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Manifold Optimization of an Internal Combustion Engine by Using CFD Analysis

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Abstract:

In today's world, major objectives of engine designers are to achieve the twin goals of best performance and lowest possible emission levels. Excellent engine performance requires the simultaneous combination of good combustion and good engine breathing. An internal combustion engine (ICE) is a heat engine where the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. In an internal combustion engine the expansion of the high-temperature and high-pressure gases produced by combustion apply direct force to some component of the engine. Exhaust manifold is one of the most critical components of an IC Engine. The designing of exhaust manifold is a complex procedure and is dependent on many parameters viz. back pressure, exhaust velocity, mechanical efficiency etc. Preference for any of this parameter varies as per designers needs. Usually fuel economy, emissions and power requirement are three different streams or thought regarding exhaust manifold design. In this paper, an existing model of an engine Exhaust Manifold is modelled in 3D modelling software. The design of the exhaust manifold is changed. In existing model the bend radius is 48 mm and exhaust is on one side, Modified model has bend radius of 48 mm and exhaust is at the centre of header, the models are modeled in Pro/Engineer. CFD analysis is done on both models at different mass flow rates of 0.07, 0.13 and 0.68. Thermal analysis is done for both models using different materials chromium, copper, manganese, nickel and stainless steel.

Keywords: ***IC Engine, Combustion, CFD Analysis, Tabular Steel , Exhaust Velocity and Back Pressure.***

Introduction:

The Exhaust Manifold is the key component in the exhaust system on a vehicle. It is responsible for collecting the exhaust gas from the engine's cylinder heads and sending it down to the exhaust pipe. At the same time, it prevents any toxic exhaust fumes from leaking into the passenger area of the vehicle. Exhaust manifolds come in two main design styles, commonly referred to as four-into-one and four-into-two exhaust manifolds. Most exhaust manifolds are made from cast iron, but aftermarket versions are often made from welded tubular steel. A damaged exhaust manifold should be replaced immediately, and car owners in the market for one need to know which features to pay attention to in order to find the right one.

An exhaust manifold is a series of connected pipes that bolt directly onto the engine head. It is an integral part of the exhaust system. Hot exhaust gas from the exhaust ports on the engine's cylinder head is funneled through the pipes and into a single collector pipe. From there, it is sent to the exhaust pipe. Exhaust manifolds are a necessary component of the exhaust system. Their design is optimized to ensure exhaust gases flow efficiently from the engine combustion chamber without creating any back pressure. A properly functioning exhaust manifold is important to prevent uneven power and engine vibrations.

Exhaust manifolds are made either from cast iron or one of a few types of steel. The majority of exhaust manifolds are made from cast iron, as it is relatively inexpensive and lasts a long time. The drawbacks to cast iron manifolds are that they are quite heavy and tend to get brittle with age and exposure to the heat cycles of an engine. Tubular steel exhaust manifolds are known for having better exhaust flow and are, therefore, found on many performance vehicles. Stainless steel exhaust manifolds are the most expensive, but are rust-resistant and extremely long lasting. Less expensive aluminized steel manifold offer many of the benefits of stainless ones, but will rust if the outer layer is scratched.

Exposure to the normal heat cycles of an engine can cause cracks in an exhaust manifold. As the vehicle continues to age, the cracks turn into holes. Once this happens, the vehicle engine sounds extremely loud and there is a likely chance that toxic fumes are entering the cabin of the vehicle. The gaskets on the exhaust manifold are equally important, and their failure has the same results. Other exhaust manifold components that are subject to failure include the exhaust system hangers, which are designed to hold up the entire system. These can break off, leaving the whole weight of the exhaust system to be carried by the manifold, and eventually causing it to fail.

Dynamic Exhaust Geometry

Today's understanding of exhaust systems and fluid dynamics has given rise to a number of mechanical improvements. One such improvement can be seen in the exhaust ultimate power valve ("EXUP") fitted to some Yamaha motorcycles. It constantly adjusts the back pressure within the collector of the exhaust system to enhance pressure wave formation as a function of engine speed. This ensures good low to mid-range performance.

At low engine speeds the wave pressure within the pipe network is low. A full oscillation of the Helmholtz resonance occurs before the exhaust valve is closed, and to increase low-speed torque, large amplitude exhaust pressure waves are artificially induced. This is achieved by partial closing of an internal valve within the exhaust the EXUP valve at the point where the four primary pipes from the cylinders join. This junction point essentially behaves as an artificial atmosphere; hence the alteration of the pressure at this point controls the behaviour of reflected waves at this sudden increase in area discontinuity. Closing the valve increases the local pressure, thus inducing the formation of larger amplitude negative reflected expansion waves. This enhances low speed torque up to a speed at which the loss due to increased back pressure outweighs the EXUP tuning effect. At higher speeds the EXUP valve is fully opened and the exhaust is allowed to flow freely.

Back Pressure

Engine exhaust backpressure is defined as the exhaust gas pressure that is produced by the engine to overcome the hydraulic resistance of the exhaust system in order to discharge the gases into the atmosphere. The exhaust backpressure is the gage pressure in the exhaust system at the outlet of the exhaust turbine in turbocharged engines or the pressure at the outlet of the exhaust manifold in naturally aspirated engines. The word back may suggest a pressure that is exerted on a fluid against its direction of flow indeed, but there are two reasons to object. First, pressure is a scalar quantity, not a vector quantity, and has no direction. Second, the flow of gas is driven by pressure gradient with the only possible direction of flow being that from a higher to a lower pressure. Gas cannot flow against increasing pressure .It is the engine that pumps the gas by compressing it to a sufficiently high pressure to overcome the flow obstructions in the exhaust system.

Types of Exhaust Manifold

There is a variety of exhaust manifolds and manifolds design, each type affecting the engine characteristics.

Fig : Cast Exhaust Manifold

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Most road car engines use simple cast manifolds that are designed to get the gases out of the cylinder and away from the engine as quickly as possible. They are cheap and easy to manufacture but usually a restriction to the engine. The problem with cast manifolds, especially on an engine that is using valve overlap to overcharge the cylinders, is that they allow interference between the cylinders and hence get in the way of that process.

A tubular manifold solves this problem. They feature a single pipe per cylinder to make sure that each pot is effectively isolated from its neighbors so gases don't interfere with each other. Tubular manifolds can be formed from steel, stainless steel, titanium or lnconel and the individual pipes will join further downstream, where they meet the exhaust pipe. There are two main ways in which these individual pipes join. They can either all meet at the same point or they can become pairs that then join together to form a single pipe to the back of the car and atmosphere. Each of these has a different effect on the engine characteristics.

Exhaust Manifold 4-2-1:

Fig : 4-2-1 Manifold

Whenever the outgoing exhaust gases reach a change in the system which causes an expansion, such as a join with another pipe, a negative pressure pulse is reflected back towards the exhaust valve. If the length of the pipe is correct, then that pulse will just arrive as the valve opens, creating an even greater pressure difference across the valve. This will then get the gases following out of the cylinder even quicker and hence, further improve benefits of trying to overcharge the cylinder with the incoming mixture. However, it will only do this at a narrow engine speed for each change in the exhaust section.

Exhaust Manifold 4-1:

Fig : 4-1 Manifold

Therefore, a four-into-one exhaust manifold will provide one pulse at one engine speed and tends to give benefits higher up in the rev range. However, a manifold that joins pairs first, like a four-into-two-into-one will effectively provide two pulses back to the exhaust valve at different speed, and therefore the outright gains won't be as significant as a four-into-one system, but will be spread further throughout the rev range, as they will occur at a broader range of engine speeds.

Exhaust Manifold Modelling

Existing Model

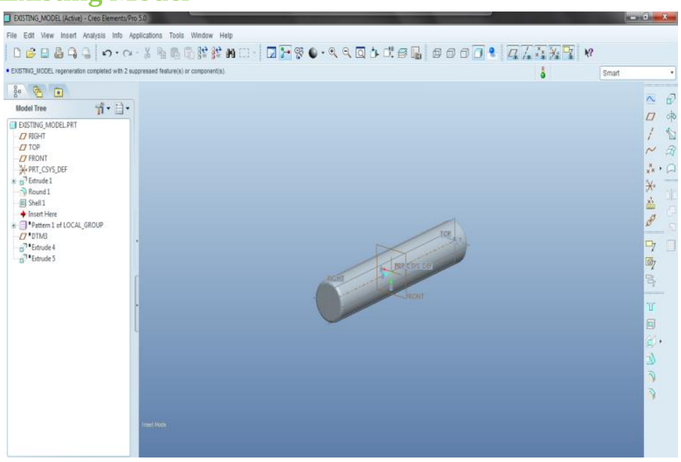

Fig : Header of Existing Model

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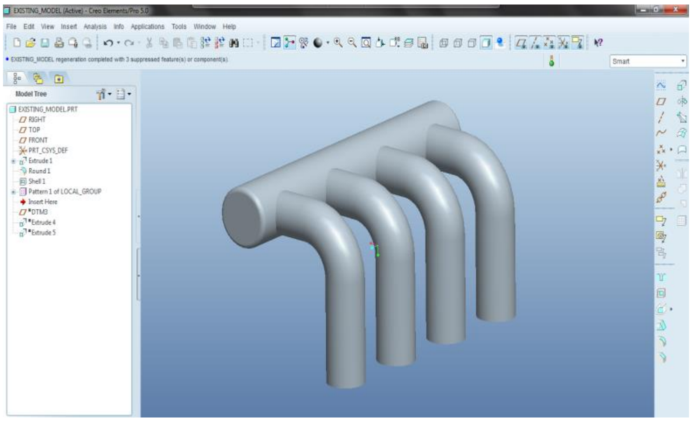

Fig : Inlet ports of Exhaust Manifold

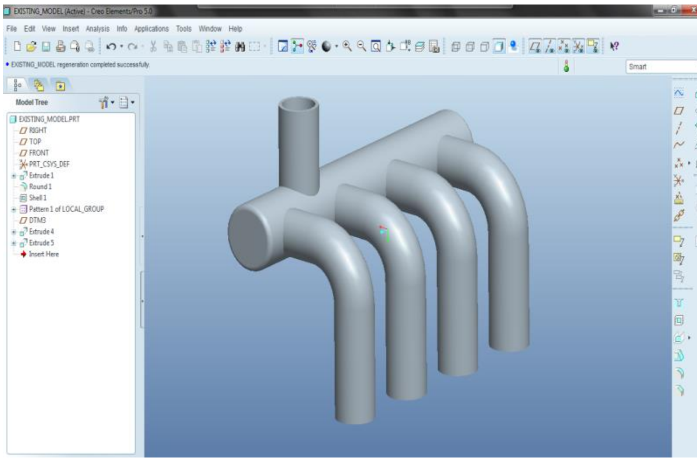

Fig : 3-D Existing Model

2D Drawing

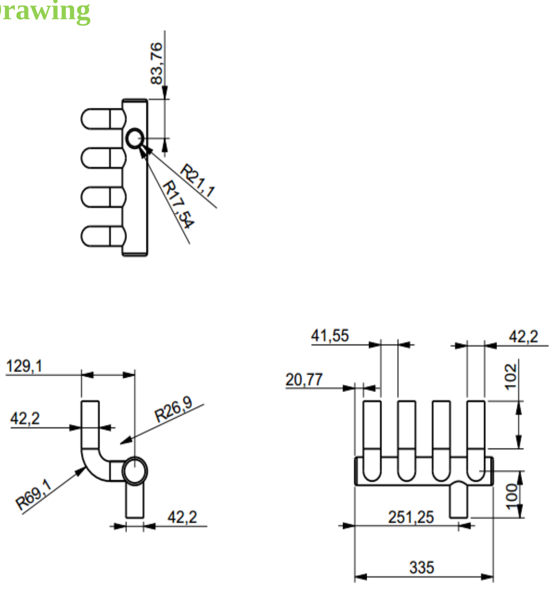

Fig : 2D Drawing of Existing Model

Modified Model

Modified model has bend radius of 48 mm and exhaust is at the centre of header.

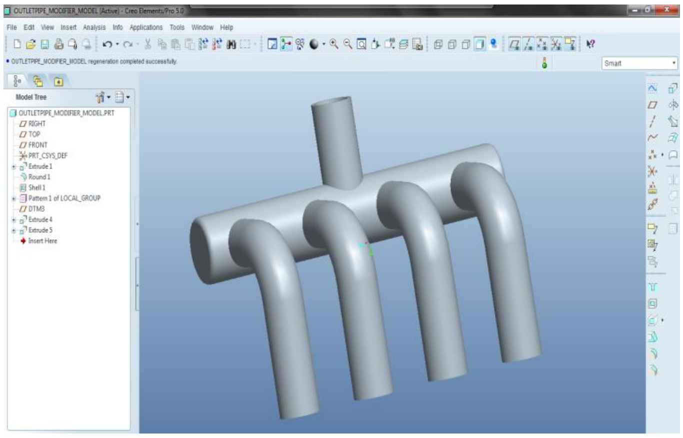

Fig : 3-D Modified Model

2D Drawing

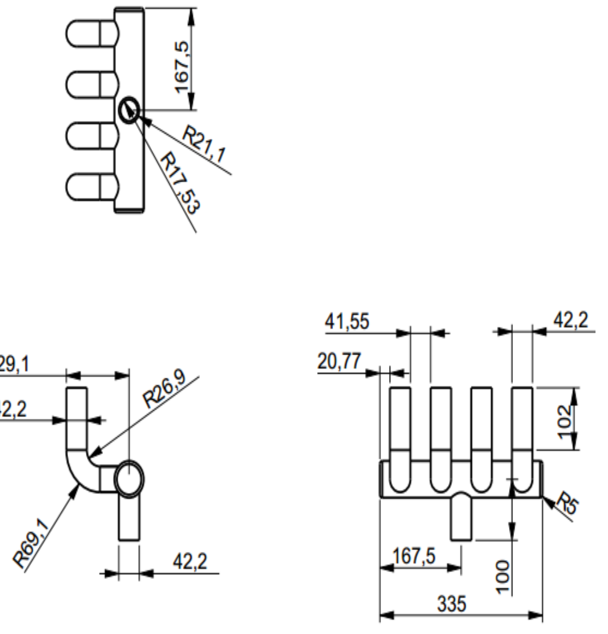

Fig : 2D Diagram of Modified Model

Analysis:

Thermal Analysis Of Exhaust Manifold

Existing Model

Set Units - /units, si, mm, kg, sec, k
File- change Directory-select working folder
File-Change job name-Enter job name
Select element-Solid-20node 90

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MATERIAL: CHROMIUM

Imported model:

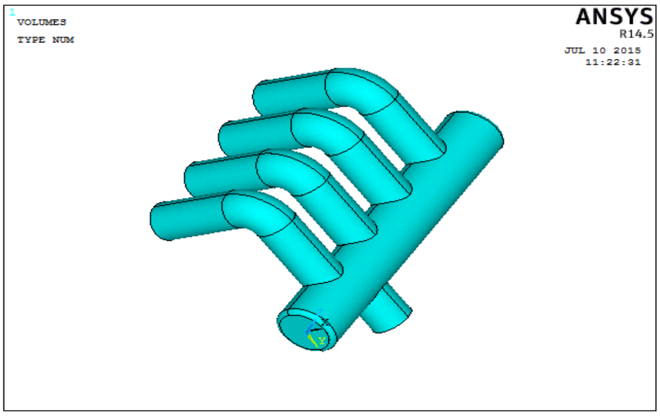

Fig. : Imported Existing Model

Meshed Model:

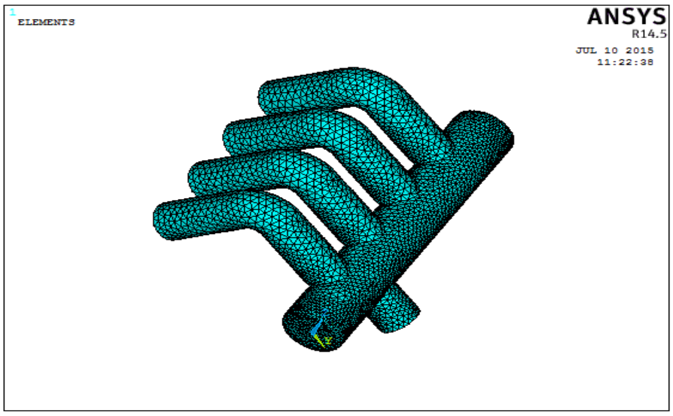

Fig.: Meshed Existing Model

Loads:

Apply Thermal-Temperature- on Area=553K
Convections – on Area-Film Co-efficient – 0.000025 W/mmK
Bulk Temperature – 303 K

Solution – Solve Current LS
General Post Processor - Nodal Solution

NODAL TEMPERATURE:

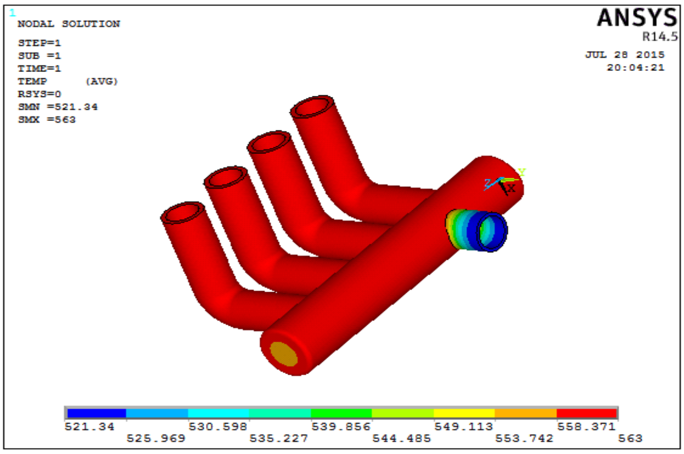

Fig : Nodal Temperature for Chromium Existing Model

THERMAL GRADIENT:

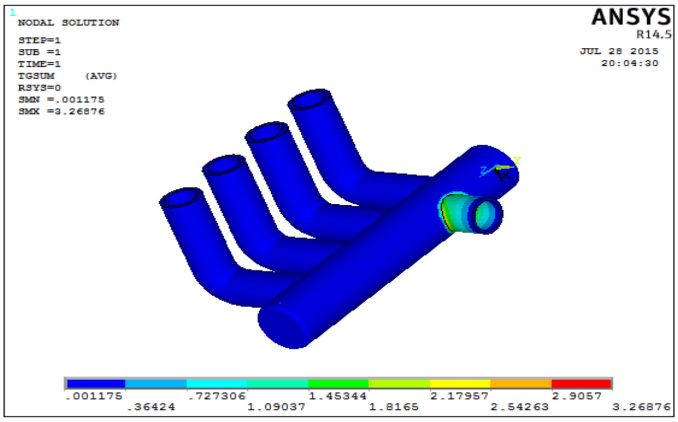

Fig : Thermal Gradient for Chromium Existing Model

HEAT FLUX:

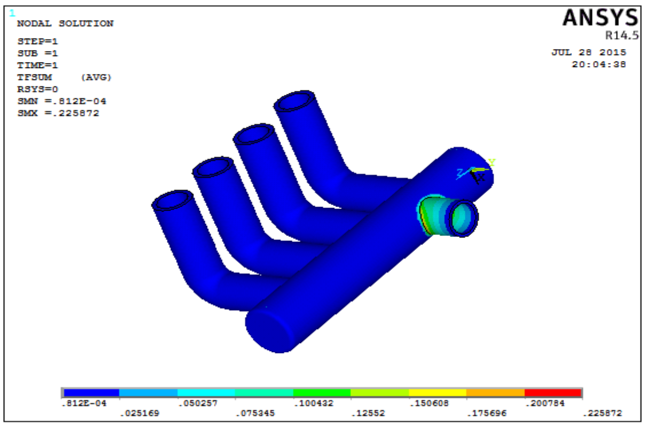

Fig : Heat Flux for Chromium Exixting Model

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MATERIAL: COPPER
NODAL TEMPERATURE:

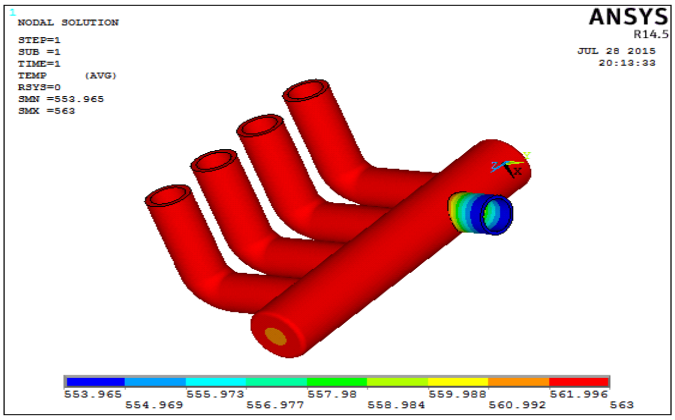

Fig : Nodal Temperature For Copper Exixting Model

THERMAL GRADIENT:

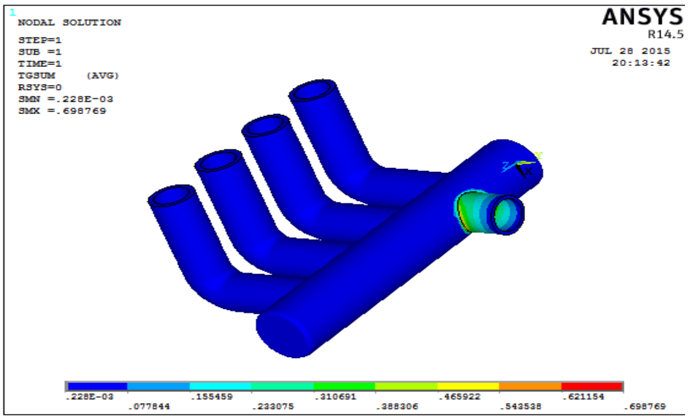

Fig : Thermal Gradient for Copper Existing Model

HEAT FLUX:

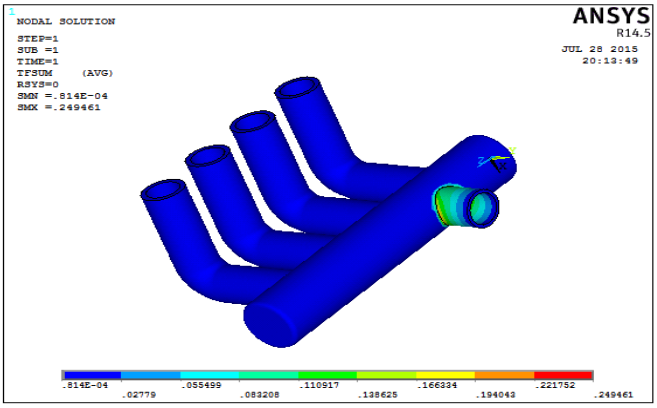

Fig : Heat Flux for Copper Existing Model

MATERIAL: MANGANESE
NODAL TEMPERATURE:

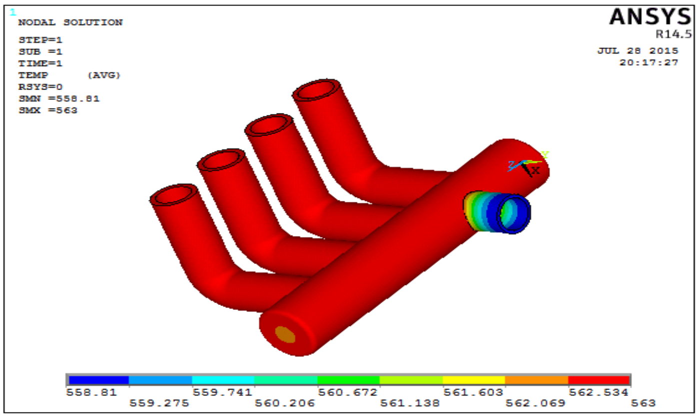

Fig : Nodal Temperature for Manganese Existing Model

THERMAL GRADIENT:

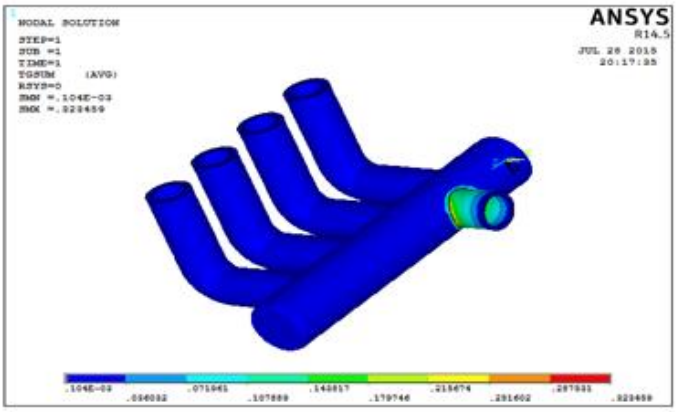

Fig : Thermal Gradient for Manganese Existing Model

HEAT FLUX:

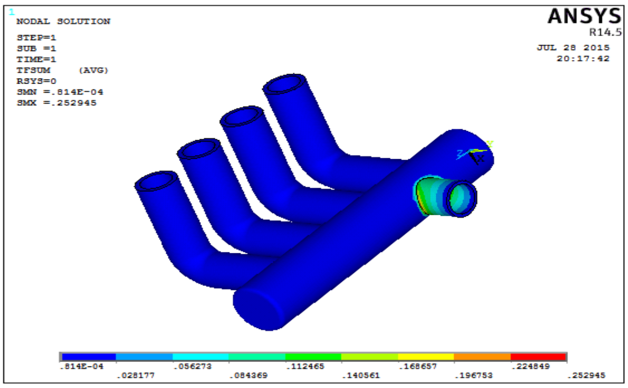

Fig : Heat Flux for Manganese Existing Model

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MATERIAL: NICKEL

NODAL TEMPERATURE:

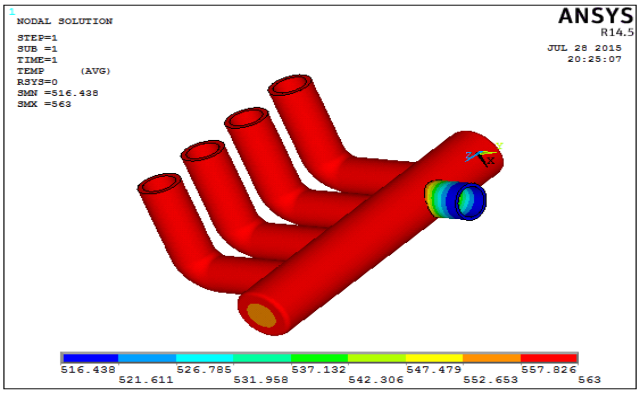

Fig. : Nodal Temperature for Nickel Existing Model

THERMAL GRADIENT:

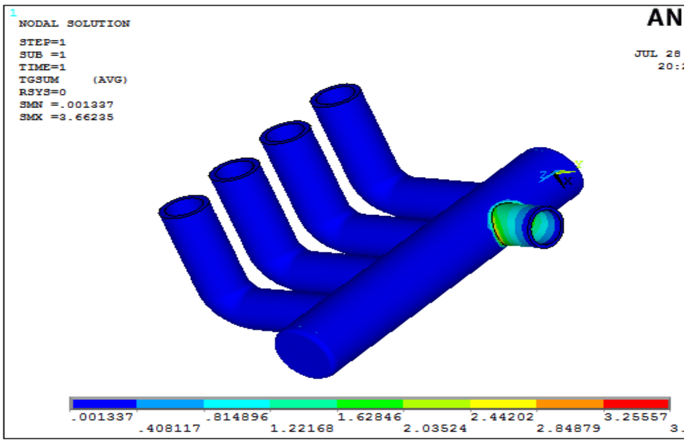

Fig : Thermal Gradient for Nickel Existing Model

HEAT FLUX:

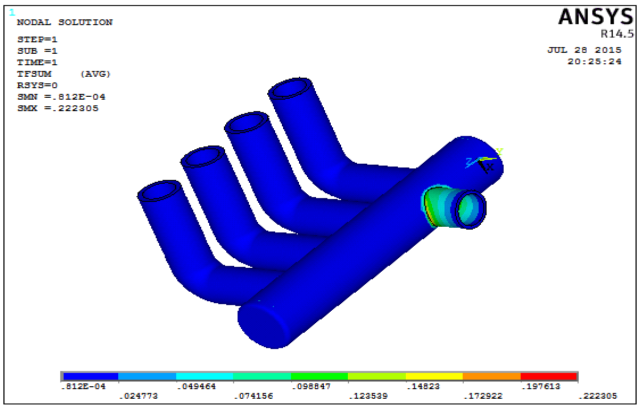

Fig : Heat Flux for Nickel Existing Model

MATERIAL: STAINLESS STEEL

NODAL TEMPERATURE:

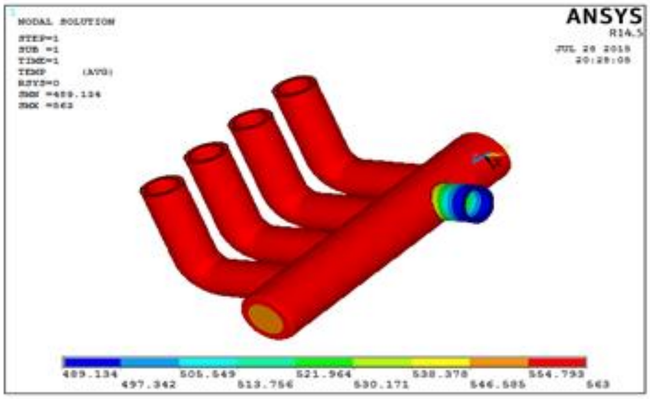

Fig : Nodal Temperature for Stainless Steel Existing Model

THERMAL GRADIENT:

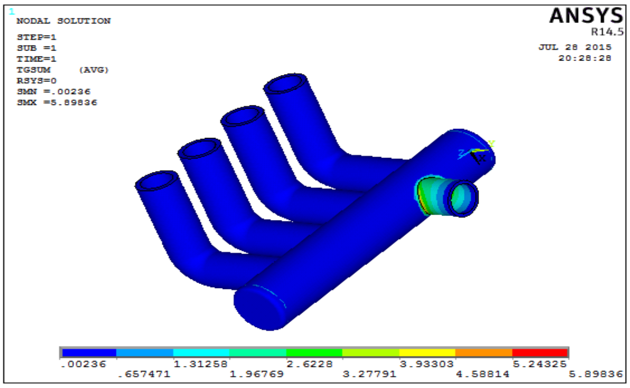

Fig : Thermal Gradient for Stainless Steel Existing Model

HEAT FLUX:

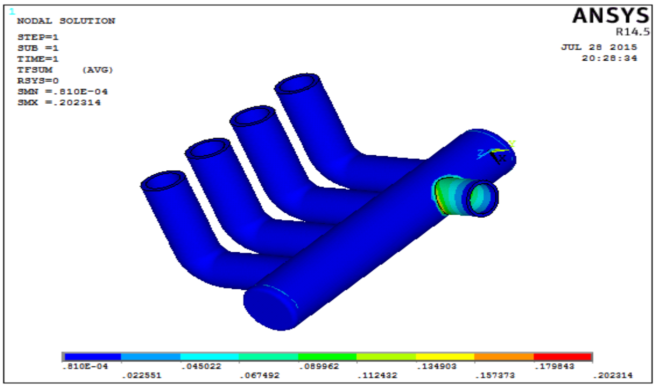

Fig : Heat Flux for Stainless Steel Existing Model

MODIFIED MODEL

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Imported Model:

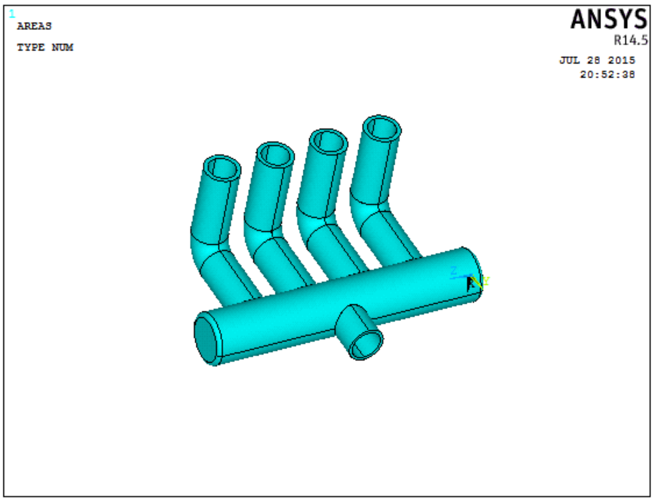

Fig : Imported Modified Model

Meshed Model:

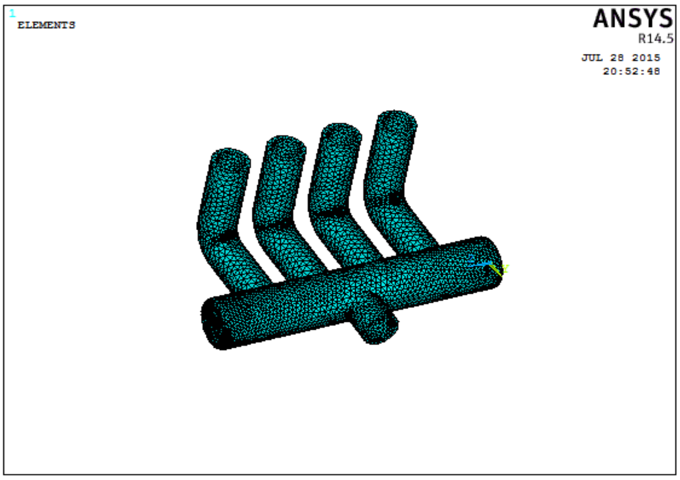

Fig : Meshed Modified Model

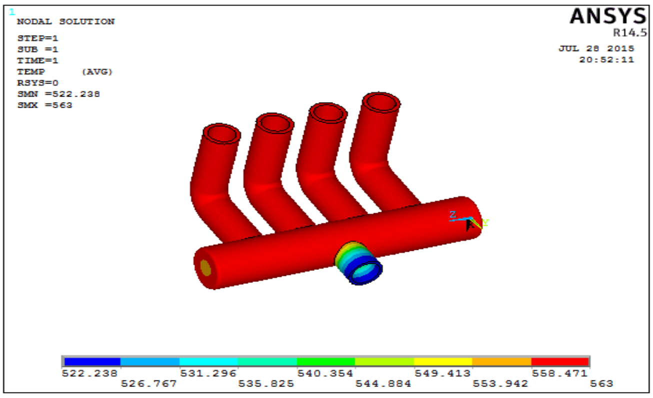

Fig : Nodal Temperature for Chromium Modified Model

THERMAL GRADIENT:

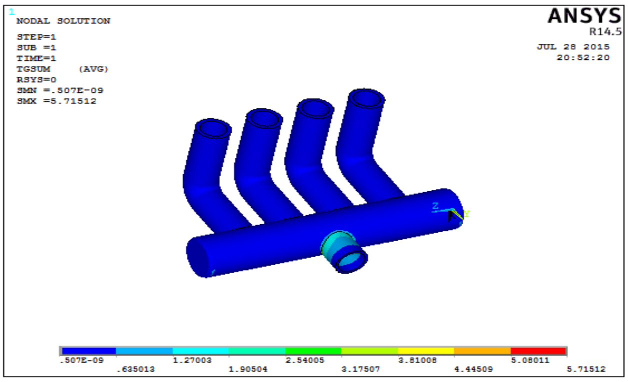

Fig : Thermal Gradient for Chromium Modified Model

HEAT FLUX:

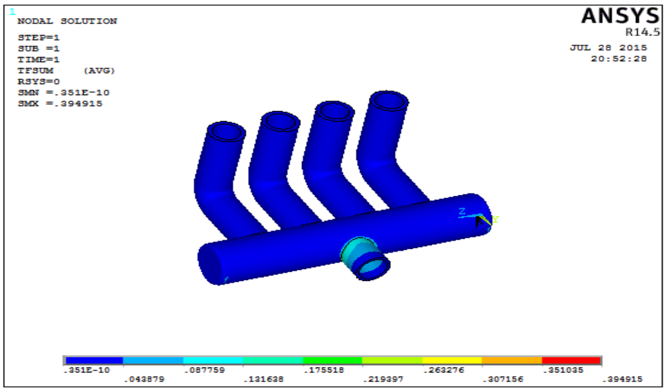

Fig : Heat Flux for Chromium Modified Model

MATERIAL: CHROMIUM
NODAL TEMPERATURE:

MATERIAL: COPPER
NODAL TEMPERATURE:

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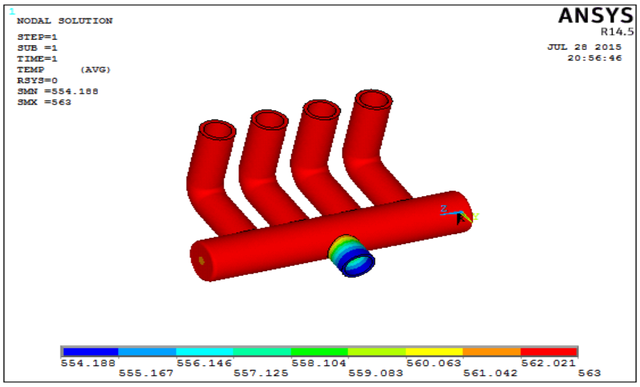

Fig : Nodal Temperature for Copper Modified Model

THERMAL GRADIENT:

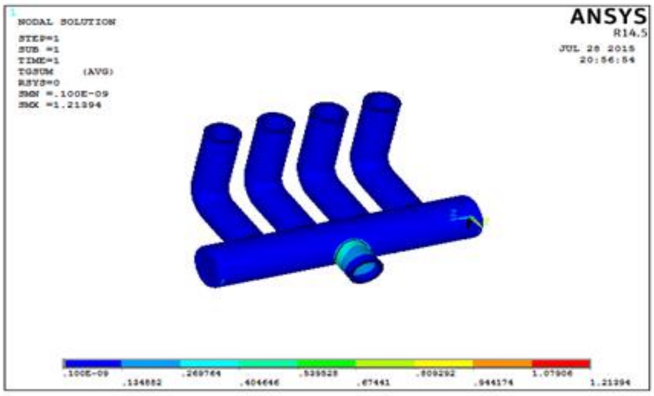

Fig : Thermal Gradient for Copper Modified Model

HEAT FLUX:

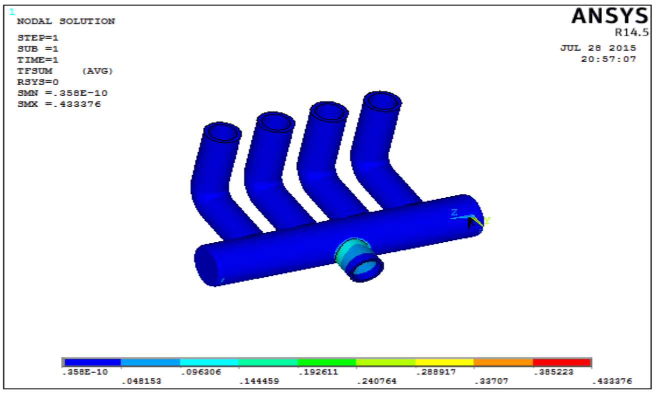

Fig : Heat Flux for Copper Modified Model

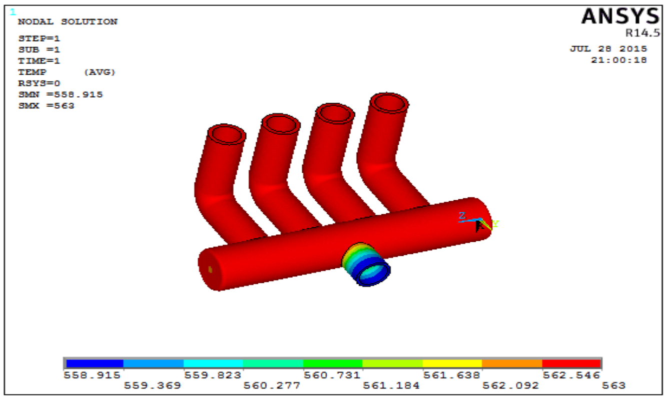

Fig : Nodal Temperature for Manganese Modified Model

THERMAL GRADIENT:

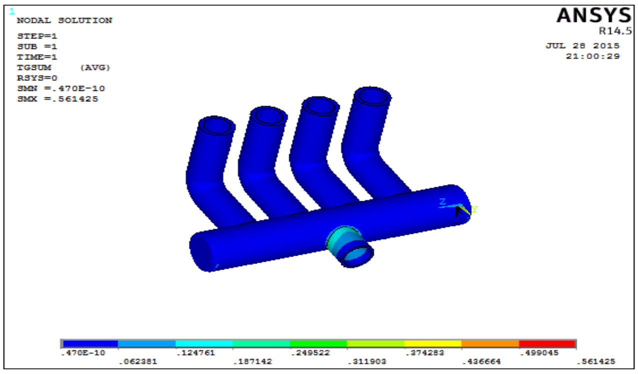

Fig : Thermal Gradient for Manganese Modified Model

HEAT FLUX:

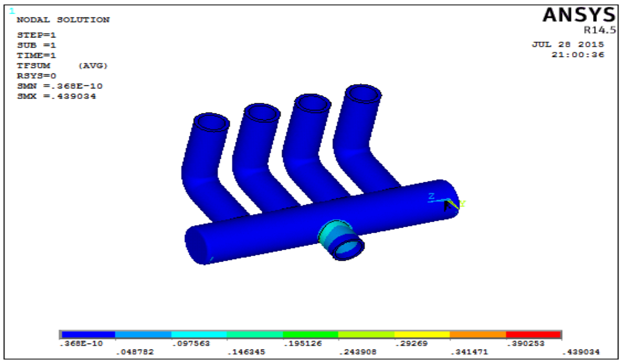

Fig : Heat Flux for Manganese Modified Model

MATERIAL: MANGANESE
NODAL TEMPERATURE:

MATERIAL: NICKEL
NODAL TEMPERATURE:

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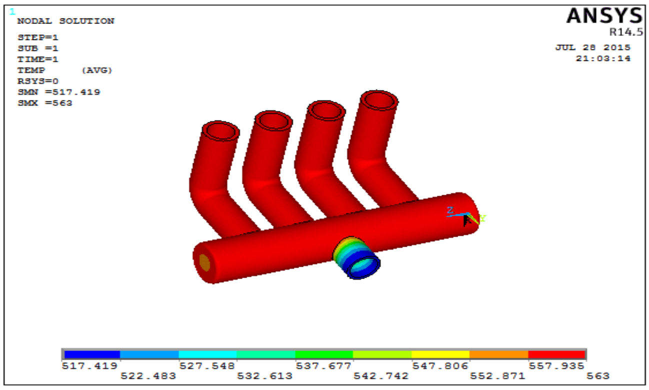


Fig : Nodal Temperature for Nickel Modified Model

THERMAL GRADIENT:

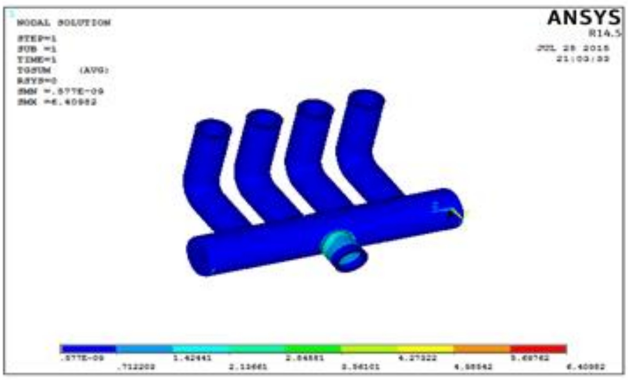


Fig : Thermal Gradient for Nickel Modified Model

HEAT FLUX:

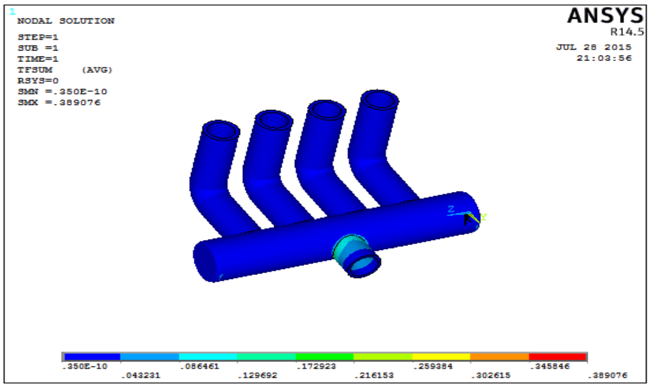


Fig : Heat Flux for Nickel Modified Model

MATERIAL: STAINLESS STEEL

NODAL TEMPERATURE:

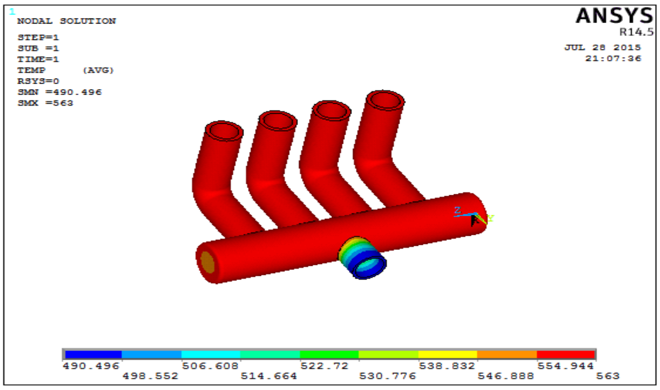


Fig : Nodal Temperature for Stanless Steel Modified Model

THERMAL GRADIENT:

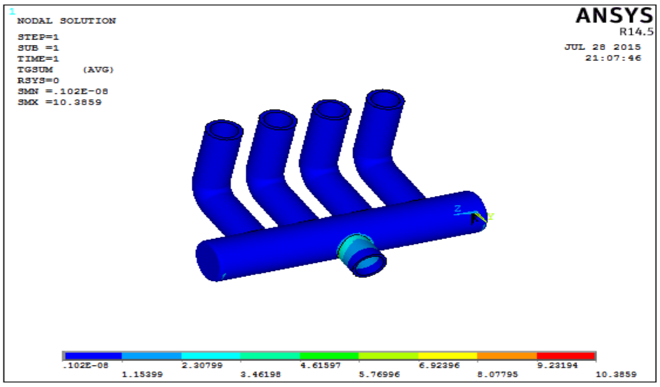


Fig : Thermal Gradient for Stainless Steel Modified Model

HEAT FLUX:

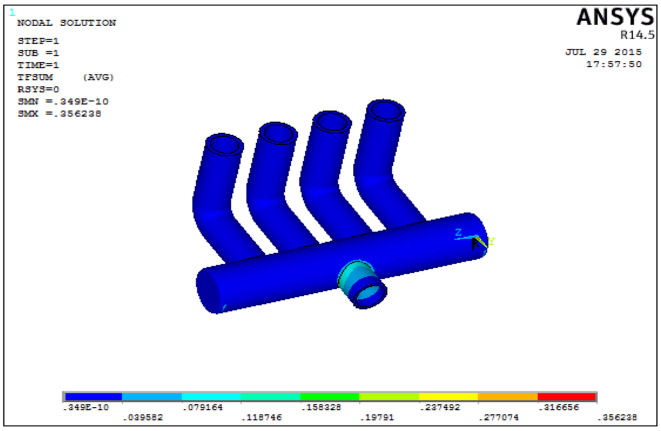


Fig : Heat Flux for Stainless Steel Modified Model

CFD ANALYSIS

Existing Model:

Mass flow Rate At 0.07:

Imported Model:

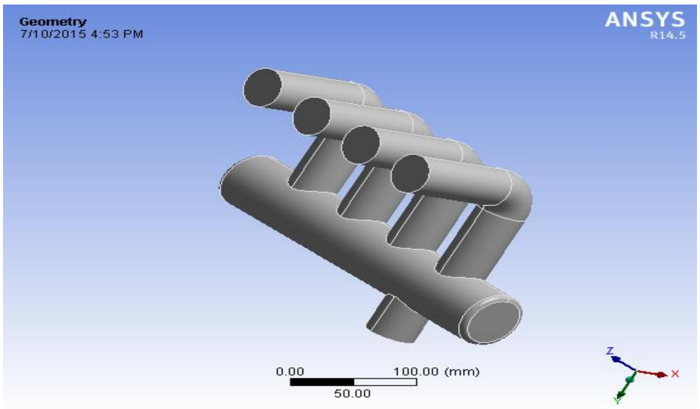


Fig.: Imported Existing Model for CFD Analysis

Meshed Model:

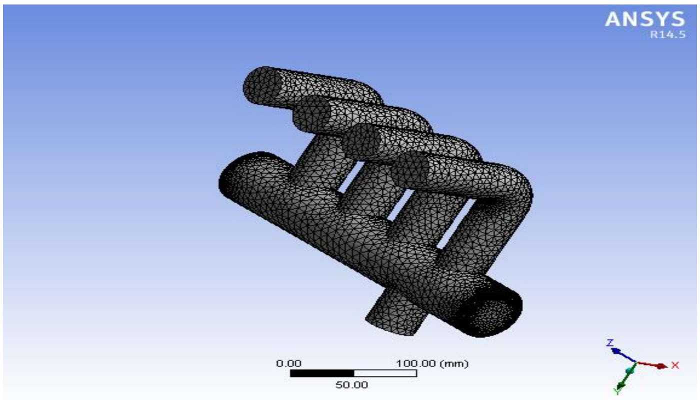
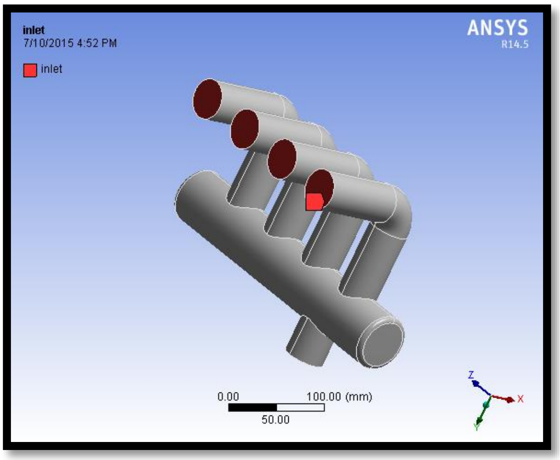


Fig: Meshed Existing Model for CFD Analysis

INLET &OUTLET:



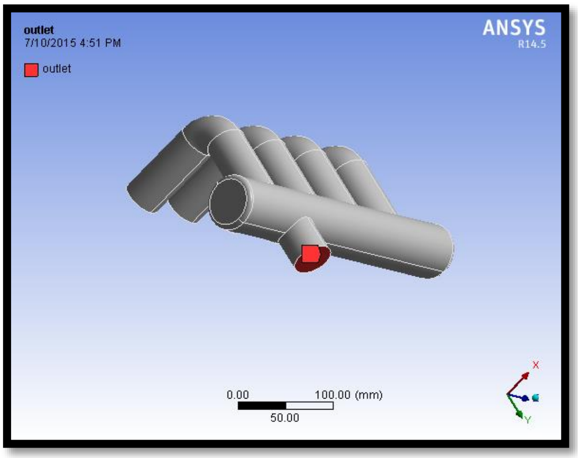


Fig : Applying Boundaries for Inlet and Outlet Ports

Material Properties:

PRESSURE:

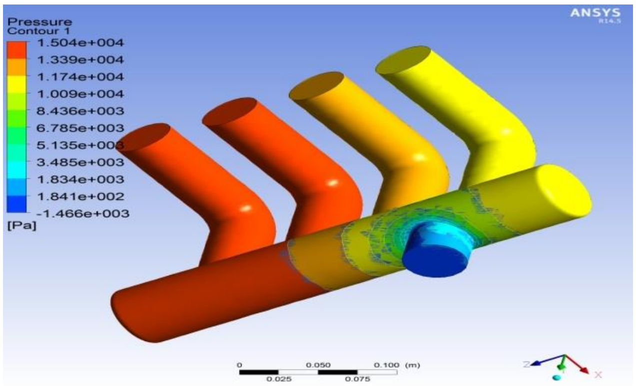


Fig : Existing Model Pressure value at Mass FlowRate 0.07

VELOCITY MAGNITUDE:

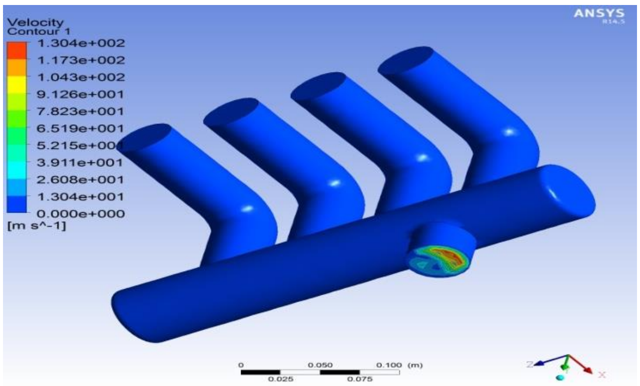


Fig : Existing Model Velocity Magnitude at Mass FlowRate 0.07

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TEMPERATURE:

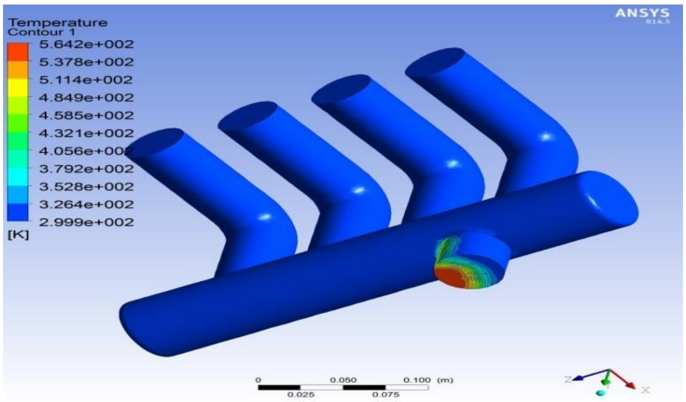

Fig : Existing Model Temperature at Mass FlowRate 0.07

MODIFIED MODEL:

Mass Flow Rate At 0.07:

Imported Model:

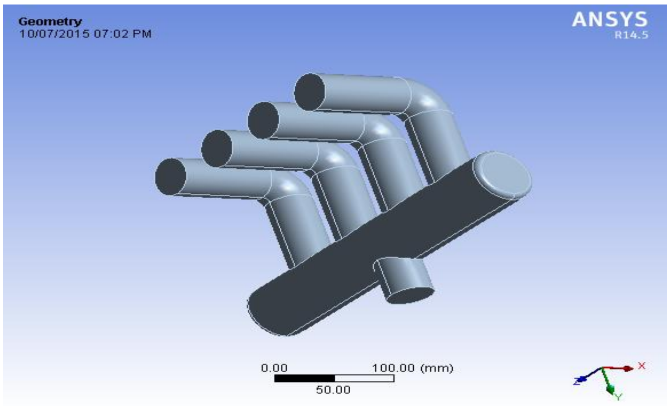

Fig : Imported Modified Model

Meshed Model:

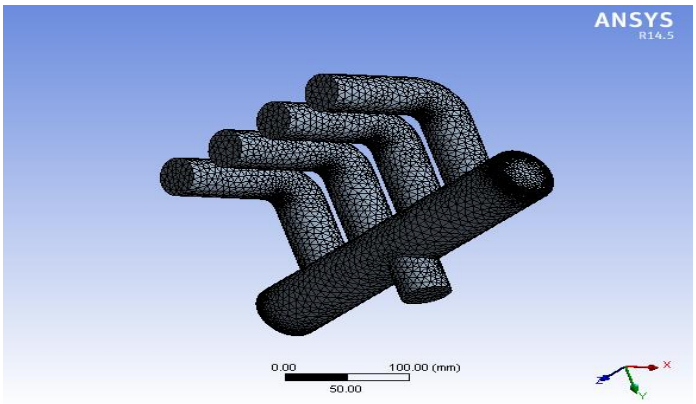

Fig : Meshed Modified Model

PRESSURE:

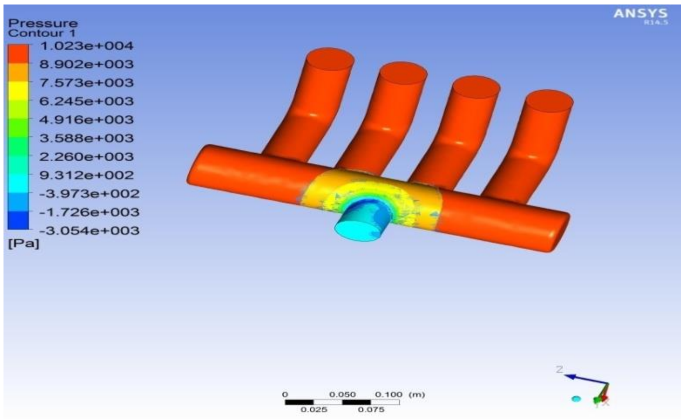

Fig : Modified Model Pressure at Mass Flow Rate 0.07

VELOCITY MAGNITUDE:

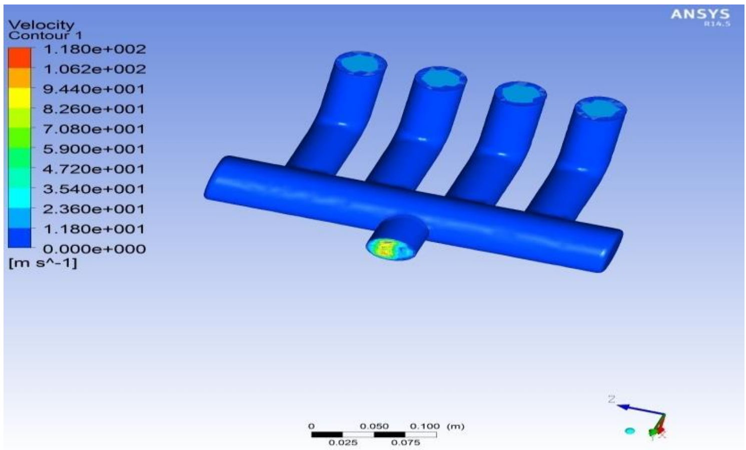

Fig : Modified Model Velocity Magnitude at Mass Flow Rate 0.07

TEMPERATURE:

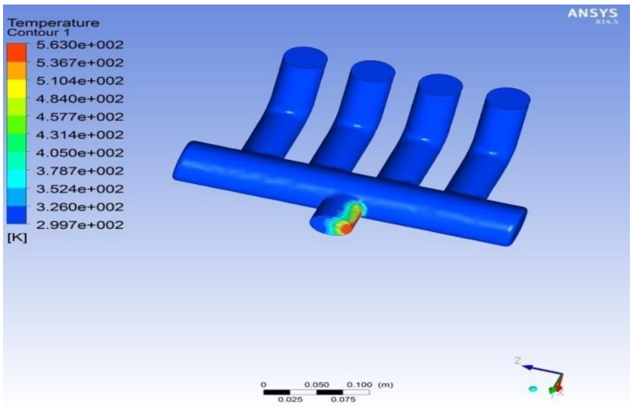

Fig : Modified Model Temperature at Mass Flow Rate 0.07

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Changing Mass Flow Rate Of Existing Model 0.13:

PRESSURE:

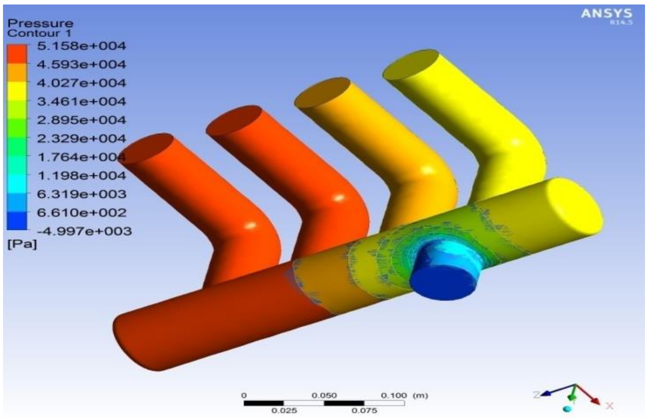

Fig : Existing Model Pressure value at Mass FlowRate 0.13

VELOCITY MAGNITUDE:

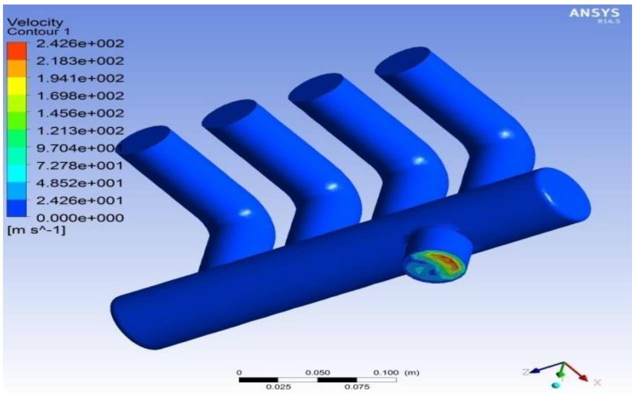

Fig : Existing Model Velocity Magnitude at Mass FlowRate 0.13

TEMPERTAURE:

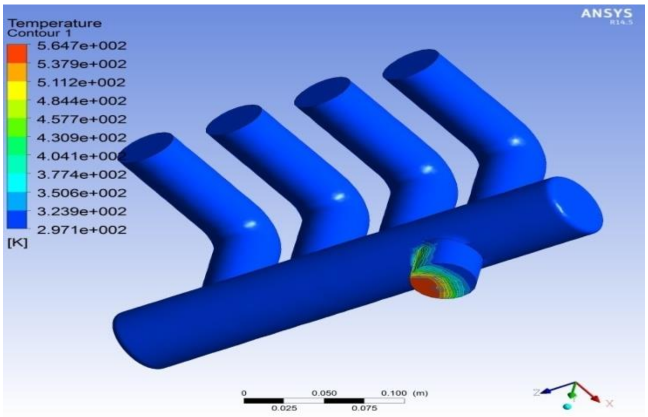

Fig : Existing Model Temperature at Mass FlowRate 0.13

Modified Model of Changing mass flow Rate 0.130:

PRESSURE:

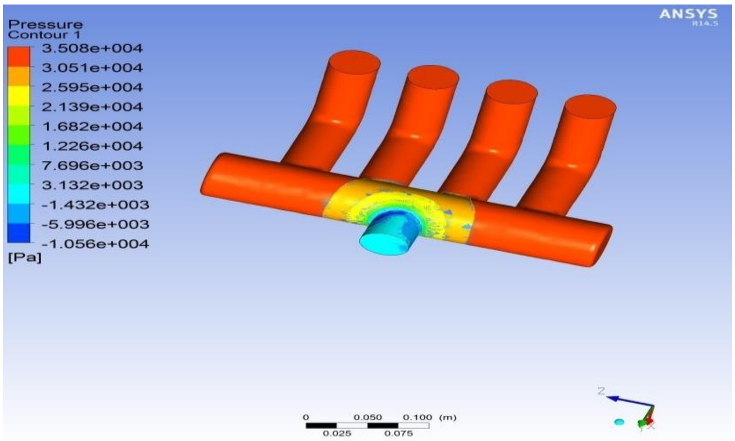

Fig : Modified Model Pressure at Mass Flow Rate 0.13

VELOCITY MAGNITUDE:

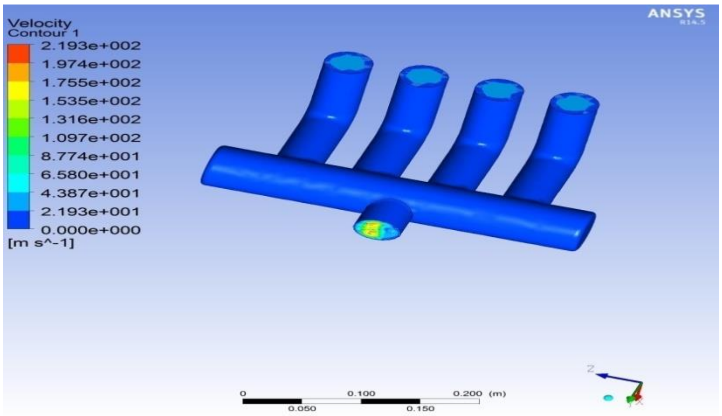

Fig : Modified Model Velocity Magnitude at Mass Flow Rate 0.13

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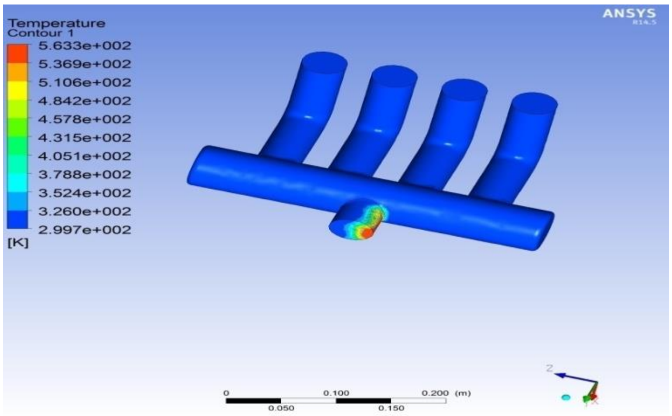

Fig : Modified Model Temperature at Mass Flow Rate 0.13

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Changing mass flow Rate Of Existing Model 0.680:

PRESSURE:

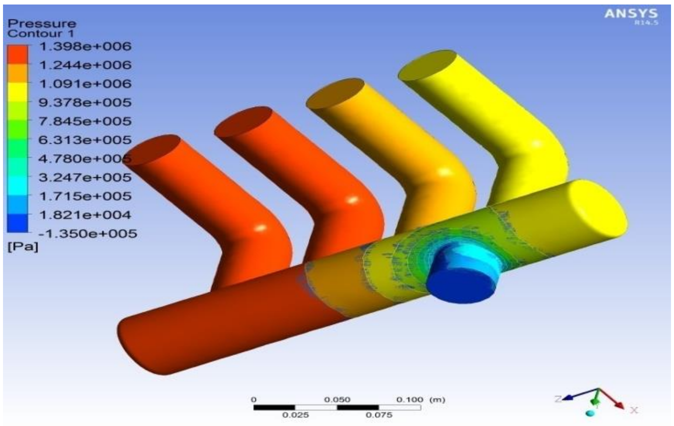

Fig : Existing Model Pressure value at Mass FlowRate 0.68

Modified model of changing Mass Flow Rate 0.680:

PRESSURE:

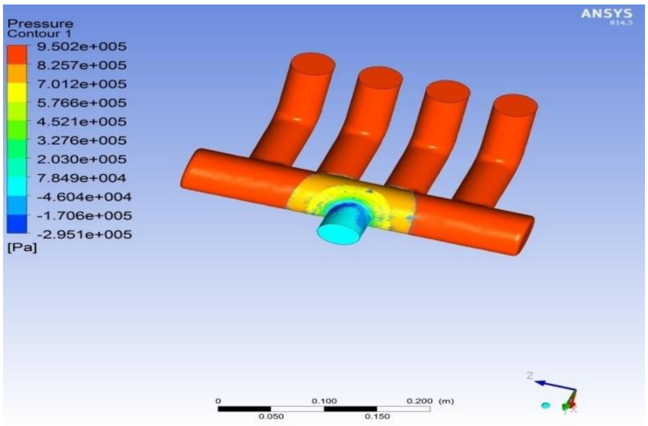

Fig : Modified Model Pressure at Mass Flow Rate 0.68

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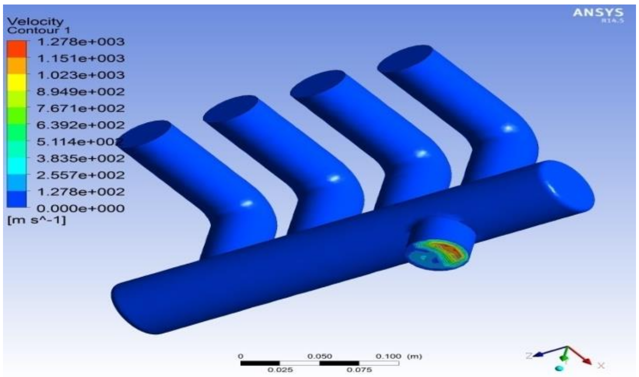

Fig : Existing Model Velocity Magnitude at Mass FlowRate 0.68

VELOCITY MAGNITUDE:

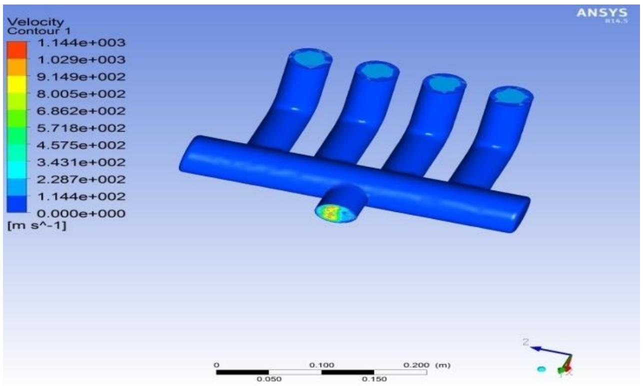

Fig : Modified Model Velocity Magnitude at Mass Flow Rate 0.68

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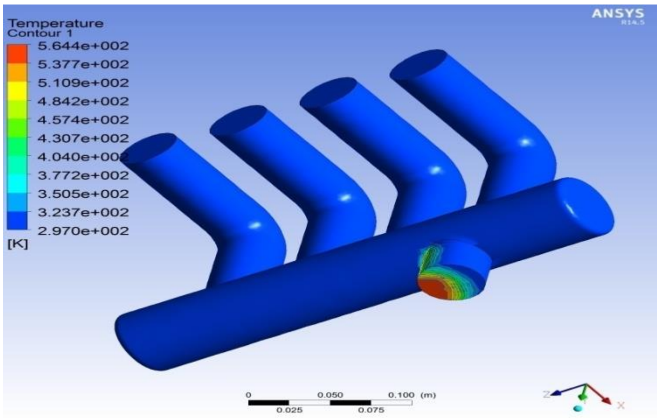


Fig : Existing Model Pressure value at Mass FlowRate 0.68

TEMPERATURE:

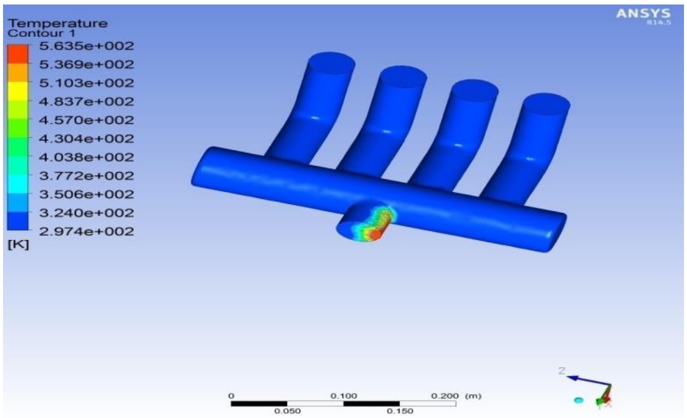
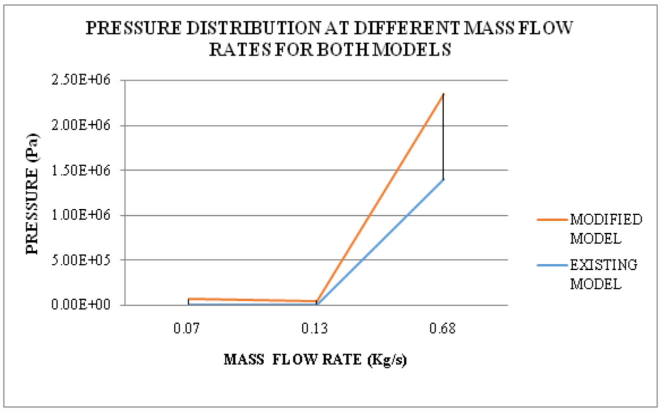
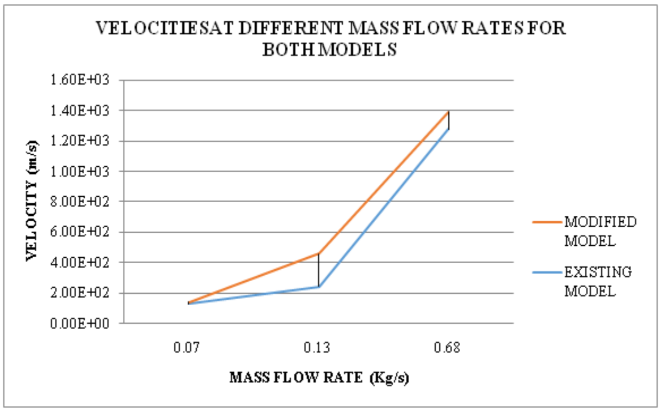
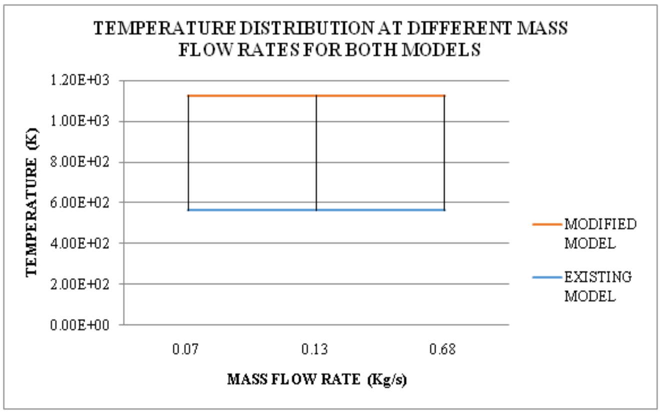


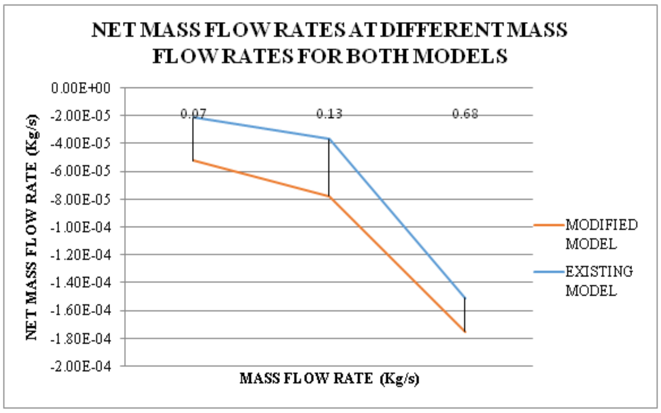
Fig : Modified Model Temperature at Mass Flow Rate 0.68

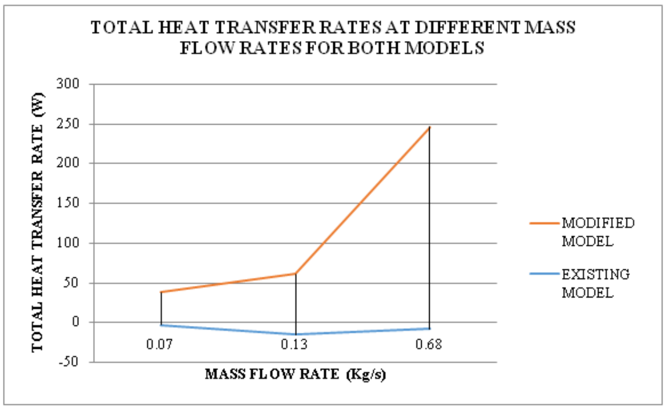
CFD ANALYSIS:



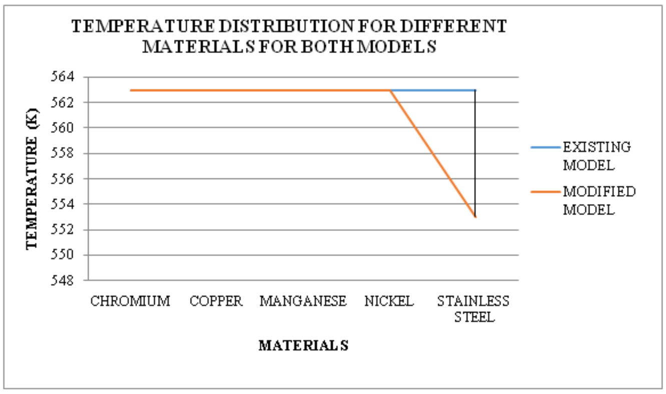


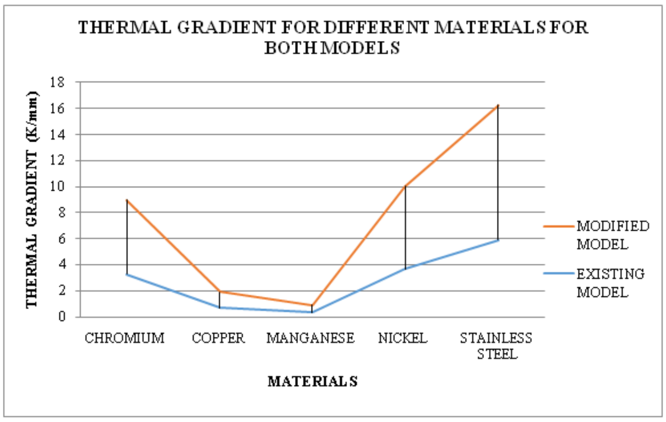


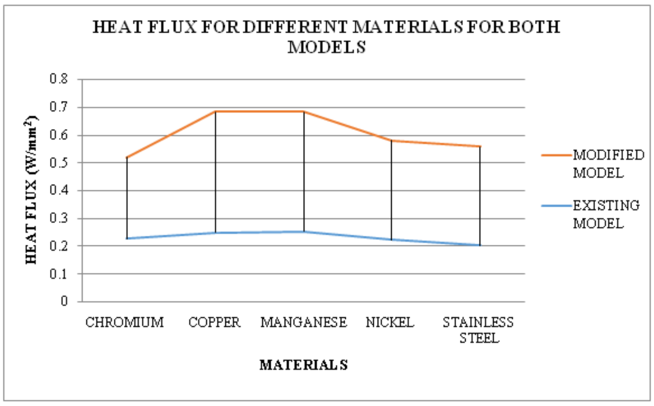




THERMAL ANALYSIS:







Conclusion

Analysis is done on both models of the exhaust manifold. In existing model the bend radius is 48 mm and exhaust is on one side, Modified model has bend radius of 48 mm and exhaust is at the centre of header. CFD analysis is done on both models at different mass flow rates of 0.07, 0.13 and 0.68. By observing the CFD analysis results, the outlet pressure, velocity and total heat transfer rates are increasing by increasing thr mass flow rates and they are more for modified model when compared with thatof original model. The net mass flow rates are decreasing by increasing the mass flow rate and is less for modified model. Thermal analysis is done for both models using different materials chromium, copper, manganese, nickel and stainless steel. By observing the thermal analysis results, the heat flux (i.e) heat transfer rate is more for Manganese when compared with other materials. The heat transfer rate is more for modified model than original model. It can be concluded that modifying the exhaust manifold is better.

Future Scope

This work can further be extended by performing a transient non-linear finite element analysis which is used to calculate the plastic deformation and thermal mechanical behaviours of the exhaust manifold assembly during thermal shock cycles, which include rated speed full load, rated speed motored and idle speed conditions.

References

[1] Muthaiah PLS, Kumar MS, Sendilvelan S. CFD Analysis of catalytic converter to reduce particulate matter and achieve limited back pressure in diesel engine. Global journal of researches in engineering A: Classification (FOR) 091304,091399, 2010; 10(5).

[2] Suresh Aadepu, I.S.N.V.R.Prasanth & Jarapala Murali Naik, Design of intake manifold of IC engines with improved volumetric efficiency, IJMETMR, http://www.ijmetmr.com/oljune2014/Article6.pdf, Volume No: 1(2014), Issue No: 6 (June), ISSN No: 2348-4845

[3] Beardsley MB et al. Thermal Barrier Coatings for Low Emission, High Efficiency Diesel Engine Applications, SAETechnical Paper 1999; 1: 2255.

[4] JacobE, Lammermann R, Pappenherimer A, Rothe D. Exhaust Gas After treatment System for Euro 4: Heavy Duty Engines – MTZ 6/2005.

[5] Jacobs T, Chatterjee S, Conway R, Walker A, Kramer J, Mueller-Haas K. Development of a Partial Filter Technology for Hdd Retrofit, Sae Technical Paper 2006-01-0213.

[6] Lahousse C, Kern B, Hadrane H, Faillon L. Backpressure Characteristics of Modern Three-way Catalysts, Benefit on Engine Performance, SAE Paper No. 2006011062,2006 SAE World Congress, Detroit, Michigan , April 36, 2006.

[7] Muramatsu G, Abe A, Furuyama M. Catalytic Reduction of Nox in Diesel Exhaust, SAE 930135, 1993.

[8] Heywood JB, Internal Combustion Engine Fundamentals (Tata McGrah Hill).

[9] Labhsetwar NK, Watanabe A, Mitsuhashi T. Possibilities of the application of catalyst technologies for the control of particulate emission for diesel vehicles, SAE Transaction 2001.

[10] Biniwale R, Labhsetwar NK, Kumar R, Hasan MZ. A non-noble metal based catalytic converter for two strokes, two-wheeler applications, SAE.