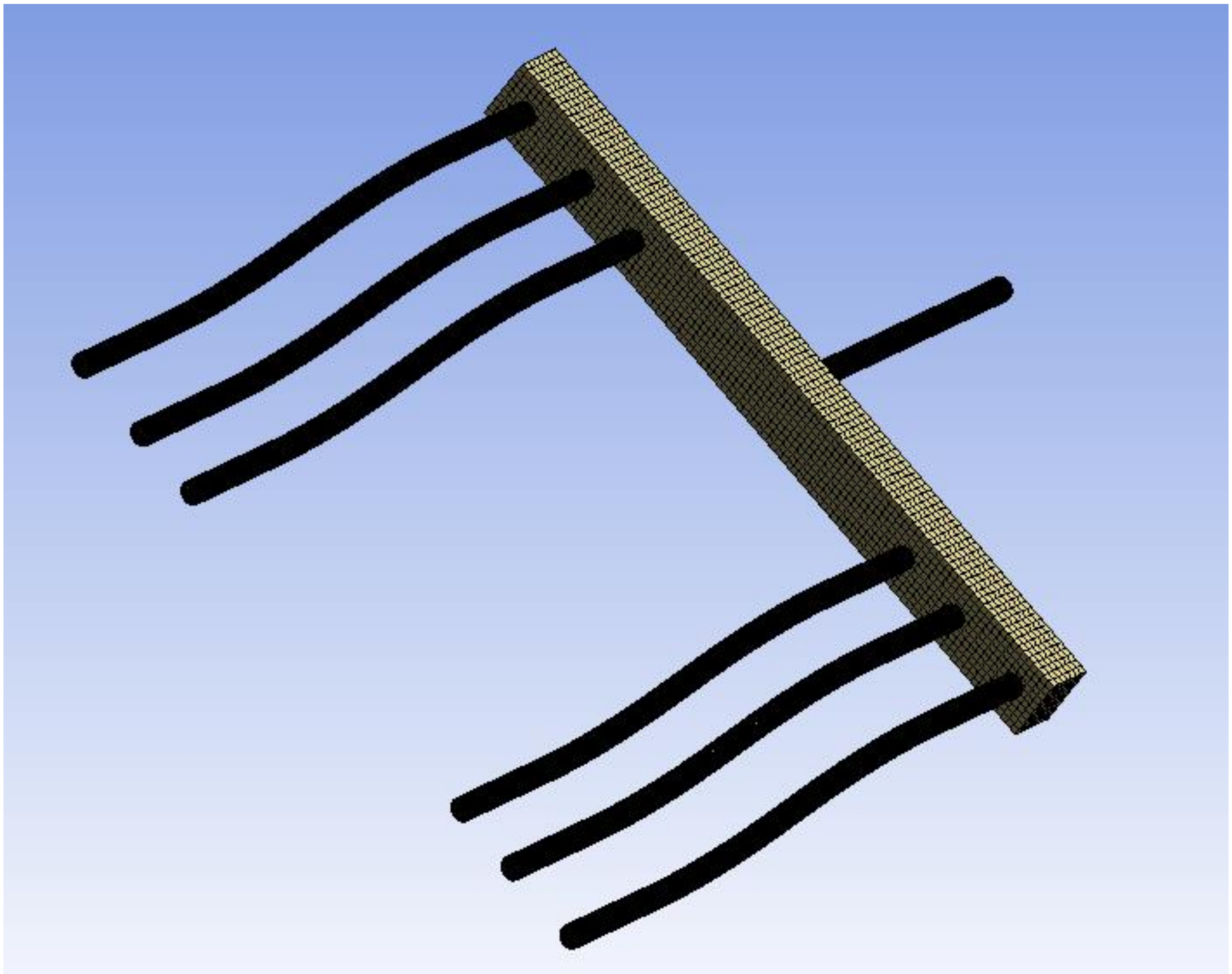

Figure 11:- Server Manifold A return with pipe curvature

1.10 Server Manifold B Baseline

We designed another Server Manifold B Baseline we had in our Lab. We can see in Figure 12 that supply server manifold B that 6 outlet pipes are equally spaced having end pipe diameters smaller and equal with each other while 4 pipes in the middle was larger and equal in diameter. We can also see in Figure 13 for return server manifold B that 6 inlet pipes are equally spaced with 2 middle pipes having smaller and equal diameters compared with other 4 next to them with larger and equal in diameters. With this design change from the server Manifold A of supply and return was made for the server manifold B baseline supply and return. Rest all the same procedure was followed for the calculations as it was for server manifold A to calculate the pressure drop across supply and return server manifold B baseline at two different temperatures 35^{o}C and 45^{o}C and flow rate 4lpm,6lpm, and 8lpm for supply server manifold B baseline and total flow rate of 8lpm for inlet of return server manifold B baseline.

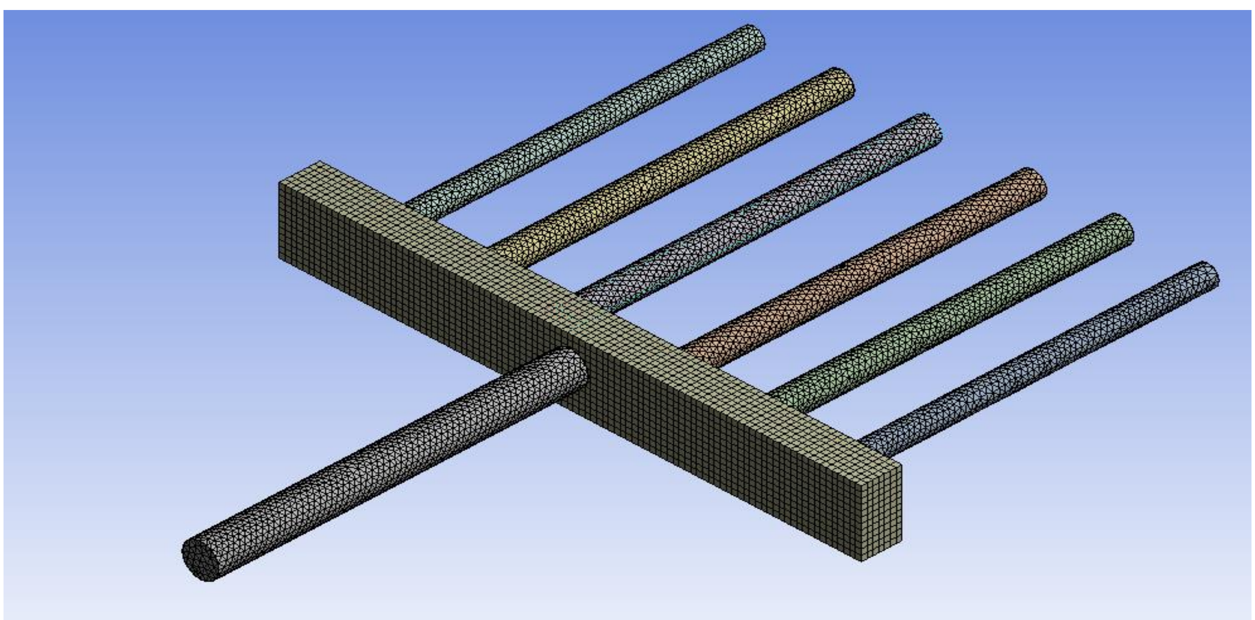

Figure 12:- Server Manifold B Baseline supply.

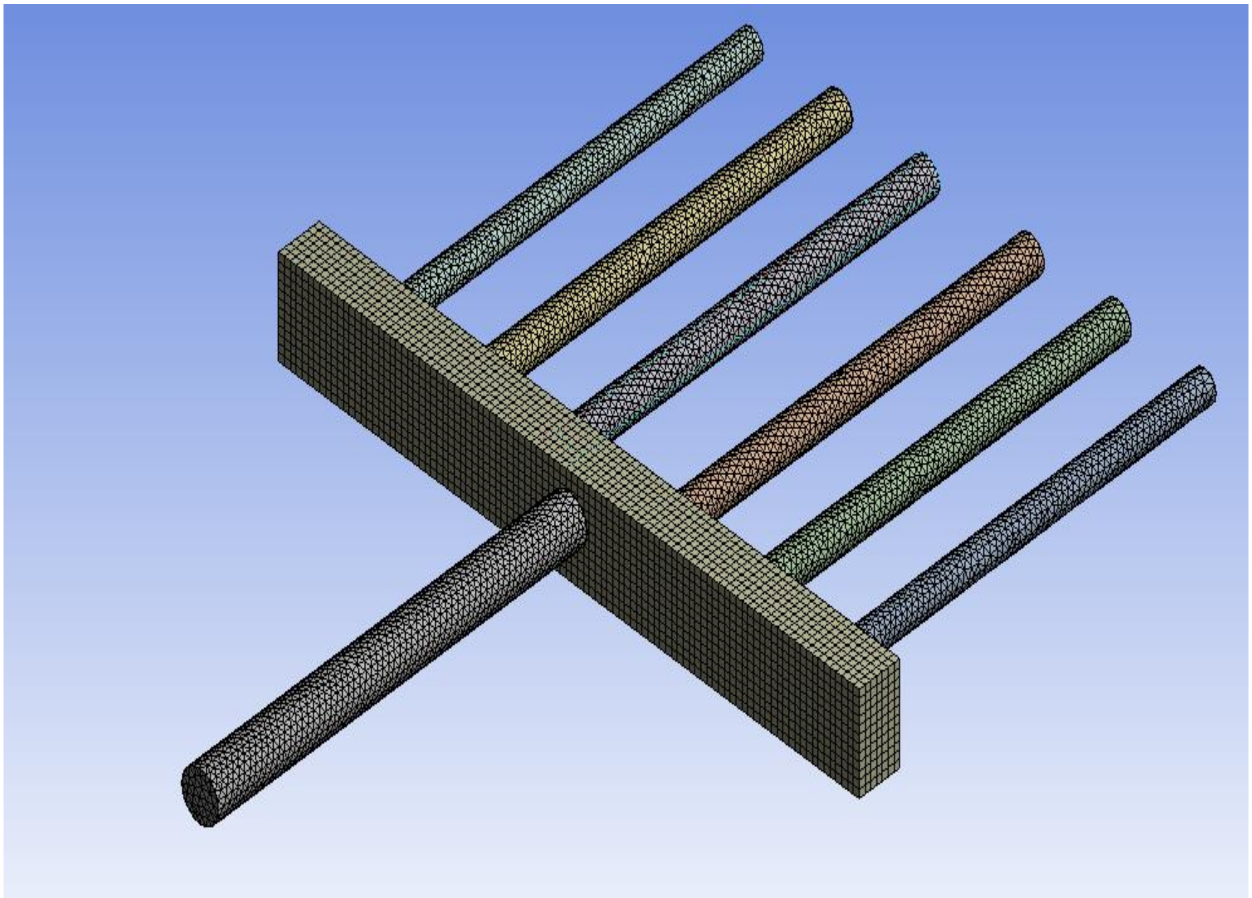

Figure 13:- Server Manifold B Baseline return.

1.11 Manifold A with fillet

Server Manifold A had sharp corner on the pipes we added small fillet at the corners of the pipe for server manifold A to see if it can cause any difference in the pressure drop. Figure 14 shows the meshing of the supply server manifold A with fillet. Figure 15 shows the meshing of the return server manifold A with fillet. Only 1 single simulation was done for supply manifold A with 8lpm flow rate at 35^{o}C inlet temperature. Figure b shows the comparison of the flows of fluid in server manifold A on the left and server manifold A with fillet added to it on the right. We can clearly see that there is recirculation of flow in server manifold A without fillet while there is decrease in recirculation of the flow in manifold with fillet.

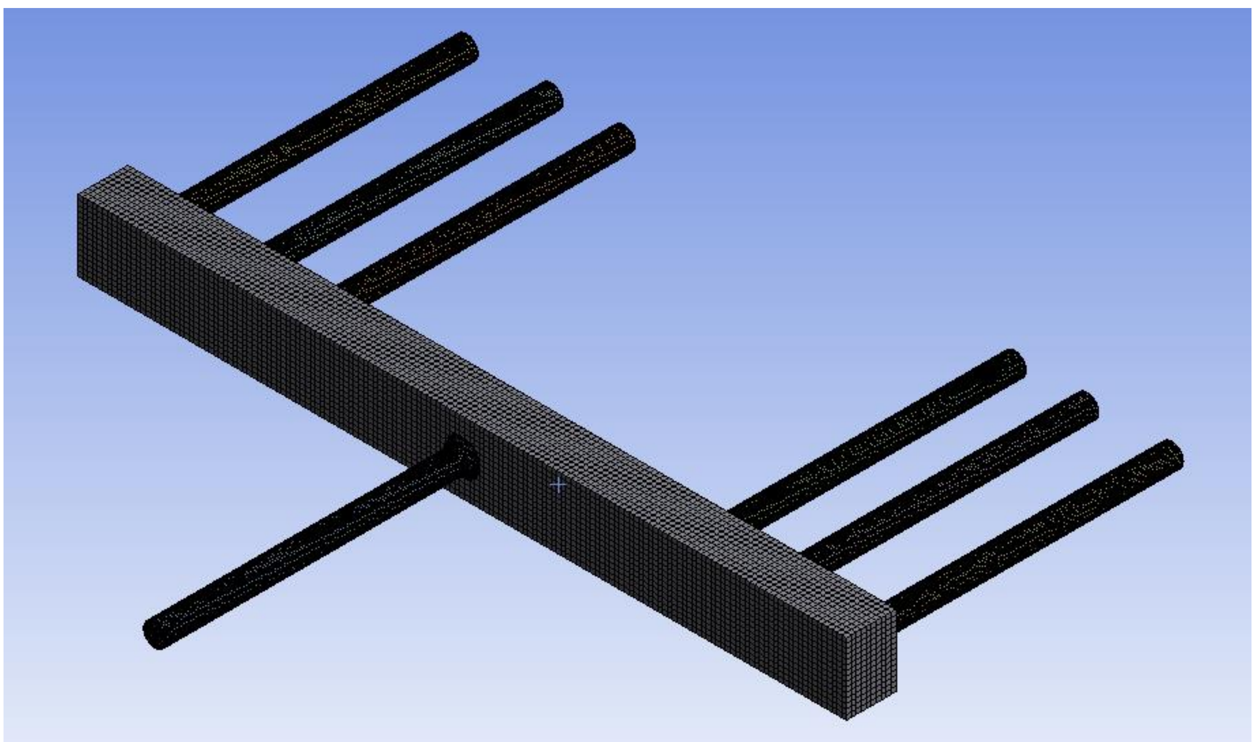

Figure 14:- Meshing of supply Server Manifold A with fillet.

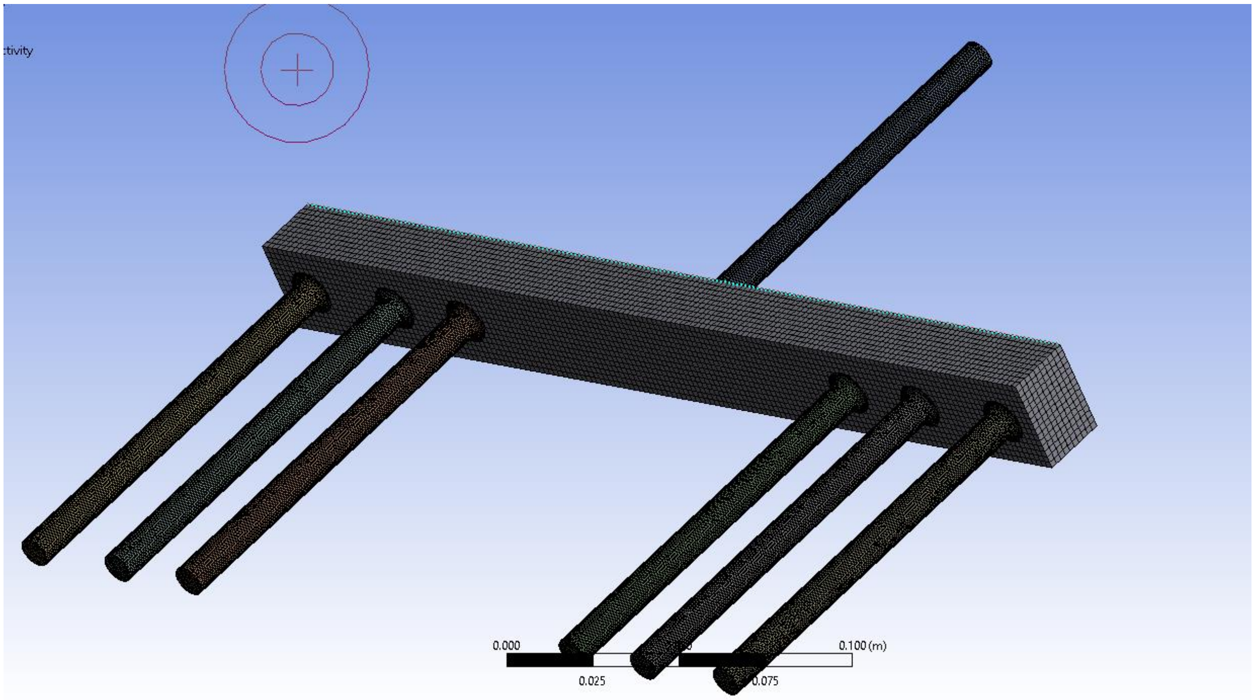

Figure 15:- Meshing of return Server Manifold A with fillet.

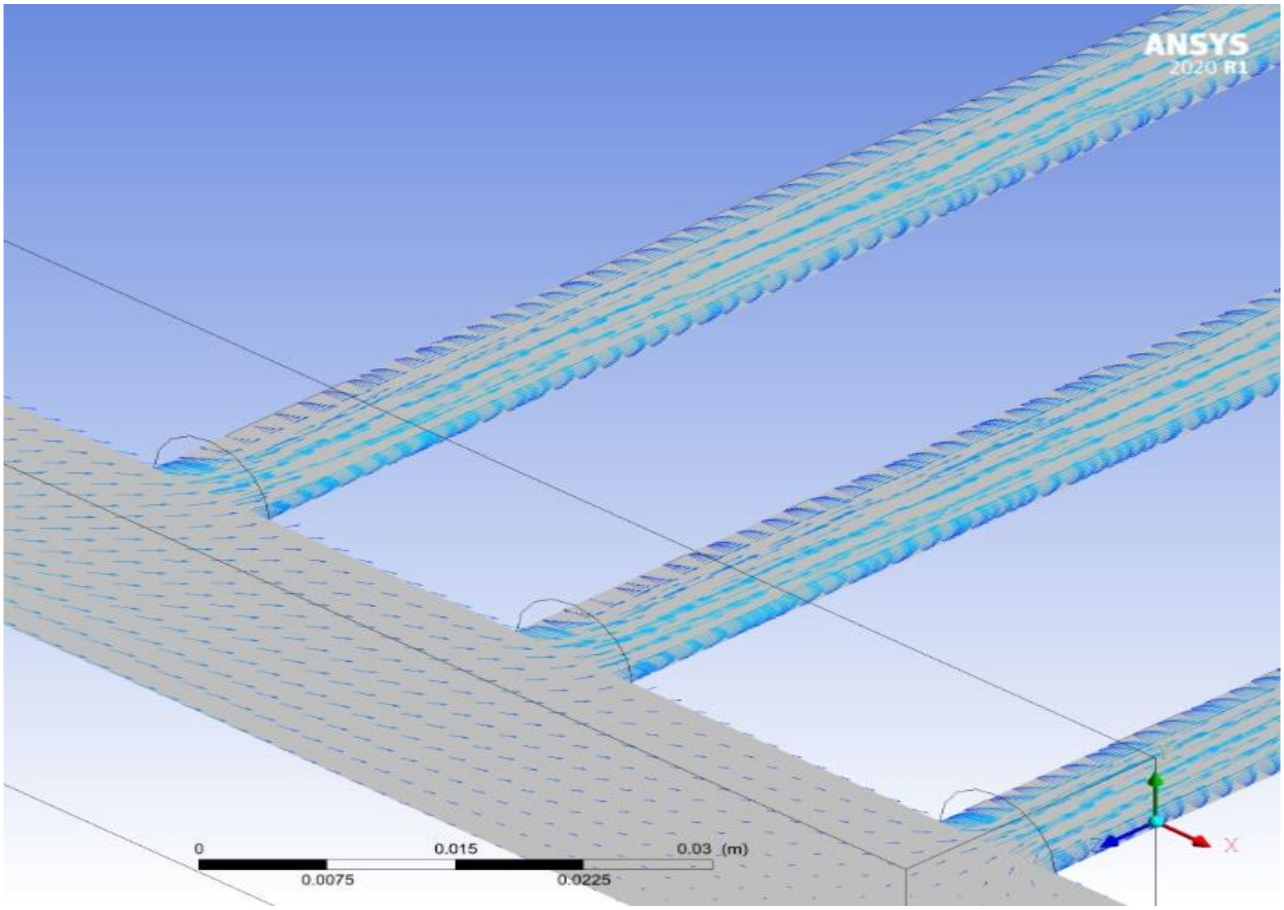

Figure 16:- Fluid flow of Server Manifold A without fillet

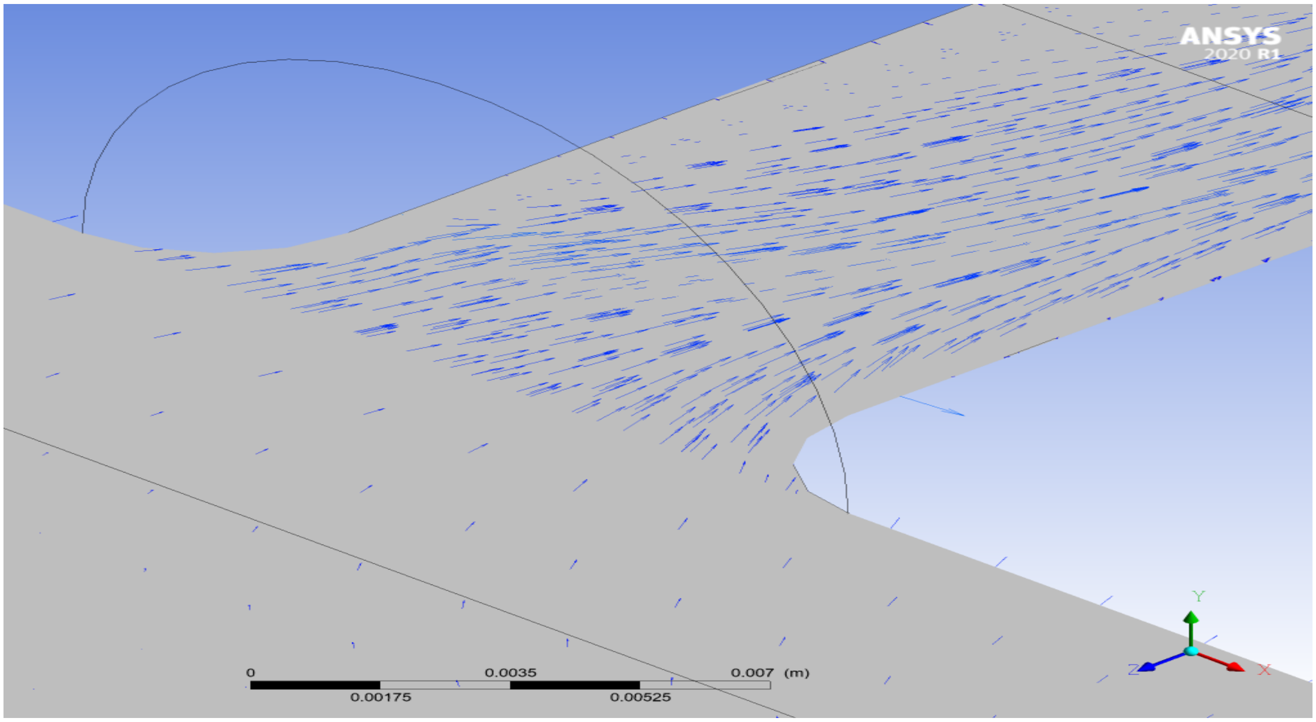

Figure 17:- Fluid flow of server manifold A with fillet.

RESULTS AND DISCUSSION

1.12 Server Manifold A

Figure 18 shows the result Flow rate vs Pressure drop of server manifold A supply for different flow rates 4lpm, 6lpm, and 8lpm at different temperatures 35^{o}C and 45^{o}C respectively. Where the blue line in the graph shows the result for server manifold A supply at 35^{o}C at 4lpm, 6lpm and 8lpm, and red line in the graph shows the result for server manifold A supply at 45^{o}C at 4lpm, 6lpm and 8lpm. Figure 19 shows the Temperature vs Pressure drop of server manifold A return for 8lpm flow rate at different temperatures 35^{o}C and 45^{o}C. We observe that the Total pressure drop of server manifold A from supply to return at 35^{o}C with 8lpm flow rate is 4619.72 Pa. While total pressure drop of server manifold A supply and return at 45^{o}C with 8lpm flow rate is 5399.42 Pa. From the total pressure drop across the server manifold we can clearly notice that there is higher pressure drop at higher temperatures and lower pressure drop at lower temperatures.

While Figure 20 shows the experimental results performed in the lab which shows the result of 6588.66 Pa. pressure drop for 8lpm flow rate. We can clearly see the 18% variation between experimental and CFD results.

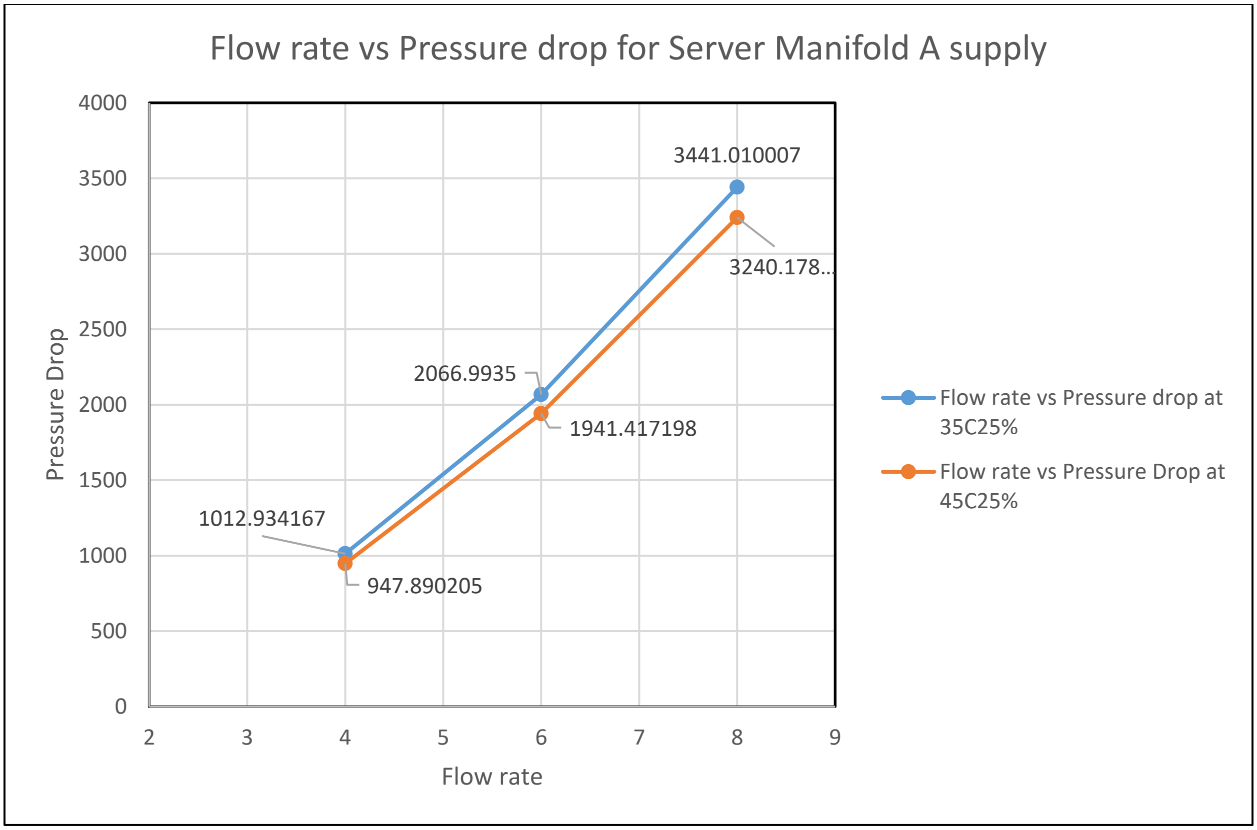

Figure 18:- Flow rate vs Pressure drop for Server Manifold A supply

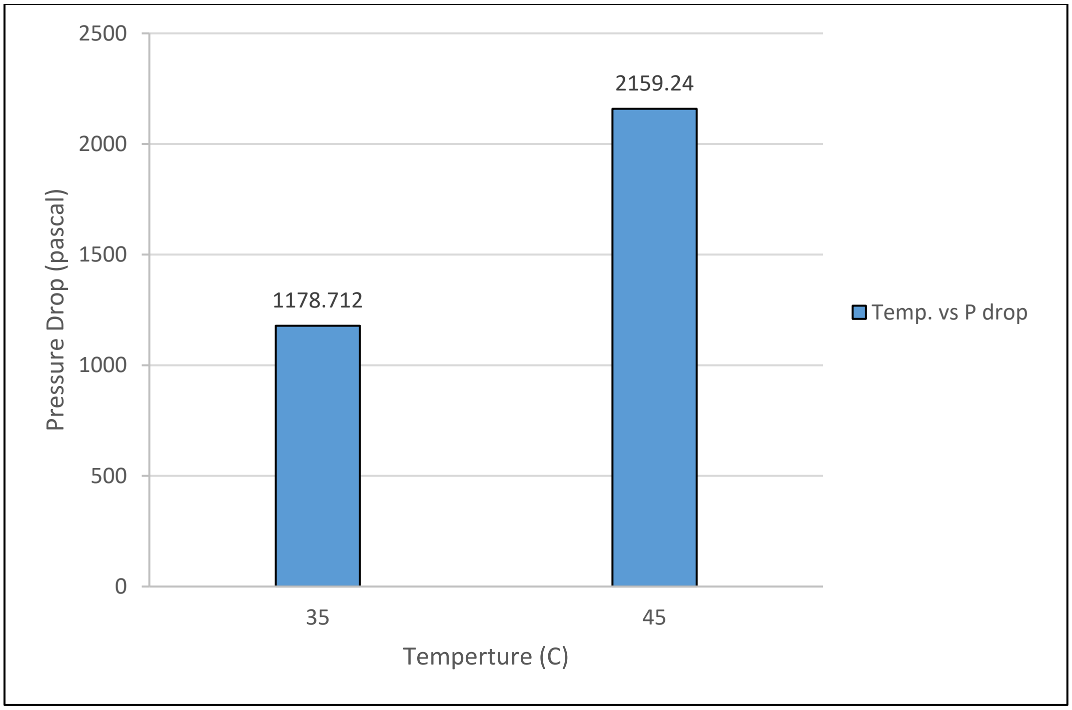

Figure 19:- Temperature vs Pressure drop for Server Manifold A return.

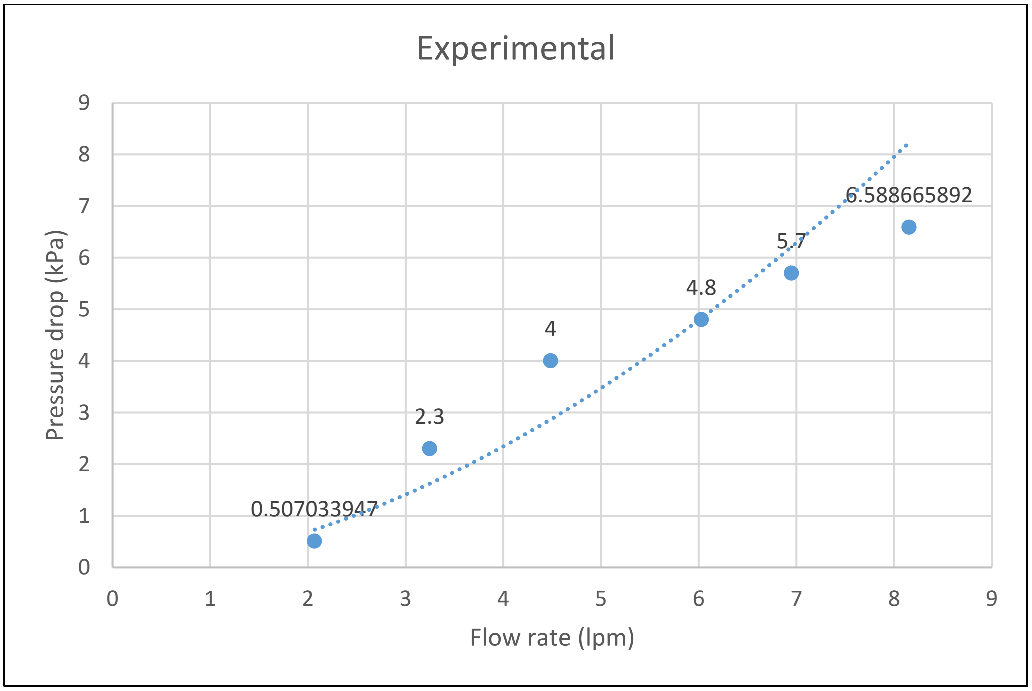

Figure 20:- Flow rate vs Pressure drop Experimental results for Server Manifold A supply and return.

1.13 Server Manifold A with pipe kinks

Figure 21 shows the result Flow rate vs Pressure drop of server manifold A supply with pipe kinks for different flow rates 4lpm, 6lpm, and 8lpm at different temperatures 35^{o}C and 45^{o}C respectively. Where the blue line in the graph shows the result for server manifold A supply with pipe kinks at 35^{o}C at 4lpm, 6lpm and 8lpm, and red line in the graph shows the result for server manifold A supply with pipe kinks at 45^{o}C at 4lpm, 6lpm and 8lpm. Figure 22 shows the Temperature vs Pressure drop of server manifold A return with pipe kinks for 8lpm flow rate at different temperatures 35^{o}C and 45^{o}C. We observe that the Total pressure drop of server manifold A from supply to return with pipe kinks at 35^{o}C with 8lpm flow rate is 5603.68 Pa. While total pressure drop of server manifold A supply and return with pipe kinks at 45^{o}C with 8lpm flow rate is 5789.03 Pa. From the total pressure drop across the server manifold we can clearly notice that there is 3% increase in the total pressure drop at 8lpm when the temperature is raised from 35^{o}C to 45^{o}C.

We can also notice that when the pipe kinks are introduced in the Server Manifold A there is 17.55% increase in pressure drop in Server Manifold A with pipe kinking than Server Manifold A without pipe kinking for 8lpm flow rate at 35^{o}C inlet temperature.

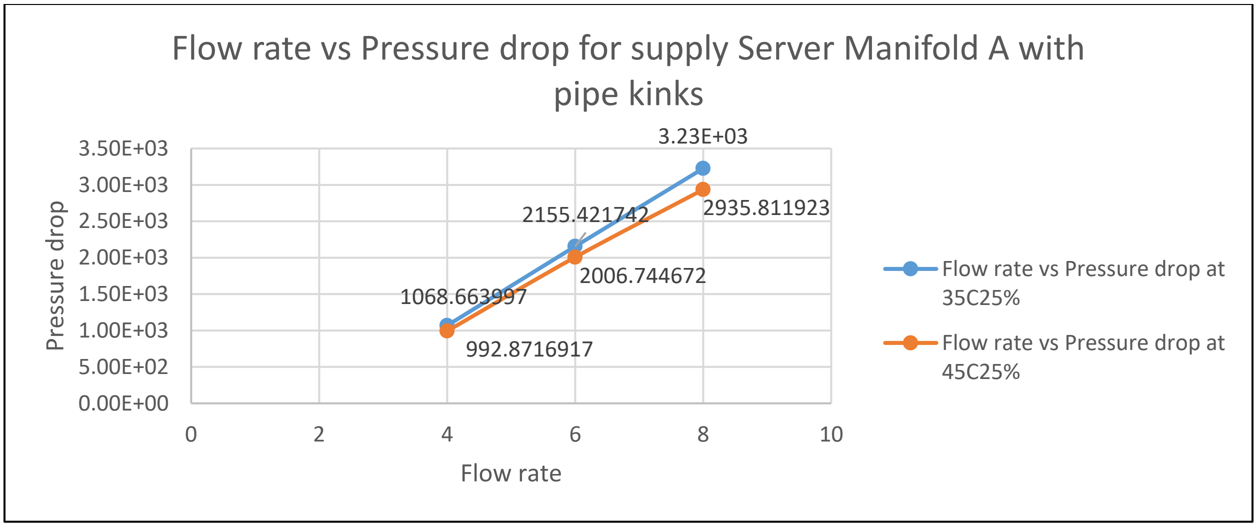

Figure 21:- Flow rate vs Pressure drop for supply Server Manifold A with pipe kinks

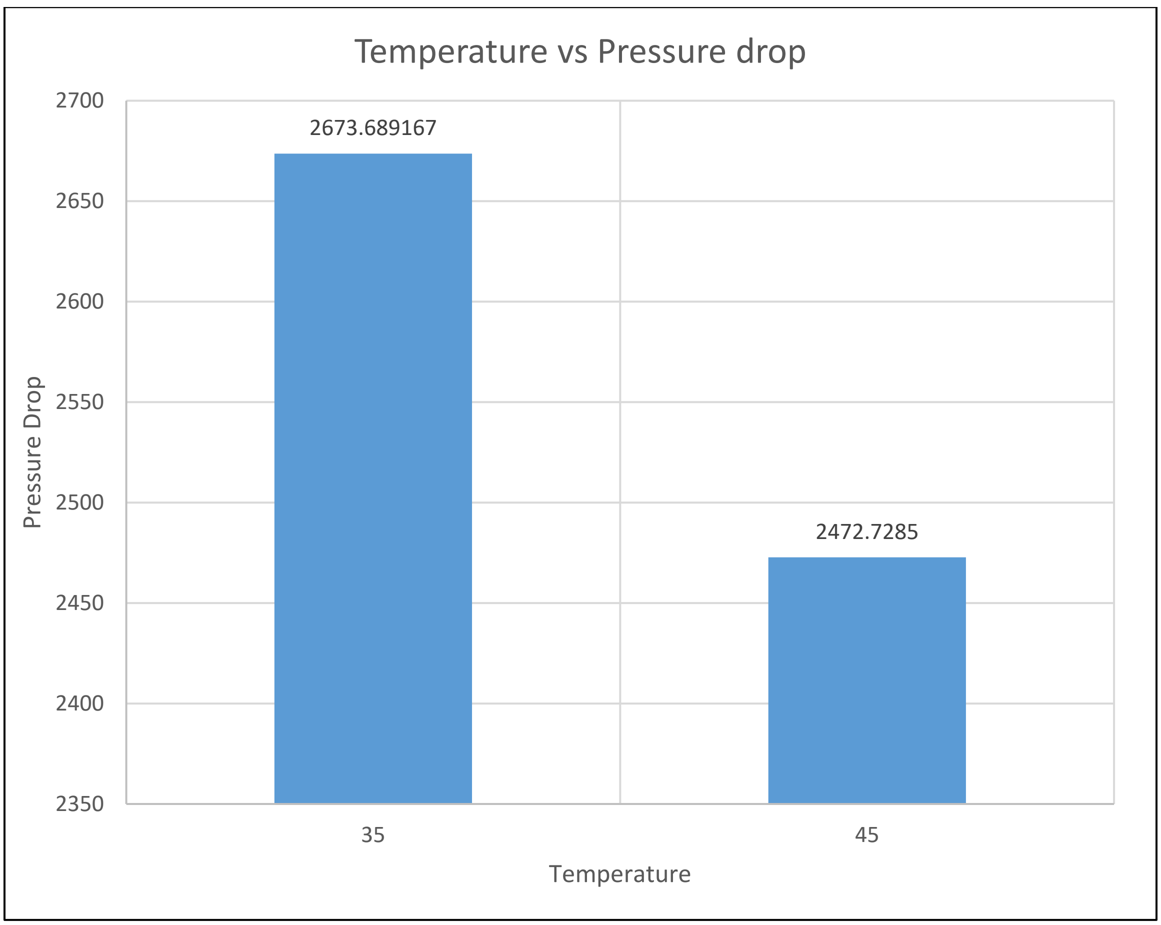

Figure 22:- Temperature vs Pressure drop for return Server Manifold A with pipe kinks.

1.14 Server Manifold A with pipe curvature

Figure 23 shows the result Flow rate vs Pressure drop of server manifold A supply with pipe curvature for different flow rates 4lpm, 6lpm, and 8lpm at different temperatures 35^{o}C and 45^{o}C respectively. Where the blue line in the graph shows the result for server manifold A supply with pipe curvature at 35^{o}C at 4lpm, 6lpm and 8lpm, and red line in the graph shows the result for server manifold A supply with curvature at 45^{o}C at 4lpm, 6lpm and 8lpm. Figure 24 shows the Temperature vs Pressure drop of server manifold A return with curvature for 8lpm flow rate at different temperatures 35^{o}C and 45^{o}C. We observe that the Total pressure drop of server manifold A from supply to return with curvature at 35^{o}C with 8lpm flow rate is 6006.66 Pa. While total pressure drop of server manifold A supply and return with curvature at 45^{o}C with 8lpm flow rate is 5792.36 Pa. From the total pressure drop across the server manifold we can clearly notice that there is 3.56% increase in the total pressure drop at 8lpm when the temperature is raised from 35^{o}C to 45^{o}C.

We can also notice that when the pipe curvature are introduced in the Server Manifold A there is 23.09% increase in pressure drop in Server Manifold A with pipe curvature than Server Manifold A without pipe curvature for 8lpm flow rate at 35^{o}C inlet temperature.

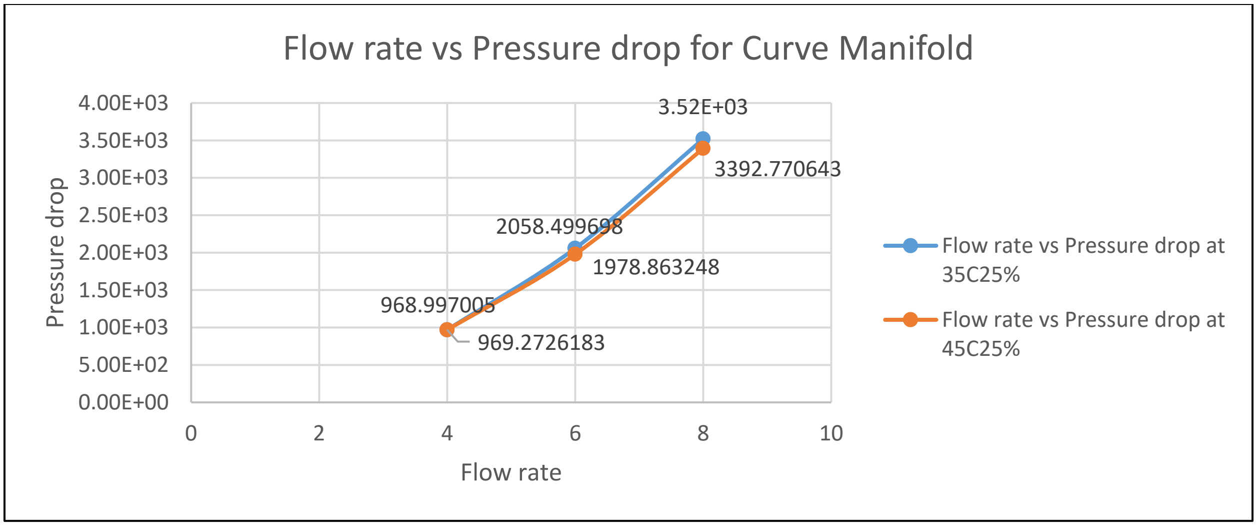

Figure 23:- Flow rate vs Pressure drop for supply Server Manifold A with pipe kinks

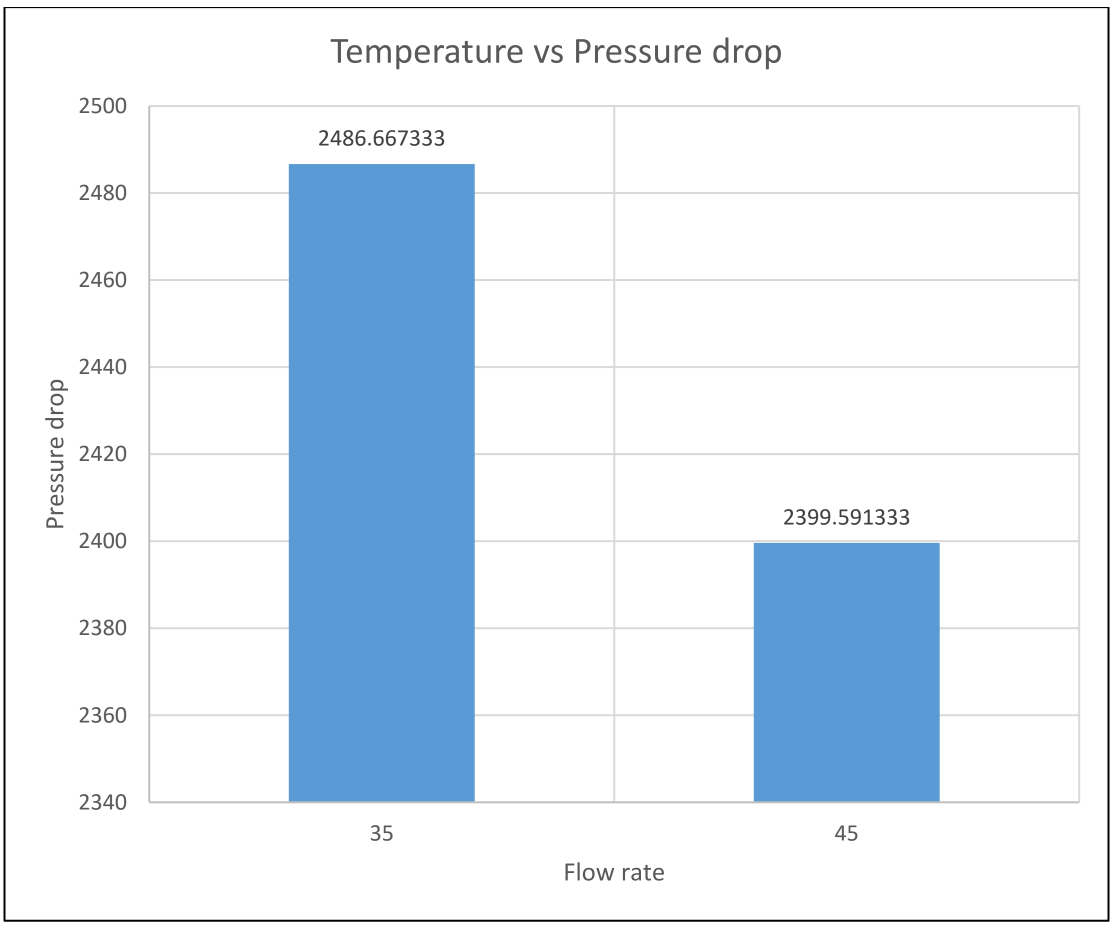

Figure 24:- Temperature vs Pressure drop for return Server Manifold A with pipe curvature

1.15 Server Manifold B Baseline

Figure 25 shows the result Flow rate vs Pressure drop of server manifold B supply for different flow rates 4lpm, 6lpm, and 8lpm at different temperatures 35^{o}C and 45^{o}C respectively. Where the blue line in the graph shows the result for server manifold B supply at 35^{o}C at 4lpm, 6lpm and 8lpm, and red line in the graph shows the result for server manifold B supply at 45^{o}C at 4lpm, 6lpm and 8lpm. Figure 26 shows the Temperature vs Pressure drop of server manifold B return for 8lpm flow rate at different temperatures 35^{o}C and 45^{o}C. We observe that the Total pressure drop of server manifold B from supply to return at 35^{o}C with 8lpm flow rate is 3741.31 Pa. While total pressure drop of server manifold B supply and return at 45^{o}C with 8lpm flow rate is 3610.72 Pa. From the total pressure drop across the server manifold we can clearly notice that there is 3.49% increase in the total pressure drop at 8lpm when the temperature is raised from 35^{o}C to 45^{o}C.

We can also notice that there is 19.01% decrease in total pressure drop of Server Manifold B Baseline than total pressure drop of Server Manifold A at 8lpm flow rate with 35^{o}C inlet temperature.

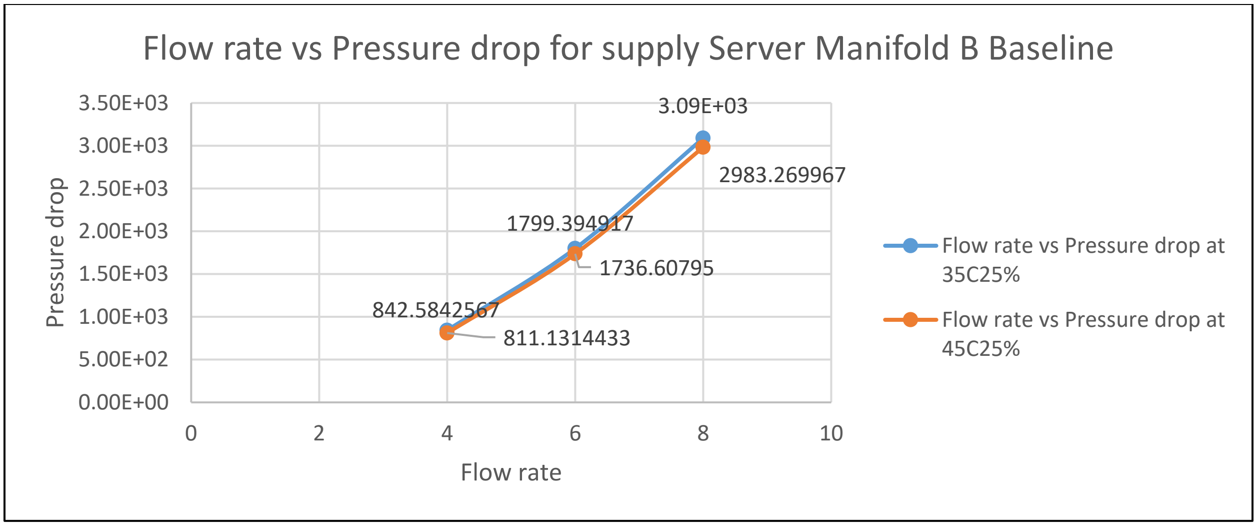

Figure 25:- Flow rate vs Pressure drop for supply Server Manifold B Baseline

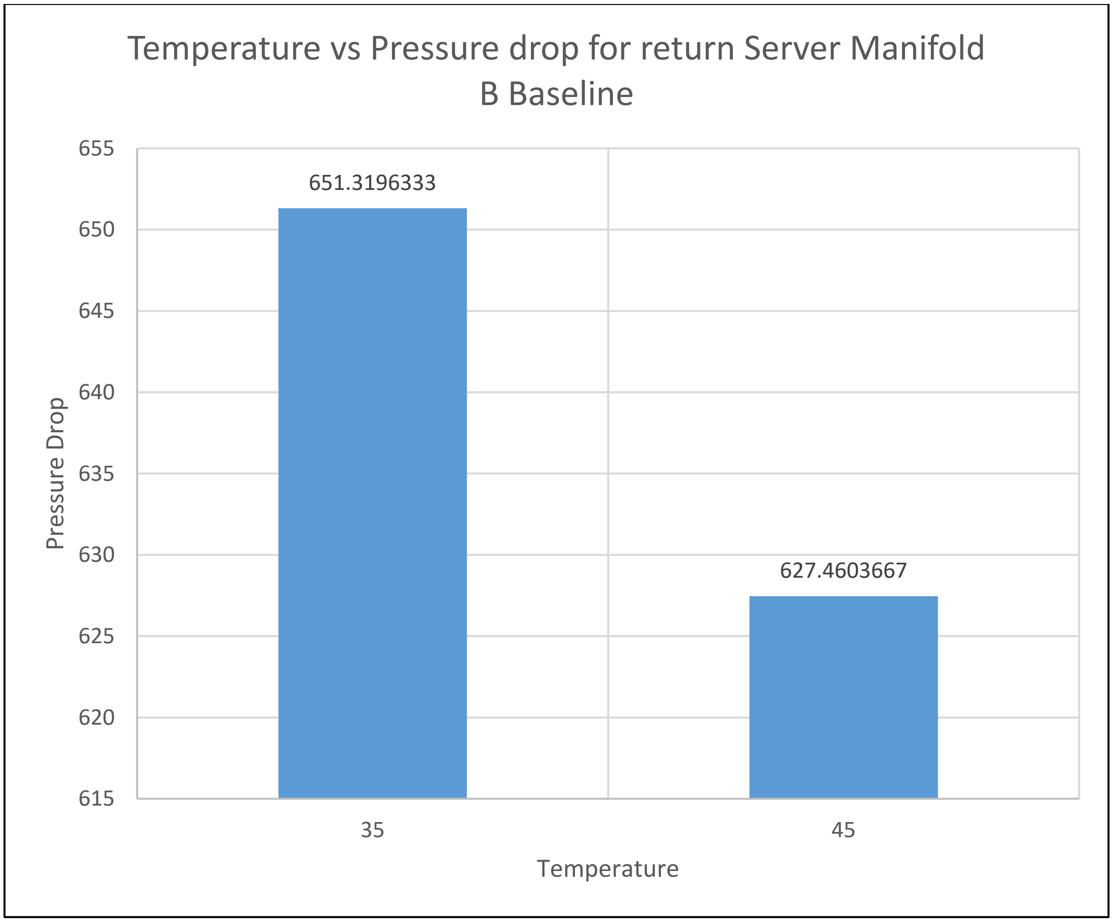

Figure 26:- Temperature vs Pressure drop for return Server Manifold B Baseline.

CONCLUSION AND FUTURE SCOPE

Server Manifold of 2 different types were studied and named as Server Manifold A and Server Manifold B Baseline. Different cases were performed on Server Manifold A like pipe kinking, pipe curvature and pipe fillet and total pressure drops were calculated and compared across the manifolds at different flow rates of 4lpm, 6lpm, and 8lpm. and inlet temperatures at 35^{o}C and 45^{o}C.

From all the above results we concluded few things. We saw that there was a 14.44% increase in total pressure drop when the inlet temperatures were increase in Server Manifold A. Also, we saw an increase of 17.55% pressure drop when pipe kinks were introduced in Server Manifold A and 23.09% pressure drop increase in Server Manifold A with curvature. When we compared Server Manifold A and Server Manifold B Baseline from the results we noticed that there was 19.01% increase in pressure drop at 8lpm flow rate with for 35^{o}C inlet temperature, Server Manifold A than pressure drop of Server Manifold B Baseline from which we can conclude that design of Server Manifold B Baseline is more effective. We also noticed that when fillet was added to Server Manifold A the pressure drop decreased 24.15% for Server Manifold A with fillet at 8lpm with 35^{o}C inlet temperature. We also saw the decrease of recirculation of flow when fillet was added to the Server Manifold A.

For the future scope we can perform similar simulations for the manifold with different flow rates at different temperatures by giving different materials to the pipes and by introducing various forms of kinks and bends or curvatures on the pipes. We can als give different surface roughness to the internal pipes or by using different liquid coolants to see the most efficient Manifold which can be used for the conditions provided.

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