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Optimisation of Automobile Radiator by Linear and Helical Tubes

Karakkayala Rohit, P. Ravi Chander, Y. Madhu Maheswara Reddy

Abstract*: An automobile radiator is a component of an automotive cooling system which plays a major role in transferring the heat from the engine parts to the environment through its complex working system. Heat losses through the radiator and the tailpipe add up to 58 to 62 percent of the total losses. Insufficient heat dissipation can result in the overheating of the engine, which leads to the breakdown of the lubricating oil, corrosion and metal weakening of engine parts, and significant wear between engine parts. To minimize the stress on the engine as a result of heat generation, automotive radiators must be designed to be more effective while still maintaining high level of heat transfer within components. This leads to the increased demand of power packed radiators, which can dissipate maximum amount of heat for any given space. In this paper we have designed and analyzed the performance of radiators by comparing linear tube radiator and two helical tube radiators as coolant inside radiator follows triple pass flow pattern. The modeling is done using CATIA. The fluid flow analysis is done with ANSYS FLUENT.

Keywords: ANSYS, CATIA, Helical tube, linear tube, Radiator, Triple pass flow pattern.

I. INTRODUCTION

Radiators are cooling devices used in automobiles to prevent engines from overheating. They form the heart of the cooling system in all the vehicles. Primarily, they are responsible for maintaining the temperature of engines, so that they can give an optimum performance. Radiators are generally fabricated from copper and brass or aluminium and consist of numbers of pipes put in a series through which coolant circulates. Most modern cars use aluminium radiators. These radiators are made by brazing thin aluminium fins to flattened aluminium tubes. The coolant flows from the inlet to the outlet through many tubes mounted in a parallel arrangement. The fins conduct the heat from the tubes and transfer it to the air flowing through the radiator.

Temperature drop for helical coiled heat exchanger is higher than the straight tube heat exchanger. This is because of the curvature effect of the helical coil. Fluid flow in the outer layer of the pipe moves faster than the fluid flow in the inner layer. This dissimilarity in the velocity will lay in a secondary flow by which heat transfer will be increased [1]. Helical coils are efficient for low Reynolds number. Also the proportion of tube diameter to coil diameter should be large enough for large intensities of secondary fluid run inside the tubes [2]. Improving a correlation for heat transfer coefficient for stream between concentric helical coils. They have increased the gap between concentric coils when compared with the experimental results data, and found that coil gap and tube diameter is the most important parameters for the heat transfer coefficient [3]. Effect of the taper angle and helical pitch on the heat transfer characteristics of the helical coils and found that change in angle changes the effect of heat transfer [4]. Heat transfer enhancement characteristics of air flow inside a circular tube with a partially decaying and partly swirl flow efforts are taken to optimize the helical coiled tube with respect to heat transfer and flow parameters for various coil pitch. Analysis of heat exchanger is done using conjugate heat transfer. The 3-dimensional flow through the helical coiled tube is considered which would overcome the anisotropic flow properties that would arise due to complex turbulence phenomenon and flow deviations [5]. Application of Nano fluids (Alumina/water and CuO/water) has enhanced heat dissipation rate to a considerable extent as compared to water as coolant. The increase in nanoparticle concentration increases heat transfer rate but may lead to increase in friction. CuO/water Nano fluid has better heat dissipation characteristics as compared to Al2O3/water Nano fluid. The highest heat dissipation rate is found with CuO/water 3% Nano fluid. Al2O3/water with 3% Nano particle concentration provided 37% increase in heat transfer rate. CuO/water 3% Nano particle concentration provided 53% increase in heat transfer rate [6]. We can conclude that by fixing the water proportion and taking the reading with different coolant (i.e. Like Ethanol, Methanol, Al2O3/water2%, Al2O3/water3% and CuO/water) CuO/water gives the highest outlet temperature 355.38K among all the mixtures and ethanol gives the least outlet temperature 336.91K in helical tube radiator. So from the result, it is desirable to use ethanol with water, which gives better performance.

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For Elliptical & Helical tubes Radiator; maximum temperature drop is due to Ethanol as coolant. In case of Helical tube radiator compared to elliptical tube radiator gives better performance such as – Maximum temperature drop, High rate of heat dissipation, Compactness and high rate of heat dissipation [7].

Coolant temperature obtained at outlet is 83.654 ^{o}C, so the temperature drop of 12 ^{o}C is obtained.

The effectiveness obtained in analysis is 0.59 which is close to the effectiveness calculated in designing the aluminum radiator. Hence the design of radiator for cooling is accurate and can be used in engine cooling systems in automobiles [8]. This paper deals with the comparison of a linear piped radiator with two new modified helical piped radiators. Radiator of 'TOYOTA CELICA ZZT231R (TOY0927AL)' is taken as a standard model. Analysis of the radiator is done through CFD (Computational Fluid Dynamics) using ANSYS Fluent software. The Temperature Distribution, Mass flow rate, Pressure and Velocity inside the radiator is observed and analyzed.

II. METHODOLOGY

Design of Radiator is done in CATIA software with appropriate dimensions & material composition, Coolant for radiator is considered by going through various research papers and concluded to use Mixture of Ethanol with Water [7]. Radiator body frame and tubes are made of Aluminum. Comparison of different design as linear tube, helical tube, Double Helical tube. Coolants inlet & outlet temperatures, mass flow rate, pressure and velocity are analyzed and will calculate efficiency of radiator. Computational fluid dynamics (CFD) is done in ANSYS FLUENT.

Modeling of Radiator in CATIA

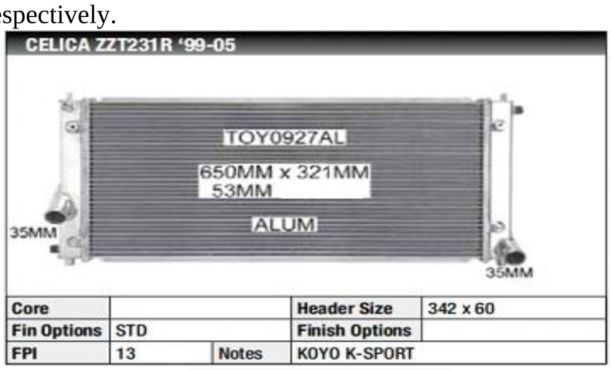
Import the Radiator models into ANSYS

Give material properties and perform Meshing

Perform CFD Analysis on Radiator models

Derive conclusions from obtained results

Radiator has been designed by standard dimensions as shown below in fig 01. Three new radiators are designed on standard dimensions as they are Linear Piped, Helical Piped, Double Helical Piped radiators as shown in fig 02, 04, 06 respectively.



Core			Header Size	342 x 60
Fin Options	STD		Finish Options	
FPI	13	Notes	KOYO K-SPORT	

Fig01. Standard Model

A. Input Data

- Air velocity: 22.7777 m/s (80km/hr)
- Air temperature: Ambient temp (273.15 K+27 C= 300.15K)
- Coolant inlet temperature: 385.15 K
- Outside temperature: 298 K
- Flow region: k epsilon standard wall function: Free slip wall Overall HT coefficient across the radiator ranges from 75 to 560 W / m2-K
- Coolant: Mixture of Ethanol & Water

B. Linear Pipe Radiator

- No of pipes = 30
- The diameter of pipes = 8 mm
- The thickness of pipe=1mm
- Length of pipes =644mm
- The thickness of pipe holder or frame= 2mm
- The cross-section of jacket= rectangle
- Length of jacket= 40 mm
- Breathe of jacket= 30 mm
- Height of jacket= 342 mm
- The material of radiator is AL alloy
- Weight of radiator= 4.942 kg *2 = 9.884 kg

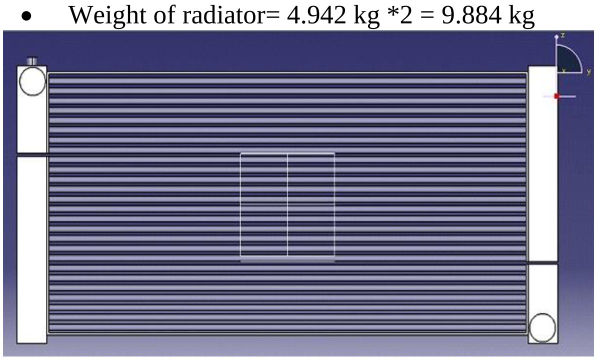


Fig02. Linear Piped Radiator

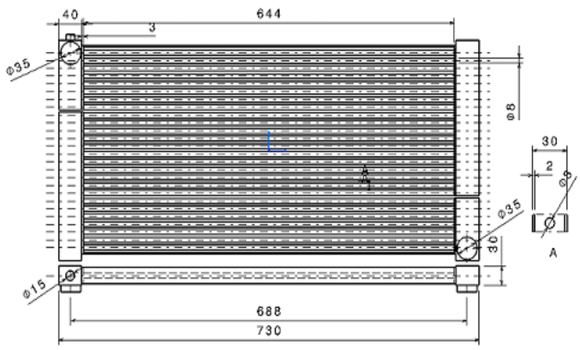


Fig03. Draft of Linear Piped Radiator

C. Helical Pipe Radiator

- No of pipes = 15
- Space between coil to coil= 20.8mm
- The diameter of pipes = 8 mm
- The thickness of pipe=1mm
- Length of pipes =644mm
- No of coils = 22
- Pitch height of coils= 28mm
- The thickness of pipe holder or frame= 2mm
- The cross-section of jacket= rectangle

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- Length of jacket= 40 mm
- Breathe of jacket= 30 mm
- Height of jacket= 342 mm
- The material of radiator is AL alloy
- Weight of radiator= 5.308 kg *2 = 10.616 kg

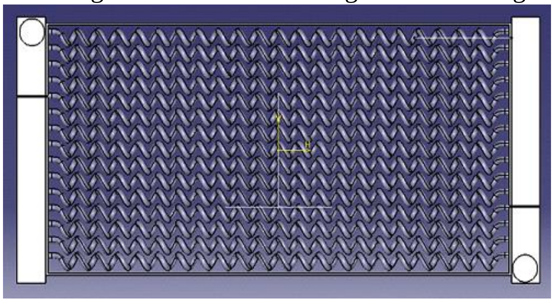

Fig04. Helical Piped Radiator

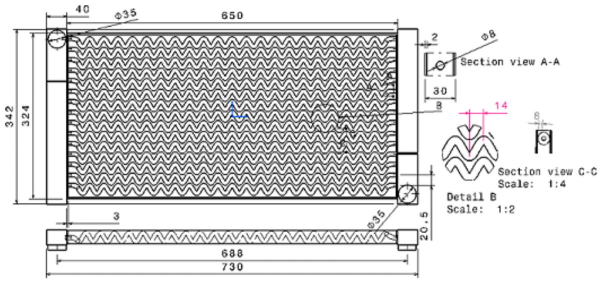

Fig05. Draft of Helical Piped Radiator

D. Double Helical Pipe Radiator

- No of pipes = 12*2= 24 pipes
- Space between coil to coil= 22 mm
- The diameter of pipes = 8 mm
- The thickness of pipe=1 mm
- Length of pipes =644mm
- No of coils = 22 in each pipe
- Pitch height of coils= 28 mm
- The thickness of pipe holder or frame= 2mm
- The cross-section of jacket= rectangle
- Length of jacket= 40 mm
- Breathe of jacket= 30 mm
- Height of jacket= 342 mm
- The material of radiator is AL alloy
- Weight of radiator= 6.794 *2 = 13.588 kg

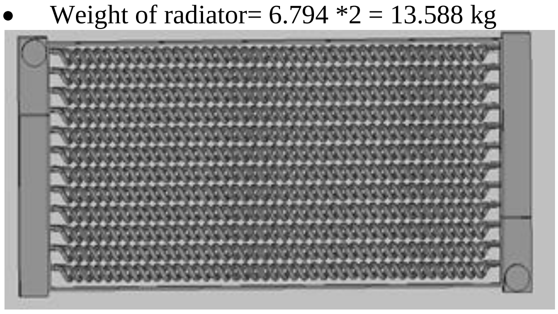

Fig06. Double Helical Piped Radiator

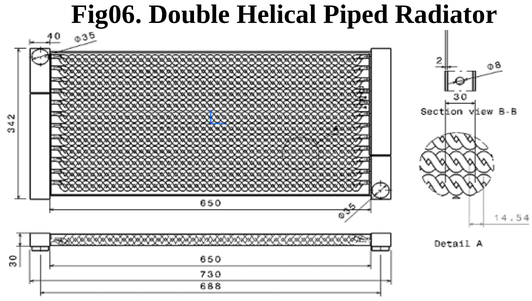

Fig07. Draft of Double Helical Piped Radiator

III. MESHING

Meshing is an integral part of the engineering simulation process where complex geometries are divided into simple elements that can be used as discrete local approximations of the larger domain. The mesh influences the accuracy, convergence and speed of the simulation. Furthermore, since meshing typically consumes a significant portion of the time it takes to get simulation results, the better and more automated the meshing tools, the faster and more accurate the solution. Meshing operation is performed on the three radiators to create subdivision of continuous geometric space into discrete geometric and topological cells. These small geometries when considered together represent the complex geometry on which analysis has to be performed. So basically meshing facilitates the analysis process and helps us to get correct results.

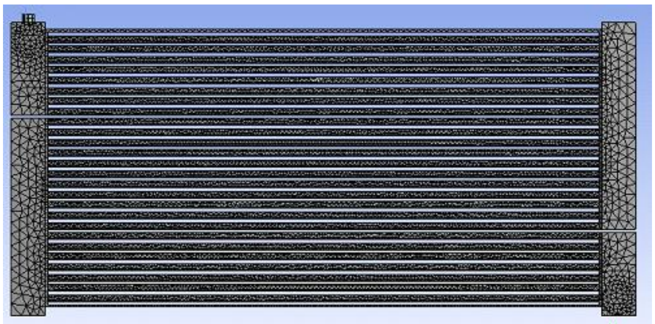

Fig08. Meshing of Linear Piped Radiator

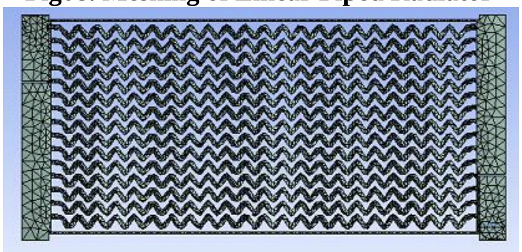

Fig09. Meshing of Helical Piped Radiator

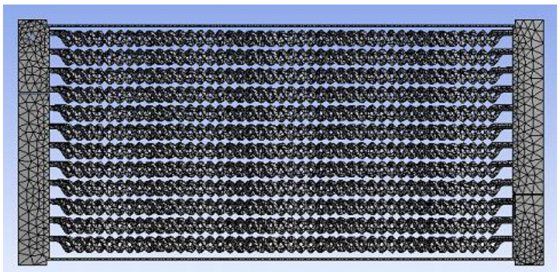

Fig10. Meshing of Double Helical Piped Radiator

IV. SECTIONAL VIEW

A small part Section is considered from the design tube to observe sectional part of the component.

A. Linear Pipe Radiator

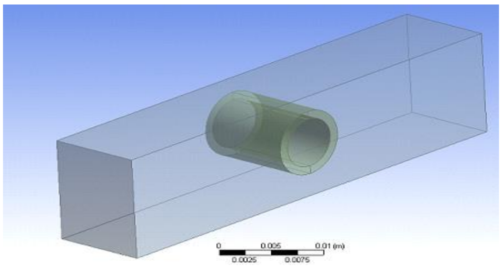

Fig11. Sectional Part of Linear Pipe Radiator

B. Helical Pipe Radiator

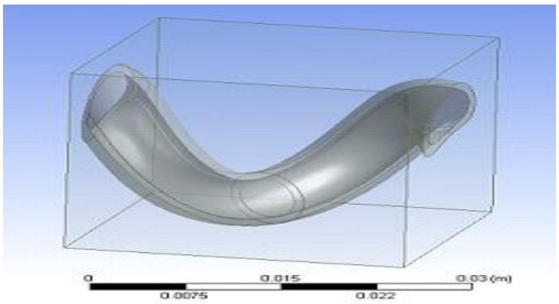

Fig12. Sectional Part of Helical Pipe Radiator

C. Double Pipe Radiator

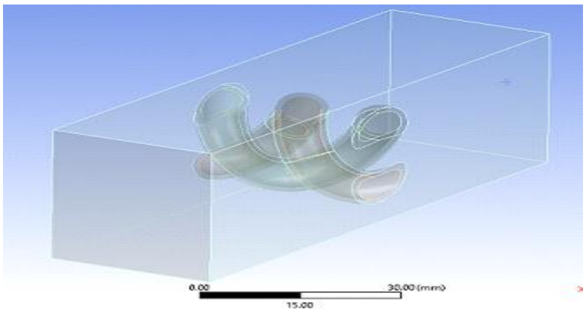

Fig13. Sectional Part of Double Helical Pipe Radiator

V. ANALYSIS

The three radiators which are designed in CATIA with particular dimensions are analyzed in ANSYS FLUENT. The flow of Coolant in radiator follows Triple Pass Flow Pattern.

A. Linear Pipe Radiator

1) Pressure Distribution

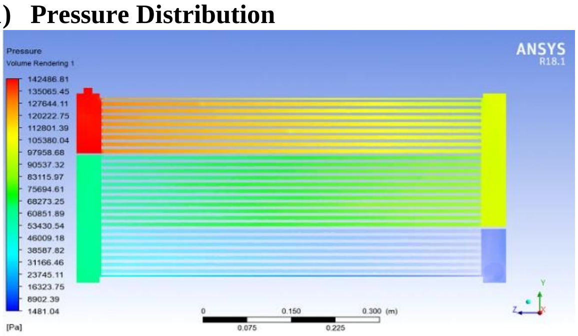

Fig14. Pressure Distribution of Linear Pipe Radiator

The color red indicates the maximum value of pressure 142487 pa = 0.142487 MPa at the inlet of radiator & blue indicate lowest pressure 1481.04 pa =0.001481 MPa at the outlet of radiators, The pressure inside the radiator fall due to the flow of water in the pipe from inlet to the outlet by number of pipes & deviations.

2) Velocity Distribution

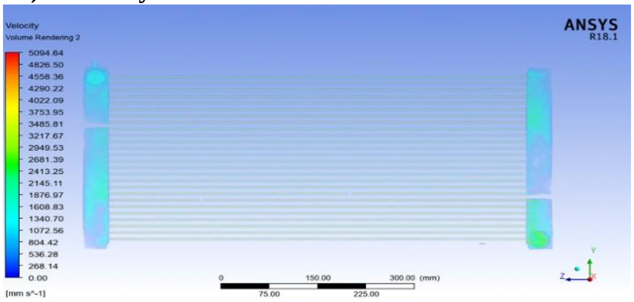

Fig15. Velocity Distribution of Linear Pipe Radiator

The color red indicate the maximum value of velocity 5094.84 mm/s = 5.094 m/s (as per the radiator in above, the velocity at inlet is 1340.70 mm/s = 1.34070 m/s) at the inlet & blue indicate lowest velocity 0 mm/s = 0 m/s (as per the radiator in above, the velocity at outlet is 804.42 mm/s =0.80442 m/s) at the outlet of radiator, the velocity inside the radiator fall due to the flow of water in pipe from inlet to outlet by number of pipes & deviations.

3) Temperatures Distribution

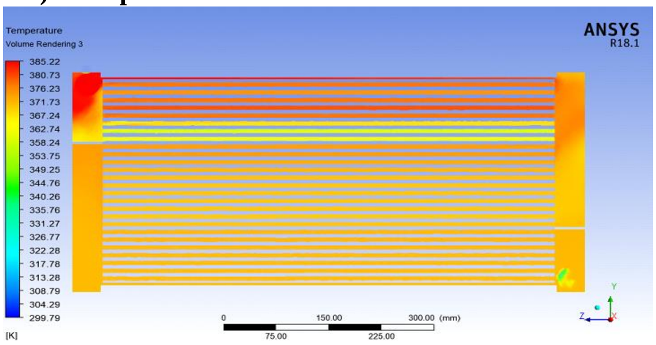

Fig16. Temperature Distribution of Linear Pipe Radiator

The color red indicate the maximum value of temperature 385.22 K = 112.07 °C at the inlet of radiator & blue indicate the lowest temperature of radiator is 362.74 K = 89.9 °C at the outlet of radiators, the temperature inside the radiator fall due to the flow of water in pipe from inlet to outlet by number of pipes & deviations, heat exchanged due to the airflow around the pipe as shown in fig16.

B. Helical Pipe Radiator

1) Pressure Distribution

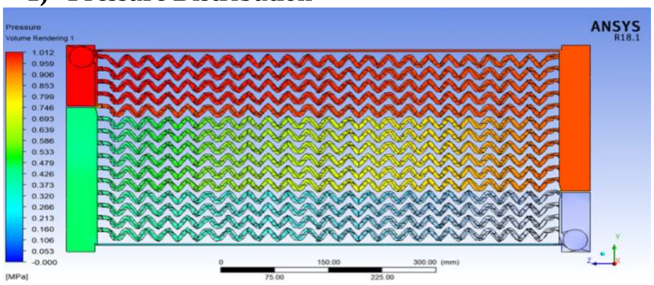

Fig17. Pressure Distribution of Helical Pipe Radiator

The color red indicates the maximum value of pressure 1.012 MPa at inlet & blue indicate lowest pressure 0.053 MPa at the outlet of radiators, the pressure inside the Radiator fall due to the flow of water in the pipe from inlet to the outlet by number of pipes & deviations.

2) Velocity Distribution

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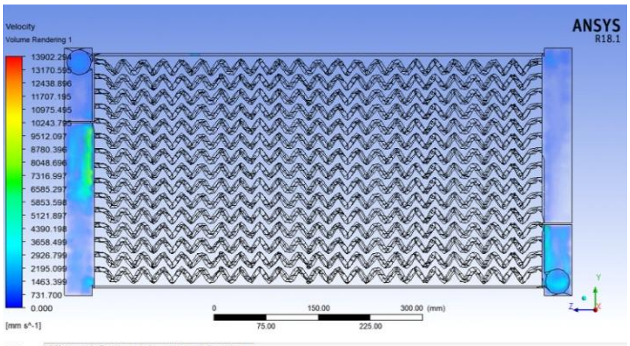


Fig18. Velocity Distribution of Helical Pipe Radiator

The color red indicate the maximum value of velocity 13.902 m/s (as per the radiator in above, the velocity at inlet is 3.658 m/s) & blue indicate lowest velocity 0 mm/s = 0 m/s (as per the radiator in above, the velocity at outlet is 0.73170 m/s) at the outlet of radiators, the velocity inside the radiator fall due to the flow of water in pipe from inlet to outlet by number of pipes & deviations.

3) Temperatures Distribution

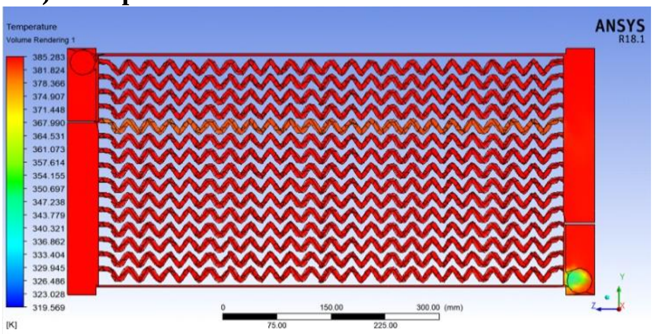


Fig19. Temperature Distribution of Helical Pipe Radiator

The color red indicate the maximum value of temperature 385.28 K = 112.13 ºC at inlet & blue indicate the lowest temperature of radiator is 343 K = 70 ºC at the outlet of radiators, the temperature inside the radiator fall due to the flow of water in pipe from inlet to outlet by number of pipes & deviations, heat exchanged due to the airflow around the pipes as shown in fig19.

C. Double Helical Pipe Radiator

1) Pressure Distribution

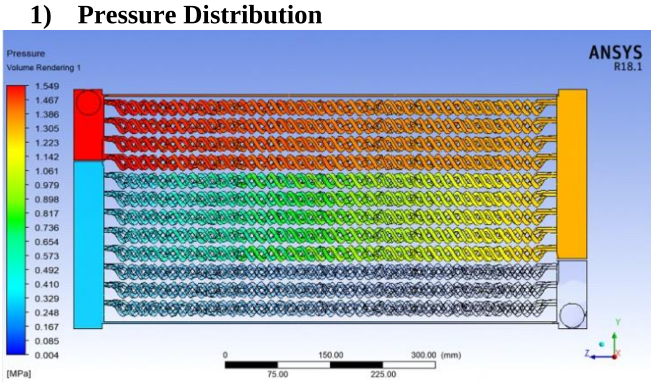


Fig20. Pressure Distribution of Double Helical Pipe Radiator

The color red indicates the maximum value of pressure 1.549 MPa at inlet & blue indicate lowest pressure 0.085 MPa at the outlet of radiators, the pressure inside the radiator fall due to the flow of water in the pipe from inlet to the outlet by number of pipes & deviations.

2) Velocity Distribution

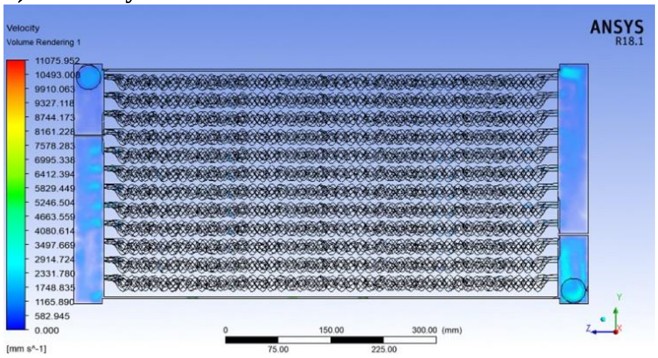


Fig21. Velocity Distribution of Double Helical Pipe Radiator

The color red indicate the maximum value of velocity 11.075 m/s (as per the radiator in above, the velocity at inlet is 3.497 m/s) & blue indicate lowest velocity 0 m/s (as per the radiator in above, the velocity at outlet is 0.582945 m/s) at the outlet of radiators, the velocity inside the radiator fall due to the flow of water in pipe from inlet to outlet by number of pipes & deviations.

3) Temperature Distribution

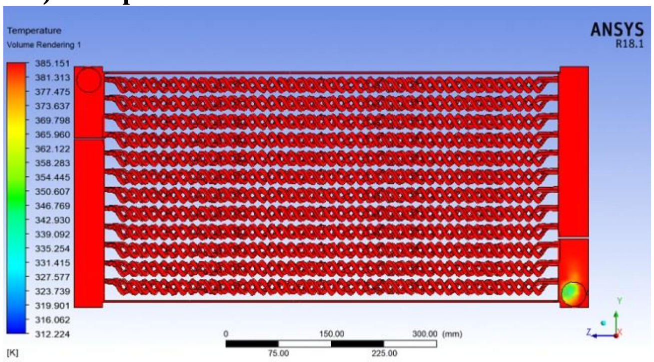


Fig22. Temperature Distribution of Double Helical Pipe Radiator

The color red indicate the maximum value of temperature 385.15 K = 112 ºC at inlet & blue indicate the lowest temperature of radiator is 355 K =82 ºC at the outlet of radiators, the temperature inside the radiator fall due to the flow of water in pipe from inlet to outlet by number of pipes & deviations, heat exchanged due to the airflow around the pipe as shown in fig22.

VI. SUMMARY & RESULTS

We have designed and analyzed a linear piped & two helical piped radiator and observed Temperature, Mass flow rate, Pressure, Velocity distribution within radiator. Coolant follows in triple pass pattern to increase effectiveness of radiator by considering a two equation k-epsilon (a constant turbulent) & standard wall functions (a concept path flow around walls) with a boundary condition of velocity & temperature of Coolant at inlet and outlet of radiator. From the data of Linear, Helical, Double Helical radiators, pressure, velocity & temperature distribution are exported from CFD report, as shown below Table01.

Table01. Pressure, Velocity & Temperature at inlet and outlet of radiators.

		Pressure		Velocity		Temperature		
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Different
	Units	MPA	Mpa	M/S	M/S	C	C	C
S. No	Radiator							
1	Linear Pipe	0.142487	0.001484	1.3407	0.80442	112.07	89.9	22.17
2	Helical Pipe	1.012	0.053	3.658	0.7317	112.13	70	42.13
3	Double Helical Pipe	1.549	0.085	3.497	0.58295	112.07	82.09	29.98

As consider Form the simulation of linear, helical & double helical radiator, the mass flow rate is extracted and noted as below Table02.

Table02. Mass Flow rate at inlet & outlet of radiators.

		Radiator				
S.No	Modal	Inlet	Outlet	Units	Outlet/Inlet	Efficiency
1	Linear	1.456061	1.45477	Kg/S	0.99911144	99.91114
2	Helical	1.412513	1.412196	Kg/S	0.99977536	99.97754
3	Double Helical	1.429776	1.428932	Kg/S	0.99940984	99.94098

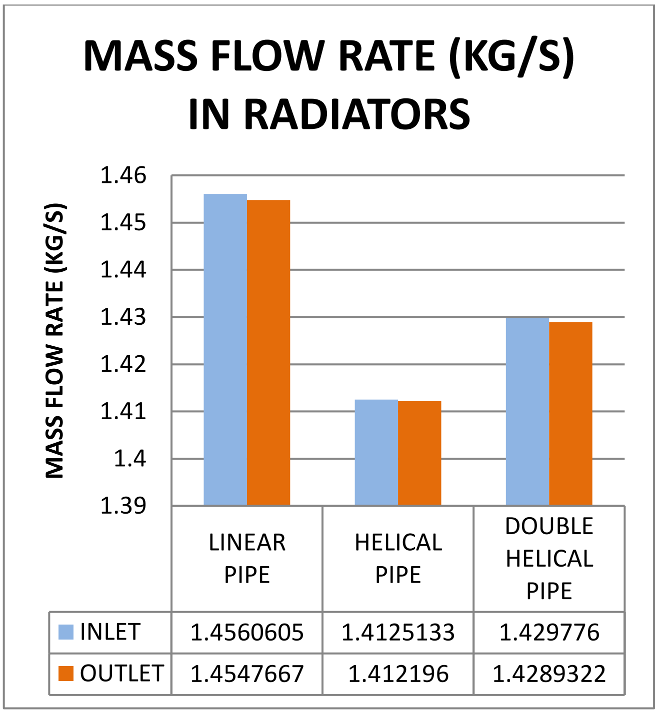


Chart-1: Mass Flow Rate of Radiators

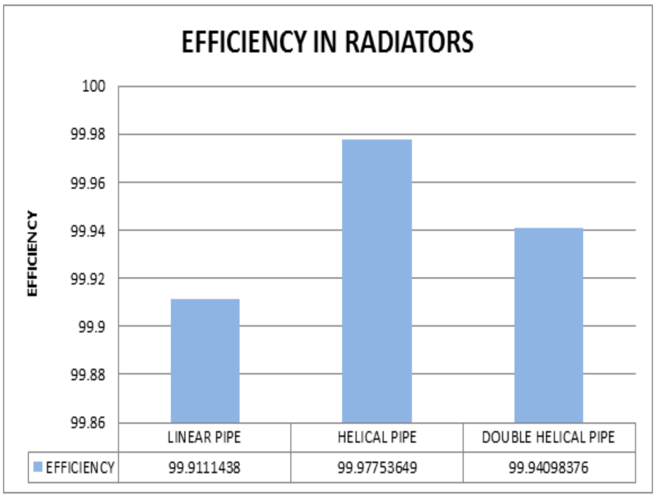


Chart-2: Efficiency of Radiators

For the above chart, the helical pipe radiator has less mass flow when it is compared to other radiators. But compare to the efficiency the same helical pipe has the highest efficiency when compared to other radiators follow by double-helical radiator.

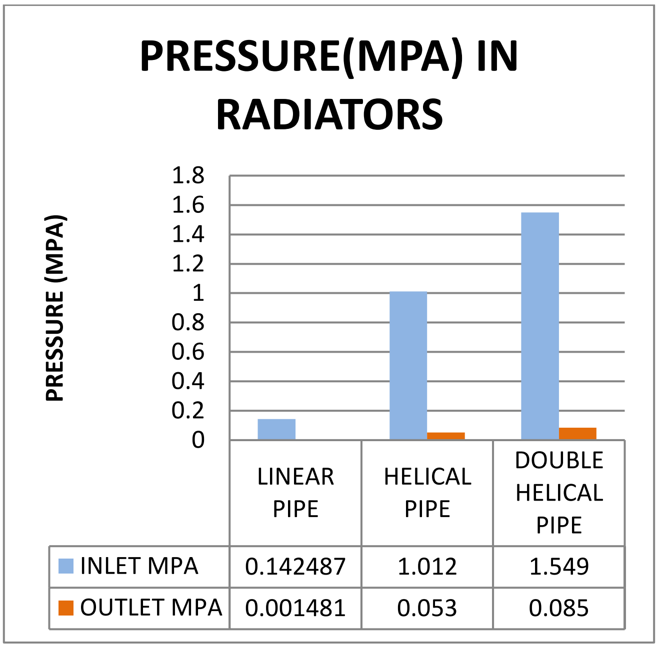


Chart-3: Pressure of radiators

As per the comparison of radiators, the double-helical radiator required more pressure to pump the coolant into the radiator.

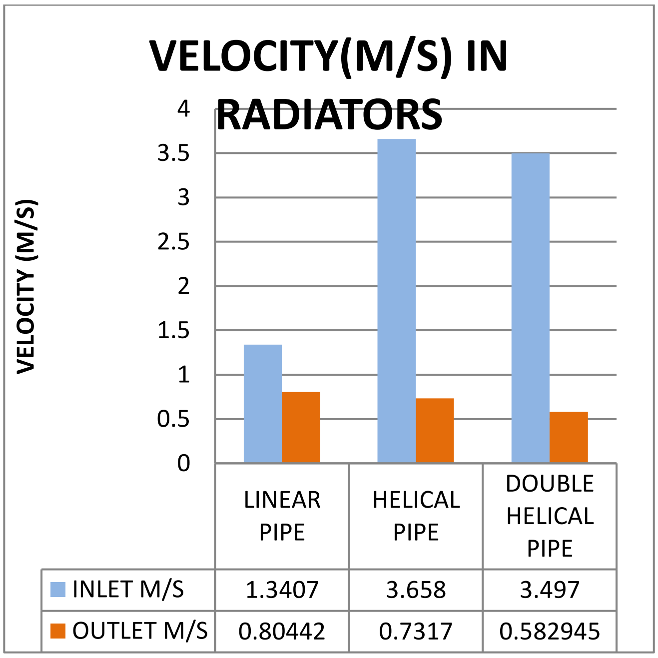


Chart-4: Velocity of Radiators

As per the comparison of radiators, the double-helical radiator required more velocity to pump the coolant into the radiator, but the outlet velocity of all radiator are relatively same. For a higher velocity flow rate, we need a higher rpm centrifugal pump.

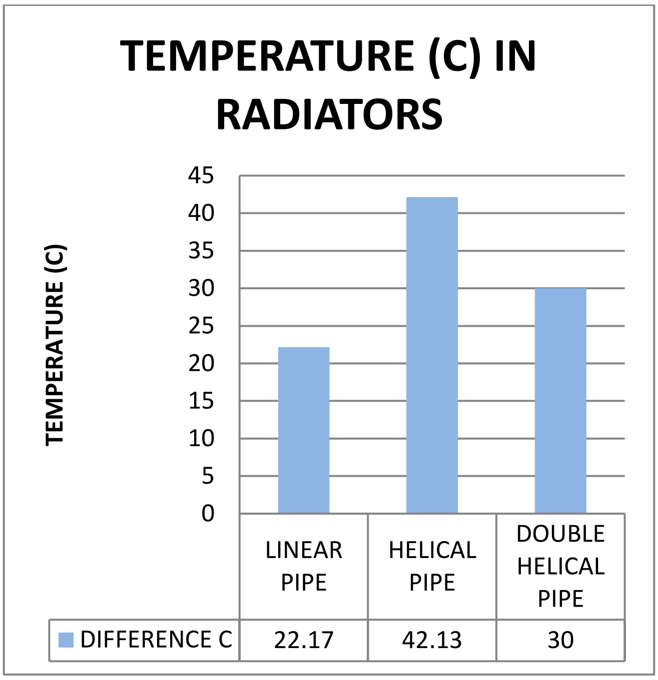
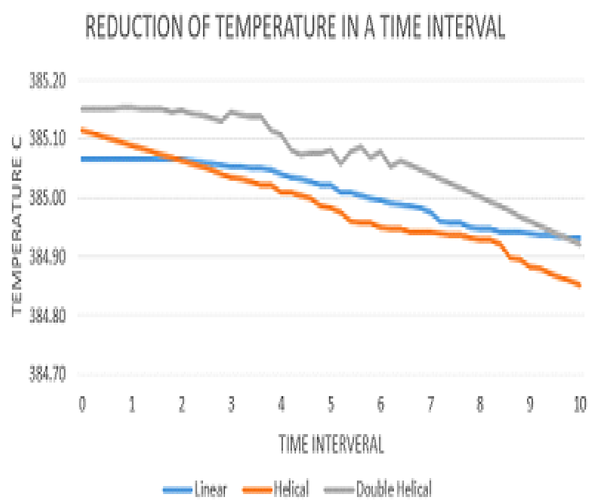


Chart-5: Temperature of Radiators

After the study of radiator, the temperature of inlet & outlet has an important role. That means the radiator which has a higher difference of temperature will have a higher Heat Transfer.



Graph-1: Reduction of Temperature

As per the graph above, the temperature of helical radiator is having a rapid reduction of temperature when it compared to the other two radiators.

VII. CONCLUSION

As the simulation of different radiators, we can conclude that by fixing the coolant proportion with different pipe shapes, helical pipe radiator gives the highest reduction of temperature from inlet to outlet. So from the above result, it is desirable to use ethanol with water as a coolant, which gives better performance by seeing temperature variations & other properties, as it gives the low temperature at the outlet. The study of radiator suggests that the velocity of coolant & mass flow rate differ by the change of shape & structure. In the end, radiator having helical pipe has more reduction in temperature when compared with linear and double helical piped radiator.

So in overall conditions, the radiator should have a high-efficiency mass flow rate & high reduction of temperature which supports to maintain optimal engine temperature and increase efficiency of engine.

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