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Research Article

Design and thermal analysis of light weight radiator for automobile applications

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ABSTRACT

This present study deals with the simulation of the radiator and its fin efficiency, where the coolant is used as air, and the working fluid is used as water and air to measure the thermal performance. Heat dissipation by conventional materials has enormous demerits. Hence, lightweight aluminium material has considerable benefits in better heat dissipation and energy transfer. The methods used in this analysis for design SolidWorks and analysis are done by cosmos software. The materials used here were copper for the fins and aluminium as the outer cover material. The properties such as thermal conductivities, heat capacity, and vapour absorption rates were calculated. From the experimental results, it was observed that the heat transfer rate was achieved in the range of 30 degrees Celsius with a change in temperature difference. An increase in fins from 10 to 20 number tends to increase the heat transfer rate by 10 to 15% as compared to other conventional materials. The results also concluded that there would be an increase in the overall efficiency of the radiator. The results also reveal that implementing copper tubes with the combination of aluminium fins has an extent decrease in heat transfer rate. Hence, a radiator for heat transfer applications can achieve a marginal temperature difference of 25 degrees Celsius to 30 degrees Celsius.

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INTRODUCTION

The dissipation of heat from one medium to another with the convective medium or conduction medium by applying a radiator is a critical factor for upcoming automobile design [1]. Even the engine in the automobile is the heart, but the radiator is the main device for the automobiles, and it dissipates the heat from the different hot temperatures [2]. The temperatures may vary between 1500 degrees Celsius to 2100 degrees Celsius. Hence, it must be designed with that bee designed using different materials [3]. The selection of materials depends upon the heat-conducting capacity of the material as well as the material life span characteristics [4]. The material also possesses high corrosive resistance and better thermal dissipation. The thermodynamic performance of the radiator should be very high compared to other cooling methods adopted for engine cooling [5]. One more major drawback of the analysis is the selection of optimal cooling fluids owing to the substantial temperature heat dissipation parameters [6]. When concerned with the light addition of additives, the right selection of coolants improves the engine's cooling performance [7]. Hence, selecting the best cooling additives that corrugate the material performance and the system performance of the radiator performance is desirable. The best materials can be chosen as lightweight materials because heat dissipation must rapidly occur with optimal cooling characteristics [8]. According to [9], the variation in fluctuations of fin efficiency depends upon the fin's stiffness characteristics and material properties, which offer resistance during the internal resistance to the flow of conduction of the coolant used in the radiator. The flat-shaped fin with a thickness of 3.8 mm gives an optimal performance with a fin effectiveness of 89%. Results also reveal that dynamic analysis with a combination of composite materials improves the heat conduction capacity of the system [10]. The fin's efficiency was gradually increased by changing optimal performance parameters such as the radiator core's stiffness and poison ratio characteristics [11]. It is also required to improve the thermodynamic properties of the fluid by utilizing the pumping fans with the aid of convective transfer mediums, which can ideally be operated in between minimum to maximum temperature conditions, which is extremely good under the operating temperature of 200 degrees celsius and atmospheric pressures [12]. From this investigation, it is understood that the system's efficiency depends upon the convective medium and type of working fluids used in the analysis [13]. The fouling factor determines the key performance factor to maximize the fin's efficiency. The impurities that occur at the inner side and surface of the material, which affect the system's performance, are predicted by this factor [14]. Many researchers [15,16] reported that radiators made up of stainless steel have more fouling factors because inadequate corrosion resistance offered by the material tends to cause poor system performance. The optimal performance is 90% in the inner load case when the nanofluid of Al_2O_3 particles is blended with graphene fluids as a coolant. Hence, this paper focuses on the analysis of radiators with Multiphysics software to find optimal cooling and minimal residual time, which can be implemented for automobile applications. The novelty of this work is to replace the steel materials with aluminium-based materials for better thermal dissipation and heat conduction capacity. The mini prototype model is designed, analyzed, and fabricated in a research centre that is available with well-equipped lab facilities. The source of working fluid utilized here is water and air. The objectives are to determine the heat dissipation capacity of the radiator with these two working fluids and to conclude which one is best for practical applications. The research gap and the novelty in work, followed by many failures, were faced by the conventional radiators made up of steel and composites in terms of less durability and high corrosion resistance. Hence, research related to aluminium material is less. This research gap and novelty of utilizing the aluminium radiator with light weight has enormous benefits in less corrosion resistance and high durability, causing better heat dissipation than other materials. The work is a prototype model constantly working further for real-world application implementations. The authors find difficulties during the fabrication of the model. They are willing to work further to add a few microns ranging from 300 microns to 400 microns of ceramic coatings to enhance the stiffness characteristics of the radiator. This model was developed to fit automotive applications and HVAC systems concerned with lightweight applications where the mass flow rates of water and air are quite simple compared to other applications such as marine, aerospace, and industrial sectors. The motivation behind the study is the utilization of lightweight radiator material made up of aluminium has enormous benefits in terms of high dissipation and low cost to avoid less corrosion behavior and less fouling factors, owing to the prevention of frequent replacements of radiators in the automobile industry.

MATERIALS AND METHODS

Materials

Table 1 shows the materials required and specifications for this analysis. Fins are made of aluminium alloy [17]. Aluminium is chosen as a fin material due to its lower density and ability to withstand higher conduction heat than other materials. Table 2 tabulates aluminum's properties.

Methods

The entire setup was drawn in SolidWorks, as shown in Figure 1. The radiator's cooling capacity estimates the performance [18]. The selection of materials is discussed in Table 1. In contrast, the meshing strategy involved here is an adaptive mesh strategy with an elemental size of 10 mm selected to minimize the computational time of the

Table 1. Material properties and specifications

S. NO	Material	Type	Quantity	Length (m)	Breadth (m)	Thickness (mm)	Diameter (mm)
1	Copper Tube	Metal	1	5	3	1	10
2	Aluminum sheet	Metal	50	2.7	2.7	1	_
3	Thermocouple	Sensor	3	1	_	_	2
4	Temperature controller	Digital	2	_	_	_	_
5	Coolant	Liquid	10 Lit	_	_	_	_

Table 2. Properties of aluminum

S. NO	Material	Aluminum
1	Point of Melting	661.3 °C
2	Point of boiling	2460 °C
3	Thermal Conductivity (K)	241.0 W/mK
4	Thermal Expansion Coefficient (**α**)	-
5	Density	2.8 g/cm^3

analysis. The entire analysis is taken for a minimal time of 20 minutes, from the preprocessing stage to the post-processing stage. The different types of materials are studied in the literature study. The study shows aluminium materials are less weighted and can conduct more heat dissipation than other materials [19]. One more merit behind using aluminium as a fin material is that it is lighter and gives higher heat dissipation than other materials. Hence, aluminium is the best insulating material for dissipating heat and transforming the heat at a convective heat medium. The model is designed and analyzed in multiphysics with different boundary conditions.

Radiator Design

The radiator and associated parts were modelled using 3D modelling software such as SolidWorks. Each part is drawn individually and assembled using the assemble option available in the Solid Works software [20]. SolidWorks is a friendly tool that can minimize errors during the assembly of radiators. The assembled model is shown in Figure 1. Figure 2 represents the front view of the radiator with the assembly of fins. The fins are corrugated in nature, improving the system's efficiency [21]. The accurate enhancement during the assembly of fins with radiator core and fins surface using surface morphology is possible in solid works. Also, the principal merit behind the usage of this tool is the efficient technique, which enhances the optimization of the design with minimal time to complete the initial part design to assembly. Hence, the perfect assembly is done using SolidWorks software, which is more accurate than other software [22].

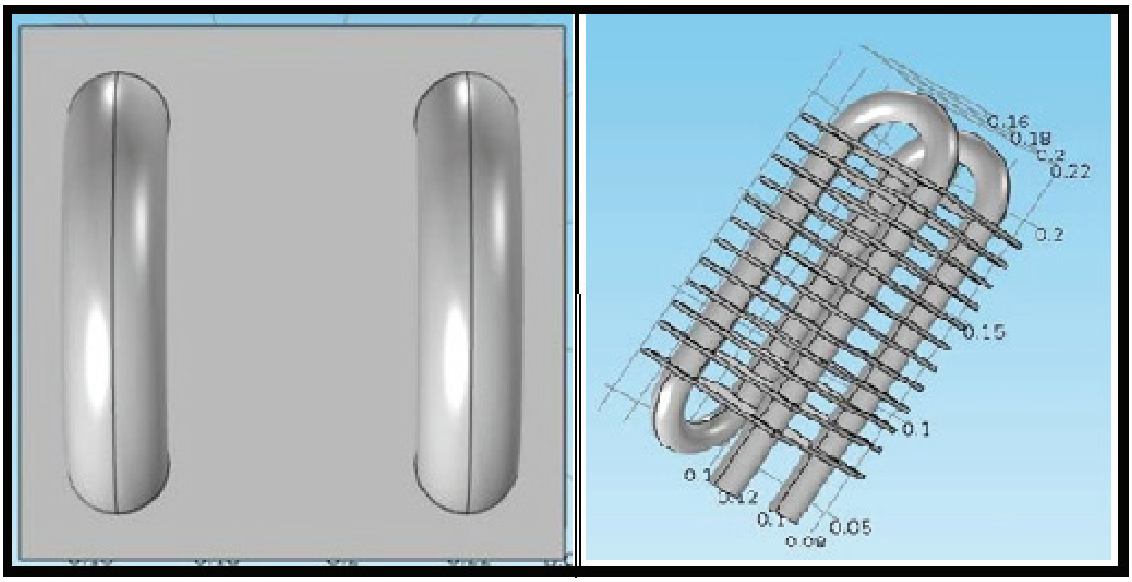

Figure 1. Top and side view of radiator developed in solidworks software.

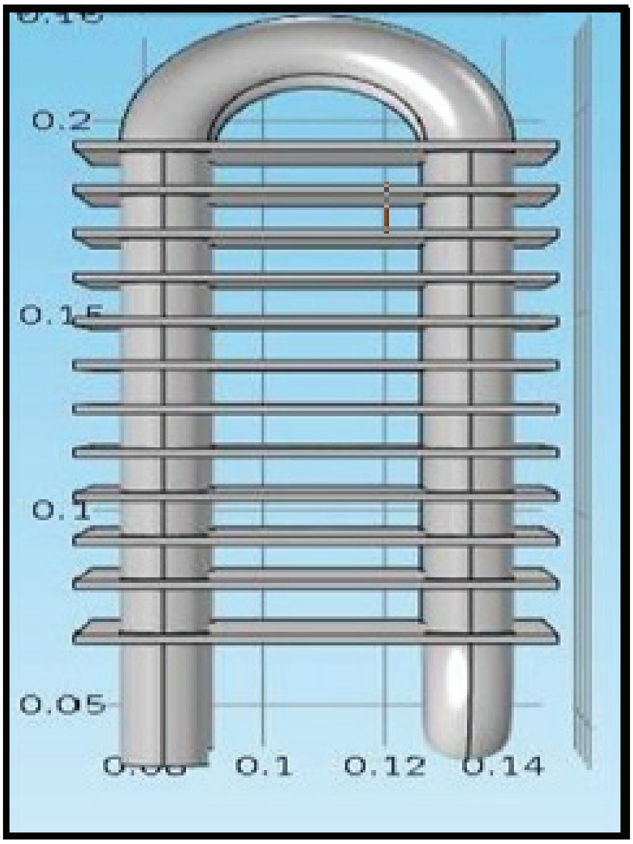

Figure 2. Front view of the radiator with fins.

ANALYSIS OF RADIATOR

Meshing Strategy

Figure 3 represents the meshing strategy of the entire radiator developed in cosmos multiphysics. The mesh elemental size of 10 mm was selected, followed by tetrahedron mesh for achieving accurate results, and the no of nodes and elements formed during the analysis is 40980 nodes

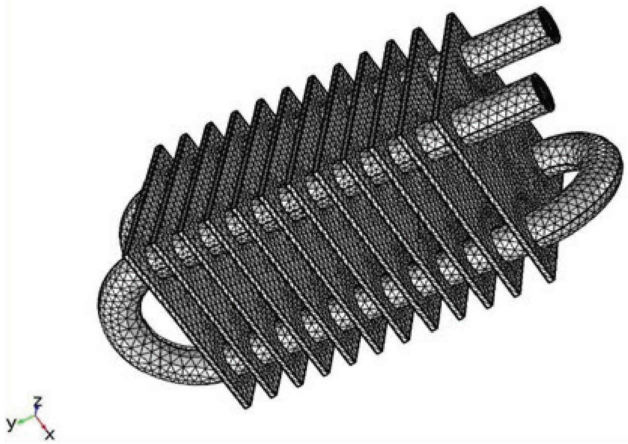

Figure 3. Meshing model of the radiator.

and 20200 elements for the radiator and 20100 nodes and 9015 elements for fins with fewer computational time of 15 minutes. The mesh convergences are obtained by 0.4%, which gives optimal deviation and less standard deviation with possible finer results. The other essential parameters, such as skewness, Jacobian, and aspect ratio, were checked, and these parameters were satisfied, which had more accurate results [23].

Boundary Conditions

The term boundary condition is defined as the term that acts as a single point of force contact, which is all the forces acting concerning the displacement due to rotation. Bending and transverse forces acting on it, technically called the degree of freedom, are zero and cause stringent resisting motion [24]. Figure 4 represents the degree of liberty applied at the top surface of the fin, the top surface of the radiator, and the bottom surface of the radiator and fin's bottom surface. Hence, all the forces acting over these surfaces become zero in terms of translational, rotational, sliding, and twisting motions [25]. The inlet condition of

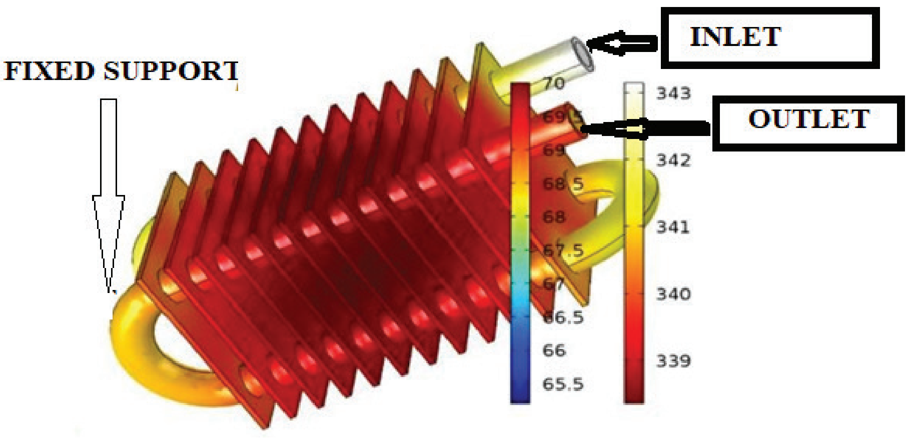

Figure 4. Boundary conditions.

the working fluid at different velocities is tested for three different mass flow rates working fluid as water and air. This stage is predominantly critical and concerned with the various velocities and other pressures. At the bottom portion of the radiator, the displacement is arrested; hence, the DOF is zero at these conditions. These values are governed by Navier stroke, which is ideally designated for real-world scenarios [26].

Governing Equations

The required equations for determining the mass flow rates of the working fluid and the base fluid depend upon the main equations, such as the continuity equation, which depends upon the mass and the Navier equations. Both equations describe the path of the mass flow rates and the tangential accelerations of the working fluids at different velocities.

The continuity equation defined in equation (1) referred to in [27] depends upon the temperature differences of the densities of the base fluids and the irrotational turbulent conditions concerned with the pressure, velocity, and time of the working fluids.

The navier stroke equation as shown in the below equation (2) referred from [28], describes the rotational flow of the hot working fluids and its significance parameters concerned with velocities, pressures and working substance densities.

$$\rho \mathrm{H}\ (r\mathrm{V} + - +vz\ ) = \mathrm{g}\rho - + \mu\ [\ (\ [v] + - +\ ]\ \text{--} \qquad (2)$$

The required equation (3) referred to [29], which is used for determining the specific heat of the hot working fluids depends upon the time concern factor and the coefficients of friction that are released from the hot gas surfaces to the radiator pipes.

$$\rho \mathrm{H}\ (\ \partial \mathrm{P} + rv + + zv\ ) = \mathrm{U}\ [\ (\mathrm{p}) + +\ ] + \mu\ \text{---------} \qquad (3)$$

Heat Dissipation Equations

The Amount of heat dissipation for the different mass flow rates is described by the following equation (4) referred from [30]

------ (4)

Q = Heat flux or heat dissipation concerned with the amount of heat flow in w/m^2

m = Amount of mass flow in kg/s

The mass flow rate that passes through the radiator can be measured with the help of a flow gas meter, and it is expressed by the equations (5) referred from [31]

= The volume of the hot gases passing through the radiator.

= The density of the working fluid in kg/m^3

The theory of mixing is used here for calculating the fractions concerning the Volume of working fluids followed by the following equation (6) referred from [32]

Density of the base fluid in kg/m^3

Density of the hot working fluid concerned to working fluid in kg/m^3

The density of the working fluid is the main physical parameter that signifies the thermodynamic performance of the radiator. The higher the density causes, the higher the dissipation of the molecules. Hence, the dissipation efficiency is very low in natural convection mode, in the range of 5.5% less than in forced convection modes. The Reynolds number identifies the nature of the working fluid, and its significance concerns the radiator's performance. In addition to the Reynolds number, the Nusselt number has more impact on identifying the nature of dissipation concerned with convective heat transfer [33].

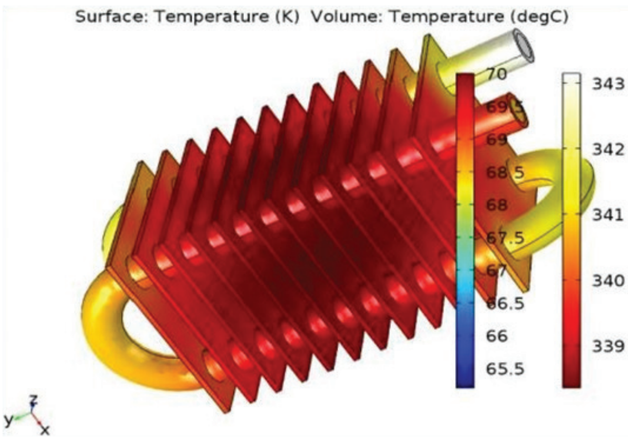

Figure 5. Post-processing results obtained.

Table 3. Testing Results

SNO	Observation	Water	Air
1	Inlet Temperature (°C)	65	27
2	Outlet Temperature (°C)	44	32.43
3	Mass flow rate (Kg/s)	0.0238	0.1459
4	Specific heat (kJ/kg°C)	4.187	1.005
5	Thermal conductivity (W/mK)	0.66	0.024
6	Density (Kg/m^3)	998	1.225

Table 4. Calculated values

S. NO	Observation	Value
1	Heat transfer coefficient (U)	350 W/mk
2	Log mean temperature difference (LMTD)	18.25 °C
3	Amount of heat transferred (Q)	2869.93 W
4	Capacity ratio (C)	0.679
5	NTU	1.68
6	Effectiveness (Ɛ)	0.65

Table 5. Cost benefit analysis

S. NO	Equipment/Component	Cost	Durability	Quantity	Total cost
1	Aluminum sheet	1800/-	5 years/till rust	1	1800
2	Copper tube	790/-	5000 cycles	1	790
3	CNC Sheering	6/-	-	50	300
4	Thermocouples	840/-	3years	3	2520
5	Temperature controller	4500/-	3 years	1	4500
6	Welding	60/-	-	6	360
7	Coolant	20/-	10 years	3	60
8	Transportation	300/-	-	3	900
9	Brine solution	500/-	10 years	1	500
10	Misce Other costs	1200	-	1	1200
11	Operating costs	20	Infinite	1	20
12	Total cost				12900/-

Table 6. Uncertainties of instruments used

S. NO	Devices	Deviations	Range	%Uncertainty
1	Load Indicator	±2.7 kg	0-150 kg	0.55
2	Working fluid Temperatures	±2.2 °C	0-840 °C	2.22
3	Brazing temperatures	±7 °deg	200-580 deg	2.1
4	Stopwatch	±0.8s	-	0.65
5	Thermocouple	±0.8	0- 700 deg	1.8
6	Pressure gauge	±2 bar	0-800 bar	1.8
7	Coolant Mass flow	±25 kg/s	0-305 kg/s	2.3

The representation of data that experimentally occurred during the simulation is termed post-processing results. It indicates the physical occurrences by simulation and the significant nature of occurrences in pictorial representation [34]. Figure 5 represents the post-processing results that occurred during the simulation. It was observed from Figure 5 that the maximum heat transfer occurred at the radiator fins up to 343 W/mk with the rise in temperature differences of 70 degrees Celsius. This is due to the phenomenon of heat conduction capacity of heat transfer by the conduction of fins made up of aluminium, which has a limited thermal conductive capacity of 345 W/mk [35]. This is due to the collision of oxygen molecules with others. This interrupted collision tends to conduct the heat to a limited extent [36]. Table 3 represents testing results and Table 4 represents calculated values.

Table 5 represents the cost-benefit analysis involved in the fabrication of this project. The materials were purchased from the local manufacturers available at chennai, and the aluminium sheets were purchased from the cosmos aluminium dealer in chennai; the thermocouples were purchased at chennai. A few products, such as coolant, are purchased from local coolant dealers in chennai.

Uncertainty Analysis

The main essential criteria satisfy the precision and accuracy of the radiator's fabrication, and possible errors depend upon the radiator's least calibration compared to the measuring instruments. Table 6 significantly represents the uncertainties that occurred during the radiator fabrication trials. Table 7 depicts the accuracies of parameters used in experimental analysis. The trials are carried out with three definite readings calibrated as a source of Gaussian distribution calculations to identify possible errors.

Table 7. Parameters and its accuracies

S. NO	Parameters	Percentage of uncertainty
1	Working fluids temperatures	±1.9
2	Mass flow rates	±1.8
3	Coil bending Pressures	±2.1
4	Fins heat transfer	±2.2
5	Flame temperatures of brazing	±1.76

The required correlations from various kinds of literature have been collected and the range of accuracies obtained from different experiments that calibrated is defined by equation [7], referred from [37]

Equation (7) defines the deviations obtained during the experimental segment and the deviations depend upon the atmospheric variables such as pressure, Temperature, and Densities of the working fluid, causing the least possible errors

The maximum possible readings that caused the errors or range of calibrated readings is defined by Equation (8) referred from [38]

The range of uncertainties that developed during the experimental segment followed by Equation [9] referred from [39]

= Obtained deviations and calibrated readings.

Fabricated Model

Fabrication is required before testing the performance of the radiator. The project laboratory does all the fins and is equipped with the model setup. The above Figure 6 illustrates the fabricated model. The transformer with 440 volts is used to carry out plasma arc welding, and aluminium baffle plates were inserted between the tubes [40]. The copper tubes were tough to bend. Hence, the required inclinations were bent using the bending machines to avoid creeping and fatigue disturbances. The tubes were cleaned with high detergents to achieve the best results [41]. The cleaned tubes and aluminium fins are exposed to air to achieve dryness. Before experimenting, the tubes are cleaned with salt sheets to avoid the corrosion effects [42]. The testing phase is important in finding fouling factors. The authors have used salt spray techniques on the aluminium plates to determine their corrosion and durability. The aluminium plates are kept in salt spray with 10% sodium hydroxide, and there is no physical change in the behaviour of the aluminium radiator [43].

RESULTS AND DISCUSSION

Effect of Temperature Distributions

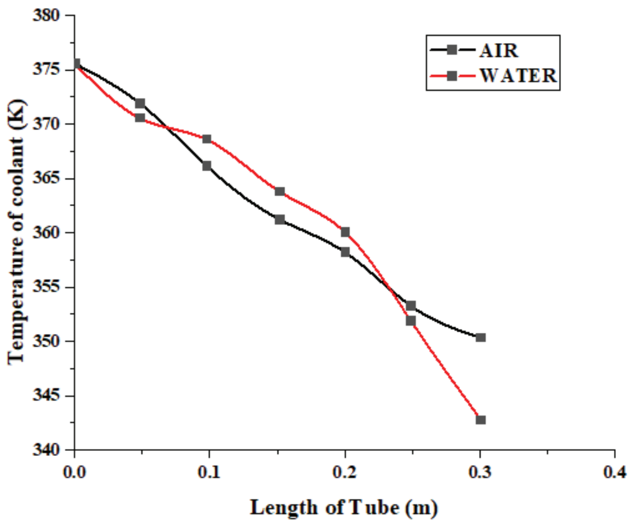

Figure 7. Temperature distribution of coolants.

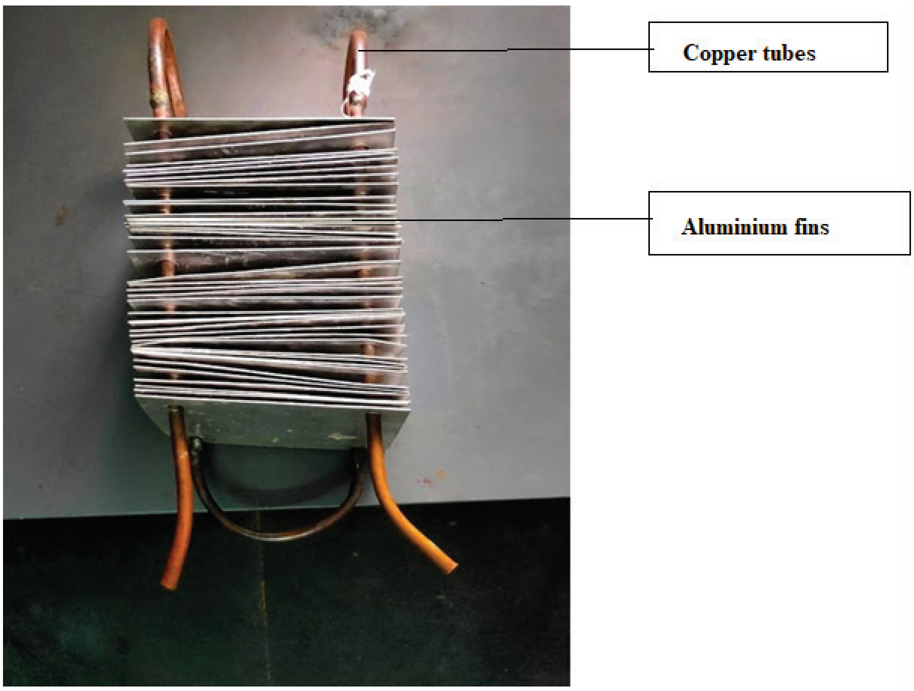

Figure 6. Fabrication model.

The temperature distribution is an essential factor in evaluating the thermal performance of the radiator; the higher the thermal dissipation, the higher the thermal efficiency of the radiator. The overall efficiency of the radiator depends upon the thermal differences and heat dissipation factors that decide the capacity of the heat transfer medium. Figure 7 explains the temperature differences obtained in the aluminium radiator experiment. It is observed from Figure 7 that the temperature distribution of water increases quite a lot with tube length. Because the specific heat of water is quite high as compared to water [44]. The specific heat of air is quite low as compared to water; hence, the medium of air as a coolant is quite tricky. As Temperature increases, the heat conduction for air decreases, but for water, as temperature increases, the heat conduction and heat dissipation rate also increase. It acts as a better conductor due to the higher specific heat and transmission capacity as compared to air [45]. The effectiveness achieved by water is good, and hence, water can dissipate heat at an enormous rate by conduction, a convection phenomenon compared to air [46].

Effect of Pressure Drop

The pressure drop in the radiator is essential in determining the pressure coefficients and their dynamic stagnation characteristics across the tubes. In other words, pressure drop factors can determine the coolant flow in the radiator with corrugated obstacles [47]. Figure 8 represents the pressure drop over coolants subjected to two different working fluids, water and air. It is keenly noted that the mass flow rate of the coolant is increased with definite intervals and tends to decrease in pressure gradually [48]. The length of the tubes corrugated with the fins increases and tends to decrease in pressure, whereas other materials possess high-pressure drops due to high density and mechanical characteristics [49]. The lower the weight of the aluminium, the less pressure drop, and the maximum drop is achieved, up to 400 pa, subjected to maximum deflections. The pressure drop for water is low compared to air due to higher density differences occurring due to the forced and turbulence effects of water due to a convective medium [50].

Effect of Mass Flow Rate and Cooling Efficiency

The flow of air as a cooling medium to dissipate the heat is required to predict the cooling capacity of the radiator [51]. The thermal performance of the radiator depends upon the heat dissipation characteristics. Figure 9 represents the mass flow rate of the air as an external source, and the internal working fluids were utilized as water and air. It is predominantly noted that the working fluid of air has low dissipation compared to water [52]. The lower the mass flow rates from 100 kg/hr with the help of forced convection; the desired efficiency was noted as 50%; If the Density of the air increased from 100 kg/hr to 150 kg/hr; the cooling efficiency of the radiator for the working fluid air is increased from 50 to 57 % and for working fluid water the radiator efficiency is achieved from 53% to 64%. At higher optimal loading conditions, the optimal cooling efficiency of the radiator is increased up to 67% for the radiator operated by air as a working fluid, and for the radiator operated by water as a working fluid, the optimal efficiency is achieved up to 70%; the corresponding mass flow rates are achieved up to 275 kg/hr.; It is desirable to note that the cooling efficiency for the working air-water medium is good compared to the air-air medium [53]. Water's higher thermal conduction behaviour gives optimal cooling effects compared to air. Hence, water is required as a coolant for optimized efficiency [54].

Mass Flow Rate and its Approach

It is experimentally needed to predict and analyze the approach based on temperature differences. This approach

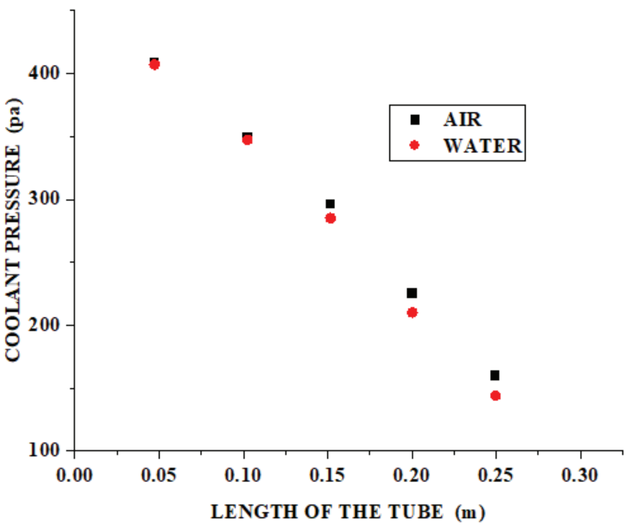

Figure 8. Pressure drop over coolants.

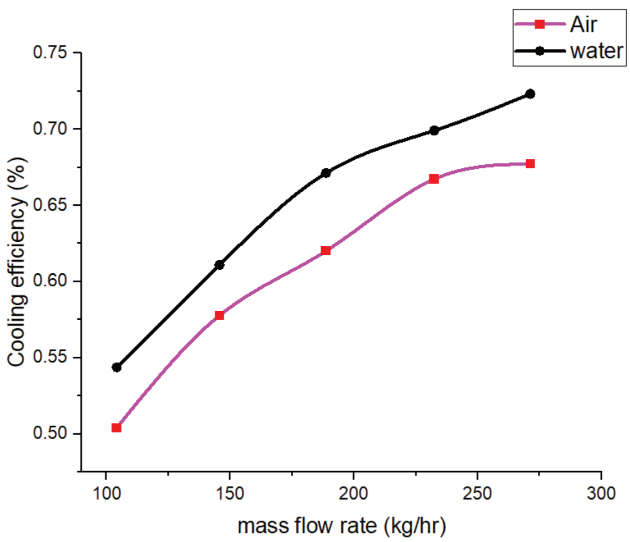

Figure 9. Mass flow rate and its cooling efficiency.

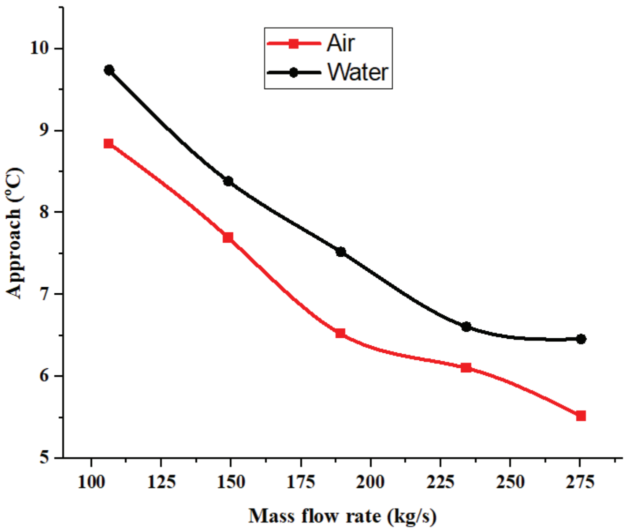

Figure 10. The approach of Temperature and its mass flow rate (ΔT = 30°C).

is highly used to determine the desired cooling effects during heat dissipation [55]. Figure 10 signifies the average temperature dissipation for the working fluids air and water. The desired effectiveness is achieved for the working fluids air with a minimal temperature difference of 10 Degrees Celcius. When the temperature reaches 20 Degrees Celsius , the corresponding mass flow rate is achieved at a maximum of up to 275 kg/hr. The mass flow rate for water as a working fluid; the corresponding temperature difference is achieved by 30 Degree Celsius because a higher dissipation rate is achieved through the water [56]. The main reason why it is the best medium with the difference in temperatures is that it acts as the best thermal conductor and the turbulent forces and higher thermal differences are created during the evolving period. The losses during the heat transfer phenomenon concerning inside the radiator are overcome by the radiator fins made up of aluminium. Hence, water as a cooling medium gives optimized results compared to air.

Cost-Benefit Analysis

The welding is done at the college campus. The CNC shearing, welding, and brazing processes are done with the help of well-trained non-teaching faculties with the least atmospheric errors. Owing to the cost study, the cost of fabricating this radiator is 12900. Which is very cheap, and the manufacturers can get enormous benefits compared to radiators made of other materials. Hence, implementing this radiator can give enormous benefits in terms of better heat dissipation characteristics and the best and cheapest cost compared to other materials. Therefore, every customer or radiator manufacturer interested in working on lightweight materials can use aluminium-based radiator fins for better heat dissipation at the lowest cost. Due to the cost-benefit analysis, aluminium is very cheap compared to other materials like steel and is more durable than steel. This is because the aluminium material's lighter weight and less corrosion resistance offered by the aluminium material results in better performance than steel and other conventional materials.

CONCLUSION

The design of the radiator is done using Solid works software, and the entire setup is imported into multiphysics software for analysis. However, the material properties of the radiator and the elemental characteristics are mentioned in the preprocessing stage of the cosmos application software. Among the various literature and various researchers' studies, it is noted that the effectiveness of the radiator depends upon the heat-conducting medium of the radiator material and the weight of the radiator. In addition, the radiator's mechanical properties must be analyzed before the radiator must be designed. The following observations were concluded during the analysis followed by

- ❖ The maximum heat conduction capacity of the fins made up of aluminium can able to withstand 345 W / MK.
- ❖ The maximum heat transfer capability of the fins is 2900 watts.
- ❖ The capacity ratio of aluminium fins can be achieved up to 0.8, whereas it can be limited to 0.6 for conventional materials. Hence, aluminium possesses better heat dissipation and better capacity than traditional materials.
- ❖ Owing to thermal heat dissipation through rapid cooling, which is simulated in the Cosmos software, the results show that rapid cooling is possible within the rapid cooling rate of 22 Degree Celsius , in contrast to other materials.
- ❖ Since the conductivity medium or source here is utilized as air or water, both the medium and the aluminium materials possess better heat conducting capability and better heat dissipation in terms of conduction, convection, and radiation.
- ❖ The thermal diffusion of the aluminium alloy-based radiator is better as compared to a conventional radiator; hence it is suggested that the use of an aluminium-based radiator gives predominated efficiency in terms of better heat dissipation;
- ❖ The life span of the radiator is increased if the working fluid is air because aluminium possesses high resistance capacities compared to other fluids.
- ❖ Aluminum's thermal conductivity is excellent compared to other conventional materials because aluminium has a high resistance to heat.
- ❖ Aluminum fins have proven optimal performance in heat dissipation, lower thermal elongation, and higher stability. Hence, aluminium was considered a material for radiator design and fabrication analysis.

- The mass flow capacity of the radiator for air is low compared to water because the specific heat of water is very high compared to air. This will decrease the performance in terms of heat dissipation but improve the life span of the radiator because fewer corrosion formations will occur if the working fluid is air.
- Overall, the fabrication and implementation of the radiator give good results owing to thermodynamic performance and life span characteristics.
- Owing to the cost study, the cost of fabricating this radiator is 12900.
- Hence, every customer or radiator manufacturer who is interested in working with lightweight materials can choose aluminium-based radiator fins for better heat dissipation at the lowest cost.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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