To Study and Do Theoretical Analysis of Compact Heat Exchangers

Presented By: ME16
Group Id: 130009401
Patel Jignesh A. (10ME17)
Patel Ravi R. (10ME19)
Patel Hardik A. (10ME15)
Patel Bhavesh A. (10ME09)

Guided By:
Prof. R.N.Mevada
Definition:-

- **Heat exchanger:**
  
  It is a device that provides exchange of thermal energy between two or more fluids at different temperature.

- **Types of heat exchanger:-**
  1. Double-Pipe heat exchangers
  2. Shell and tube Heat Exchangers
  3. Compact heat exchanger
  4. Gasketed Plate heat exchanger
  5. Condenser and evaporator
Compact Heat exchanger

• Types:-
  1. Plate fin and tube fin
  2. Tube bundle with small dia.

A heat exchanger having a surface area density greater than about 700 m²/m³ is quite arbitrarily to as a compact heat exchanger.
Fin and Tube Heat Exchanger: A Compact Heat Exchanger
Applications

• Vehicular heat exchanger
• Condenser and evaporaters
• Refrigeration industry
• Aircraft oil coolers
• Automative radiators
• Oil coolers
• Intercoolers of compressors
• Other industries
INTRODUCTION

• This proposed scheme analyzes the heat transfer process involved in the operation of an automotive radiator. The analysis of a radiator encompasses nearly all of the fundamentals discussed in a heat transfer class, including the internal and external fluid flow through a heat exchanger and the design and analysis of heat sinks and exchangers.

• The theoretical heat exchanger investigation begins with analyzing the internal fluid flow through the radiator’s circular or noncircular tubes, yielding the convective heat transfer coefficient for water.
• The external fluid flowing across the radiator tubes and fins is then analyzed to find the convective heat transfer coefficient for the air.

• The heat sink design of the radiator must then be analyzed using the Effectiveness method to find the theoretical effectiveness.

• This topic is specifically selected to integrate the numerous areas from the subject of heat transfer. Through the many challenges and successes met during this project.
• The convective heat transfer between a wall and the fluid is given by

\[ Q = hA(T_w - T_f) \]

Or

\[ Q = (hA)_p (T_w - T_f) \]

• Enhancement ratio:

\[ E = hA/(hA)_p \]
There are several methods to increase the $hA$ value:

- The heat transfer coefficient can be increased without an appreciable increase in surface area.

- The surface area can be increased without appreciable changes in the heat transfer co-efficient.

- Both the heat transfer coefficient and the surface area can be increased.
RESEARCH

- The first step of this project was to gather information on existing radiator designs and general heat exchangers. After gathering information, we gained a thorough understanding of how a radiator works and the disadvantages of the current radiator designs. This included a general patent search, using Google Scholar, and technical journal search, using different books, that related to radiators. Once we choose our design, we must research a general testing method to use as a basis for our comparison of our new design and the current designs.

- Current radiator designs of maruti 800 are extremely limited. The main problem is that current radiators experience a large resistance to heat transfer caused by air flowing over the radiator. Current radiators also experiences head resistance, are very bulky, and impose limitations on the design of the vehicle.
OBJECTIVES

• To study the design of radiator for given duty and find enhancement in the performance of it by doing systematic analysis.

• The main objective of compact heat exchangers is to produce more efficient heat exchange equipment for minimizing cost, which is to produce the physical size of a heat exchanger for a given duty.

• To optimization high heat transfer rates under the specified conditions.
EXPERIMENT

System Configuration

Figure 1: New radiator designed setup
Figure 2: Old radiator designed setup
The coolant fluid (water) that passes through the engine block enters on the high side of the radiator as the hot fluid. From here, this hot fluid fills the tube banks of the radiator and makes a single pass across the radiator.
• Cool air is then forced across the radiator’s core, by a fan and by using air produced by the motion of the vehicle, to absorb and remove the heat from the coolant. During the entire process two main forms of heat transfer occur:

• (1) convection due to the internal flow of fluid passing through circular or non-circular tubes.

• (2) convection due to the external flow of air across the tube bank.

![Figure 3: Schematic of single tube](image-url)
SETUP

• An copper stock radiator of maruti800 will be tested with an engine at idle conditions. The coolant used in the radiator is pure water. The inlet and outlet temperatures for both the water and the air will be measured using a thermocouple and multi thermometer.

• For the water, a probe can be inserted in the tube right before the fluid enters the radiator and right after it exits. The inlet and outlet temperature of air will be measure with multi thermometer.

• Inlet mass flow rate of water will be measure with Rotometer. And inlet velocity of air can be measure with Anemometer.
PROCEDURE

• The engine run with predefine mass flow rate of water. Mass flow rate set at different value by rotometer. Once the engine reached this temperature, the fan in front of the radiator will be turned on to begin cooling the radiator. The radiator, along with the fan, then cooled the radiator until the temperatures reached steady state.

• The inlet and outlet temperatures and the for air and water will be then record. Air velocity also be record by anemometer.

• This experimental process will repeated four times in order to give a range of results to compare with one another.
• Find the Heat Transfer Rate of different value by equation.

\[ Q_w = m_w \cdot \varrho_w \cdot c_w \cdot (T_{\text{win}} - T_{\text{wout}}) \]

Where,

- \( Q_w \) = Heat transfer rate in KW,
- \( m_w \) = Water flow rate in LPM,
- \( \varrho_w \) = Water density 1.0 kg/L,
- \( c_w \) = Specific heat of water 4.186 KJ/kg/°C
## SPECIFICATION

<table>
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<tr>
<th>SPECIFICATION</th>
<th>NEW RADIATOR</th>
<th>OLD RADIATOR</th>
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# RESULT

## New Radiator

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<th>$T_{a \text{in}}$ °C</th>
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• Effectiveness of new radiator

\[ Q = 4.184 \text{ KW} \]

\[ T_{h_{in}} = 42 \quad T_{c_{in}} = 29 \]

\[ T_{h_{out}} = 38.4 \quad T_{c_{out}} = 30.6 \]

\[ T_{c_{mean}} = \frac{30.6 + 29}{2} = 29.8 \]

\[ C_{pc} = 1.005 \text{ KJ/kg K} \]

\[ Q = m \cdot C_p \cdot \Delta T \]

\[ 4.184 = m \cdot 1.005 \cdot 1.6 \]

\[ m = 2.60 \text{ kg/s} \]
\[ T_{h\,\text{min}} = \frac{42 + 38.4}{2} = 40.2 \]

\[ C_{ph} = 4.174 \text{KJ/kgK} \]

\[ Q = m \cdot C_p \cdot \Delta T \]
\[ 4.184 = m \cdot 4.174 \cdot 3.6 \]
\[ m_h = 0.278 \text{ kg/s} \]

\[ m_h \cdot C_{ph} = 0.278 \cdot 4.174 = 1.160 \text{ KW/K} \]

\[ m_c \cdot C_{pc} = 2.60 \cdot 1.005 = 2.613 \text{ KW/K} \]
\[ \varepsilon = \frac{Q_{actual}}{Q_{max}} \]

\[ = \frac{m_c c_{ph}(T_{in} - T_{out})}{C_{min}(T_{in} - T_{cin})} = \frac{1.160(42 - 38.4)}{1.160(42 - 29)} = 0.2761 = 27\% \]
• Effectiveness of old radiator

\[ Q = 3.720 \text{ KW} \]
\[ T_{\text{h in}} = 42 \quad T_{\text{c in}} = 29.8 \]
\[ T_{\text{h out}} = 39.8 \quad T_{\text{c out}} = 30.8 \]

\[ T_{\text{c mean}} = \frac{29.8 + 30.8}{2} \]
\[ = 30.3 \]

\[ C_{pc} = 1.005 \text{ KJ/kg K} \]
\[ Q = m \cdot C_p \cdot \Delta T \]
\[ 3.720 = m \cdot 1.005 \cdot 1 \]
\[ m = 3.70 \text{ kg/s} \]
\[ T_{h\ min} = \frac{42 + 39.8}{2} \]

\[ = 40.9 \]

\[ C_{ph} = 4.175 \text{KJ/kgK} \]

\[ Q = m \ C_p \ \Delta T \]
\[ 3.720 = m \ 4.175 \ 2.2 \]

\[ m_h = 0.405 \text{ kg/s} \]

\[ m_h \ c_{ph} = 0.405 \times 4.175 \]

\[ = 1.690 \text{ KW/K} \]

\[ m_c \ c_{pc} = 3.70 \times 1.005 \]

\[ = 3.7185 \text{ KW/K} \]
\[ \eta = \frac{Q_{actual}}{Q_{max}} \]

\[ = m_c c_p(T_{in} - T_{out}) = 1.160(42-39.8) = 0.180 = 18\% \]

\[ C_{min}(T_{in} - T_{cin}) \]

\[ 1.160(42-29.8) \]
SOFTWARE DESIGN
NEW RADIATOR

Scatterplot of Tw INLET(0C) vs Mass flow rate, Tw INLET(0C) vs Mass flow rate

Variable
- Tw INLET(0C) _1 * Mass flow rate(LPH)_1
- Tw INLET(0C) _2 * Mass flow rate(LPH)_2
- Tw INLET(0C) _3 * Mass flow rate(LPH)_3
- Tw INLET(0C) _4 * Mass flow rate(LPH)_4

53
50
46
42

MASS FLOW RATE

TW INLET
NEW RADIATOR

MASS FLOW RATE 250LPH

Air velocity (m/s) vs. Tw outlet (°C) graph.
NEW RADIATOR

MASS FLOW RATE 250LPH

Air velocity (m/s) vs. Tair inlet (°C) for a new radiator with a mass flow rate of 250 LPH.
NEW RADIATOR

MASS FLOW RATE 250LPH

Air velocity (m/s)
Tair outlet (°C)

MASS FLOW RATE 250LPH

Air velocity (m/s)
NEW RADIATOR

MASS FLOW RATE 250LPH

Variable
- Tw outlet
- Tair outlet

Heat transfer (KW)

Y-Data
NEW RADIATOR

MASS FLOW RATE 250LPH

Heat transfer (KW) vs. Air velocity (m/s) for NEW RADIATOR with a MASS FLOW RATE of 250LPH.
NEW RADIATOR

HEAT TRANSFER VS Tw OUTLET

Variable
- Heat transfer(KW)_1 * Tw outlet(0c)_1
- Heat transfer(KW)_2 * Tw outlet(0c)_2
- Heat transfer(KW)_3 * Tw outlet(0c)_3
- Heat transfer(KW)_4 * Tw outlet(0c)_4
NEW RADIATOR

MASS FLOW RATE VS Tw OUTLET

- Massflow rate(LPH)_1 * Tw outlet(0c)_1
- Massflow rate(LPH)_2 * Tw outlet(0c)_2
- Massflow rate(LPH)_3 * Tw outlet(0c)_3
- Massflow rate(LPH)_4 * Tw outlet(0c)_4
NEW RADIATOR

HEAT TRANSFER VS AIR VELOCITY

Air velocity (m/s)

Heat transfer (KW) 250 LPH
Heat transfer (KW) 275 LPH
Heat transfer (KW) 500 LPH
Heat transfer (KW) 1000 LPH
NEW RADIATOR AND OLD RADIATOR

HEAT TRANSFER RATE VS MASS FLOW RATE (250 LPH)

Variable
- Blue circle: Heat transfer (KW) NEW
- Red square: Heat transfer (KW) OLD

Mass flow rate (LPH) 250

Heat transfer rate (KW)
NEW RADIATOR AND OLD RADIATOR

Scatterplot of Mass flow rate(L vs Tw outlet(0c)_1, Tw outlet(0c)_5
MASS FLOW RATE VS Tw OUTLET

Variable
- Tw outlet(0c)_1
- Tw outlet(0c)_5

Mass flow rate(LPH)250

Tw OUTLET
NEW RADIATOR AND OLD RADIATOR

HEAT TRANSFER RATE VS AIR VELOCITY (250LPH)

Variable
- Heat transfer (KW) NEW
- Heat transfer (KW) OLD

HEAT TRANSFER RATE

Air velocity (m/s)

0.668
0.871
1.133
1.307
0.4070
0.6390
0.9000
1.1624
### CONCLUSION

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The heat transfer processes for the radiator are analyzed in a real life situation. The objectives of the project, to find the inlet and outlet temperatures of the fluids in the radiator, were accomplished successfully. There were numerous assumptions that were necessary to complete the theoretical calculations. Although these assumptions changed the final values for the theoretical heat transfer rate, the differences are expected. When first analyzing the radiator, there were many challenges and obstacles that hindered the advancement of the project. These challenges presented with opportunities to learn from mistakes and link concepts into an integrated whole. This project provided an in depth understanding of the theoretical knowledge learned in heat transfer and offered a chance to use this information to solve real world problems.
• Future Work

• SOFTWARE ANALYSIS
Matthew Carl et al[1] The heat transfer processes for the radiator are analyzed in a real life situation. The objectives of the project, to find and compare the inlet and outlet temperatures of the fluids in the radiator. There were numerous assumptions that were necessary to complete the theoretical calculations. Although these assumptions changed the final values for the theoretical outlet temperatures and heat transfer rate, the differences are expected. The theoretical values are good approximations of the real values found experimentally.
Brandon Fell et al[2] Our task was to design a new concept for an automotive radiator. It was required to reject an increased amount of heat (5%) from current radiator designs while lowering the fluid inlet temperature (10%). Our task is to design an automotive radiator to work in conjunction with advanced nanofluids. The new radiator design will be used in new General Motors hybrid vehicles. These hybrid vehicles have multiple cooling systems for the internal combustion engine, electric engine, and batteries.

Q. Yuet al[3] showed that one way to decrease the thermal resistance associated with the air is to change the type of fin material used. Instead of using aluminum fins, fins constructed of carbon-foam were used. The fins were constructed out carbon-foam that had a porosity of 70%, a thickness of 0.762 mm, and a height of 8.725 mm. The fin density was set to 748 fins/m.
The geometry of the fins on the radiator is sinusoidal. The troughs of the fins touch the lower adjacent tube and the peaks of the fins touch the upper adjacent tube. The heat from the tubes emanates through the fins. The fins and tubes are then cooled by the air from the fan, which is traveling across the radiator. To simplify the geometry for the ease of calculations, the fins are assumed to be straight instead of sinusoidal. This is a minor transition in geometry since the shape and position of the actual fins are so close to the straight configuration. The following formulas are given below to calculate the fin efficiency. The fin efficiency equation takes into account the geometry of the fin and its dimensions to find the efficiency the fin will have.
• Joardar et al[4] The use of vortex generators was the technique used to improve the current radiator design. These incorporated wings on the fins which produced vortices that helped to increase the turbulence of the air. By increasing air turbulence, the convective coefficient associated with the air is increased. An increase in this value causes the thermal resistance associated with the air to be reduced.

• Some parameters that affected the performance of the vortex generators were angle of attack, and the ratio of vortex generator area to heat transfer area. With the use of the vortex generators, there was an increase in the convective heat transfer coefficient. Since the air-side resistance is directly related to this value, an increase in this value will decrease the thermal resistance due to the air. Therefore, this configuration would be more beneficial than current radiator designs.
Figure: 4.3. Vortex generators increase convective heat transfer
C. Harris et al[5] possible improvement to the automobile radiator was seen through the analysis of micro heat exchangers. These heat exchangers incorporated the use of micro-channels and were fabricated from plastic, ceramic, or aluminum. One area was on a heat transfer rate to volume basis in which the micro heat exchanger was better by more than 300%. These improvements were achieved by limiting the flow to smaller channels which increased the surface area/volume ratio and reduced the convective thermal resistance associated with the solid/fluid interface.

Prof. D. K. Chavan[6] The Heat Exchangers or Radiators used in automobiles/IC Engines are either rectangular or square in shape, but the air blown/sucked by means of the fan is in circular in area, developing low velocity zones in the corners-hence it is proposed to eliminate corners and develop circular radiators. The object of work is to have a circular radiator which is compact-made with minimum material-less costly-more efficient-that will work with minimum power consumption of fan and maximum utilization of air flow.
In the testing, a comparative analysis between different coolants has also been shown. Here, one of the coolants is used as water and other as mixture of water in propylene glycol in a ratio of 40:60. Here a big difference in the cooling capacity of the radiator is seen when the flowing coolant from water is changed to mixture. This is on the account of a very high value of specific heat of water in comparison to the mixture. It therefore can be concluded that the water is still the best coolant but its limitation are that it is corrosive and contains dissolved salts that degrade the coolant flow passage. By making a mixture with ethylene glycol its specific heat is decreased but its other properties are enhanced.
S. R. Patil et al[8] Automotive radiator is key component of engine cooling system. Radiator size depends on heat load as well packaging space availability. Heat load depends on heat rejection required to keep engine surface at optimum temperature. Generally LMTD or $\varepsilon$- NTU method is used to do heat transfer calculations of radiator. Both methods have its own advantages and preferred according to data availability. When radiator inlet and outlet temperature are known LMTD gives faster solution. When any of the temperature is unknown LMTD method undergoes iterations to find solution. In this case $\varepsilon$-NTU is better.
Patankar and Prakash[9] presented a two dimensional analysis for the flow and heat transfer in an interrupted plate passage which is an idealization of the offset stripe fins heat exchanger. The main aim of study is investigating the effect of plate thickness on heat transfer and pressure drop in offset strip fins channels.
REFERENCES


Thank You