DESIGN AND MATERIAL SELECTION OF AN AUTOMOBILE RADIATOR

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Abstract
The concept of automobile radiator is discussed in this paper. The radiator is a part of an automobile which is used mainly to cool down the heated coolant of an engine. Its basic working is based on the heat exchanger principal except here one of the working fluid is air. An overview of this radiator is discussed in this paper and by the assuming general dimensions and properties like thermal conductivity, porosity, air resistance, mass flow rate, density etc. a preferable effectiveness shall be observed.

Keywords: Radiator, Material Selection, Design, Analysis component.

Introduction

The Engines have changed our way of life. From zooming automobiles to faster than sound aircrafts, we have come a long way. Although the need for stronger engines in more confined spaces have caused problems of heat dissipation in the engines [1]. In the case of insufficient heat dissipation, there is a formation of internal stresses in the engine which hamper the life of the engine and also affect the performance of the engine. The heating of the engine also leads to overheating and viscosity breakdown of the lubricating oil and also the weakening of the engine metal parts [1]. This arises the need for a cooling mechanism for the engine. Nowadays, this task is accomplished with the help of a cooling system which consists of a radiator, fan, thermostat, and water pump and radiator pressure cap [1]. The radiator is actually a type of heat exchanger [1].

Literature Review

Types of Radiators

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RECTANGULAR RADIATOR [2]

This Design is the most popular one used nowadays. Hot water or the coolant is made to flow through the tubes of the radiator. These tubes are surrounded by a number of fins along the entire length of the tube [2]. A fan circulates the air along the fins in order to provide the necessary cooling of the coolant. It is a type of forced induction cooling as the atmospheric air is forced onto the radiator to cause cooling. Fins are used to increase the heat transfer area to maximize cooling. When cooled the coolant ultimately comes out of the outlet port of the heat exchanger.

Heat exchanger for air conditioner [2]

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Square shaped heat exchanger [2]

This type has a square shaped design as opposed to the rectangular and elliptical design in the previous two. Here the fan is provided to deliver air only to a circular area rather than the whole system area. [2] If the side if the heat exchanger is D, the difference in the area of the cooled and uncooled region would be 0.24 D2.. [2]

METHOD OF HEAT TRANSFER TECHNIQUES

Some of the methods which are used to transfer heat in the radiators are as discussed below. The best one is the one which uses the least pumping power for transferring the maximum amount of heat. [7]

ACTIVE METHOD [7]

It is done by external mechanical devices which run on external power. The devices used are fans and blowers which cool with the method of forced induction. [7]

PASSIVE METHOD [7]

This method uses the principle of increasing of the effective surface area which causes more heat available at the surface for cooling. It does not require any external means of cooling system like fans. [7] This paper will use passive method over the other two as we know that through our design we can achieve better efficiency than the other two methods.

COMPOUND METHOD [7]

Sometimes both the methods are used simultaneously to achieve better cooling. It uses both external power sources and geometry design changes for better cooling. [7] One would argue that it has the high ground over the both methods but that is not true. It also has innate drawbacks of both the methods making it stand on the same ground.

MATERIALS TO BE USED IN THE RADIATOR

Based on the requirements of radiator, material are selected for this design.

PIPING AND CASING MATERIAL

Following materials are selected based on design criteria:

Aluminium (6061) T6

Aluminium 6000-series alloys (eg:- Al6061) have much better corrosion resistance and on further addition of a T6 heat treatment, the toughness and resistance to fatigue crack growth can be improved, hence increasing its strength by as much as 30%. [5] Thermal conductivity for aluminium 6061 is 180 W/(m*K) and when the density is considered, the specific thermal conductivity of aluminium (thermal conductivity divided by specific gravity) is 54 W/(m*K). [4]

Copper Alloy

A copper alloy which is suitable for a heat exchanger contains 1 to 4.5 wt % of Zn, 1.0 to 2.5 wt %, preferably contains 1.5 to 2.0 wt % of Sn, 0.005 to 0.05 wt %, 0.01 to 0.04% of P, and the balance substantially Cu and inevitable impurities, and has grain size which is not greater than 0.015 mm and preferably below 0.01 mm. [6] The alloy shows high resistance to corrosion which can be caused by the coolant or the external atmosphere. This also shows a good solder wettability which allows the solder joint to have proper conduction at its eutectic temperature. Brass shows a rather inferior corrosion resistance as compared to this alloy. [6]

FOAM MATERIAL

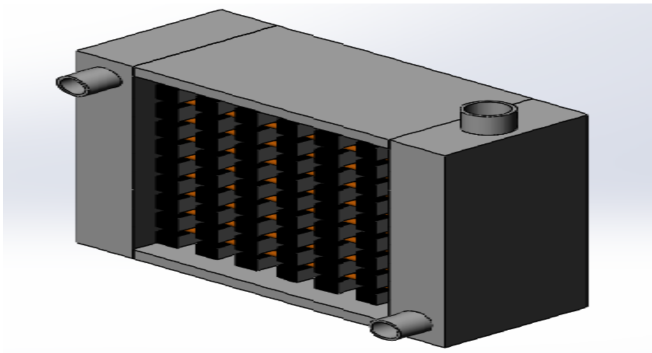
Carbon Graphite Foam

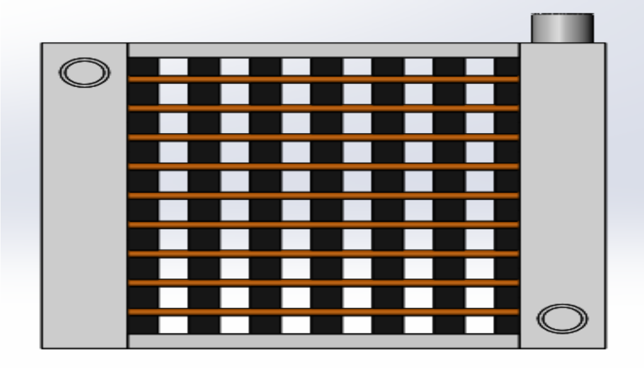
Carbon graphite foams are sponge like material. They are porous in nature, thus allows the air to flow through it in addition to flowing around it. Also carbon graphite foam provides a large surface area per unit volume [4] due to large and numerous pores, thus larger surface area will increase the surface area exposed to the air and hence reduces the air side resistance. Carbon graphite foams are very light in weight [4] when compared to conventional materials used in current radiators like aluminium or copper fins, thus making them more durable. One of the major properties is that it can be manufactured from a block to any desirable shape by means of milling, cutting, drilling, etc. One major disadvantage associated with carbon graphite foam is that it is expensive to produce. However, new production methods show potential to lower the price in the near future. [3]

METHODOLOGY

MODELLING IN SOLIDWORKS

Solid Works software is the standard in 3D product design used for representing 3D visualization of a product. The design built in this software are easy to process and requires less time. The below figure shows a solid model of a radiator by using solid works. By taking the general dimensions we have drawn a radiator model in solid works.





Dimensions

Width: 23 inch [3]
Height: 21 inch [3]
No. of tubes: 18
Diameter of tube(outer): 0.5 inch
Diameter of tube(inner): 0.4 inch
Inlet and Outlet Port Diameter: 2 inch

DESIGN ANALYSIS OF RADIATOR

Analysis of Radiator on the Basis of Material

Thermal Conductivity / Specific Gravity

- Aluminium 6061 T6 = 54 W/(m*K) [4]
- Copper alloy = 45 W/(m*K) [4]

To minimize cost for a strength design
Performance index = Tensile Strength(MPa)/Cost Per Kg

- Aluminium 6061 T6 = 290/345 = 0.8406
- Copper Alloy = 317.16 /650 = 0.4879

From the above parameters, Aluminum 6061 T6 is more suitable than copper alloy.

Calculation Analysis on the Basis of Medium

Assuming an air cooled heat exchanger

Sr. No.	Observation	Air(cold)	Water(hot)
1.	**Inlet Temperature (°C)**	28 [2]	52 [2]
2.	**Outlet Temperature (°C)**	34.365	44 [2]
3.	**Mass Flow Rate (kg/hr)**	525.35 [2]	100 [2]
4.	**Specific Heat (kJ/kg°C)**	1 [2]	4.18
5.	**Thermal Conductivity (W/m*k)**	0.024 [2]	0.66 [2]
6.	**Density (kg/m³)**	1.1 [2]	1000 [2]

We know that the value of overall heat transfer coefficient (U) of an air cooled heat exchanger is between the ranges of 300-450 W/m2K. Let us assume its value be equal to 350 W/m²K [2]

Therefore, using energy balance equation

$$m_a \times C_{ph} \times (T_{hi} - T_{ho}) = m_w \times C_{pc} \times (T_{co} - T_{ci})$$

$$100 \times 4.18 \times (52 - 44) = 525.35 \times 1 \times (T_{co} - 28)$$

$$T_{co} = 34.365\ °C$$

$$Heat\ transfer\ (q) = m_a \times C_{ph} \times (T_{hi} - T_{ho})$$

$$= 100 \times 4.18 \times (52 - 44) = 3344\ Watt$$

Let us assume Heat exchanger is counter Flow in nature, we get

$$\Theta_1 = T_{hi} - T_{co}$$

$$= 52 - 34.365 = 17.635\ ^oC$$

$$\Theta_2 = T_{ho} - T_{ci}$$

$$= 44 - 28 = 16\ ^oC$$

Log Mean Temperature Difference(θ_m),

$$(\theta_m)_{counterflow} = (\theta_1 - \theta_2) / Ln(\theta_1 / \theta_2)$$

$$= (17.635 - 16) / Ln\ (17.635/16)$$

$$= 16.8\ ^oC$$

Total Flow Rate Area,

$$[2]\ (A_f) = n \times (\pi/4) \times d_i^2$$

$$= 18 \times (\pi/4) \times (10.16 \times 10^{-3})^2$$

$$= 1.4593 \times 10^{-3}\ m^2$$

Also,

$$[2]\ A_f = m/(v \times \rho)$$

$$1.4593 \times 10^{-3} = 100 / (v \times 1000)$$

$$V = 68.53\ m/hr$$

For correction factor required dimensions, we find P and R

$$[2]\ P = (T_{co} - T_{ci}) / (T_{hi} - T_{ci})$$

$$= (34.365 - 28) / (52 - 28)$$

$$= 0.265$$

$$[2]\ R = (T_{hi} - T_{ho}) / (T_{co} - T_{ci})$$

$$= (52 - 44) / (34.365 - 28)$$

$$= 1.257$$

Hence, from the chart correction factor (F) = 0.9

(https://sistemas.eel.usp.br/docentes/arquivos/5817712/LOQ4086/lmtd.correction.factor.

pdf)

Area of the heat transfer(A) after considering correction factor is given as,

$$A = q \ / \ \left(U \times F \times \theta_{m(counterflow)}\right) = 3344 \ / \ (350 \times 0.97 \times 16.8) = 0.5863 \ m^2$$

Effectiveness of Heat Exchanger

- For water

$$C_H = m_w \times C_h = (100 \times 4.18 \times 1000) \ / \ 3600 = 116.11 \ W/K = C_{min}$$

- For air

$$C_C = m_a \times C_c = (525.35 \times 1 \times 1000) \ / \ 3600 = 145.93 \ W/K = C_{max}$$

- Capacity ratio (C)

$$C = C_{min} \ / \ C_{max} = 116.11 \ / \ 145.93 = 0.796$$

- No. of transfer unit (NTU)

[2] $$NTU = (U \times A) \ / \ C_{min} = (350 \times 0.5863) \ / \ 116.11 = 1.7673$$

Using NTU- ε correlation for cross flow HE with both fluids unmixed, we have

[2] $$\varepsilon = 1 - exp\left[(1/C)\left(NTU\right)^{0.22}\{\exp[-C\left(NTU\right)^{0.78}]-1\}\right]$$

$$\varepsilon = 1 - exp\left[(1/0.796)\left(1.7673\right)^{0.22}\{\exp[-0.796\left(1.7673\right)^{0.78}]-1\}\right]$$

$$\varepsilon = 0.6366$$

Conclusion

The effectiveness of the radiator is being calculated on the basis of design and material selection discussed above opting certain parameters. Various materials like Aluminium 6061 T6 and copper alloy are observed on the basis of their thermal conductivity and specific thermal conductivity. Taking designing parameter and materials into account a preferable radiator is been constructed.

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