Chapter 1

Introduction, Literature Review and Need of Study
1.1 INTRODUCTION

The proposed work relates to an improved heat exchanger (Radiator) design for either heating or cooling of a fluid. Also, it deals with the work particularly which relates to an improved fan assisted air-cooled heat exchanger used in Automobiles, Internal Combustion (IC) engines, Refrigeration system, and Power plants. In the race for manufacturing, everybody is working hard not only to enhance quality, efficiency, performance of their equipments but also to improve components including heat exchangers.

Different types of heat exchangers are known, in which air is used as heat transfer medium as it is freely and abundantly available, without any disposal issues. In known heat exchangers, flow of air is induced naturally or is aided by the use of one or more fans. The use of fan reduces the size and the cost of the equipment, which makes it more compact. Hence, fan assisted air cooled heat exchangers are more popular than others. In known air-cooled heat exchangers, the fan either forces or draws the air through the heat exchanger, some of which are described herein below by way of examples.

In present system, the fans are placed behind the heat exchangers to force/ draw the atmospheric air. These exchangers use a shroud. This directs the air over the entire area of the heat exchanger. A study was undertaken to find out the distribution of airflow and variation of its temperature [6].

Generally, all conventional heat exchangers are either square or rectangular in shape and the fans with circular blades are used to create the flow of air through them. For the present heat exchangers, there are several drawbacks or disadvantages which can be classified as follows –

a) Fans with circular blades deliver air in a circular area even when the heat exchangers are square in shape.

b) The velocity of the air flow generated by the fan is not constant or uniform along its entire axial direction. It is almost zero at the centre and gradually increases at the rate of square of the radius.

c) When the thickness of the heat exchanger is constant, there has been no attempt to increase the heat transfer area at the periphery of such heat exchanger. The heat transfer area near the hub of the fan should be zero. Since this is not the case with present heat exchangers, they do not offer optimum utilization of material and air velocity.
d) A square or rectangular shrouds were provided for the fan to convert the circular flow of air into the required shape.

Further the known equipments consume more power, more material and are therefore not cost effective [19]. Therefore it has been proposed to develop a new heat exchanger, which would avoid all the disadvantages of the known equipments [5].

1.2 HEAT EXCHANGERS IN AUTOMOBILES

Various heat exchangers employed in modern automobiles are,

- Radiator
- Transmission Oil Cooler
- Engine Oil Cooler
- Evaporator
- Condenser
- Engine water Jackets
- Exhaust Gas Cooler
- Brake Drums
- Turbo intercooler

1.3 COOLING SYSTEMS

During combustion in the IC engines, temperature of hot gases in the cylinder approaches to 2700 K. Such high temperatures are not suitable for the proper working of the engine and have adverse effects such as seizing of the piston- cylinder or damage to any other engine parts. Hence the temperature has to be brought down to 180-200 °C at which the engine will work efficiently.

Overcooling is also not desirable as it decreases the thermal efficiency (\(\eta_{th}\)). Hence main aim of the cooling system is to maintain the engine running at the most efficient operating temperature.

There are two types of cooling systems namely:

1. **Air Cooled Systems:** Air Cooled Systems are employed in applications such as two wheelers and airplanes. Air cooling is achieved by provision of fins on the cylinder and the cylinder head which conduct and dissipate the required amount of heat to the surrounding air. These systems do not require a radiator and water circulating pump. Air
cooled systems prove to be effective only in cold atmospheric conditions and these systems are less efficient as compared to liquid or water cooling systems.

2. **Liquid or Water Cooled Systems:** Liquid or Water Cooled Systems are generally used in four wheelers. In this system cooling liquid (water) jackets are made around the cylinder head, cylinder for removal of heat generated in the engine. However as the cooling liquid absorbs the heat from the engine cylinder it becomes hot and is cooled with the help of a radiator; partly by the fan and the remaining due to the flow of air over the radiator caused by the forward motion of the automobile.

**Components of Liquid (or water) Cooling Systems:**

![Figure 1.1: Components of Liquid Cooling](image1.png)

**Fig. 1.1:** Components of Liquid Cooling

![Figure 1.2: Schematic Diagram Of The Liquid Cooling Systems](image2.png)

**Fig. 1.2:** Schematic Diagram Of The Liquid Cooling Systems
Fig.1.2 shows the schematic diagram of the liquid cooling systems of a 4 –cylinder engine.

It mainly consists of a Radiator, Thermostat valve, Water pump, fan etc. Working of the system is self explanatory. In the central section it consists of a central radiator core. The upper section contains upper tank and lower section contains lower tank. The upper tank is connected to water outlet from engine through hose pipes. Lower tank is connected to engine jackets inlet through hose pipes. Generally used central cores have 2 designs viz. Tubular and Cellular.

Thermostat: It prevents cooling liquid below 75°C to enter the radiator. Hence the engine attains maximum efficient operating only. It has a bellow with alcohol in it. This alcohol evaporates causing the bellow to expand which in turn operates the butterfly valve and allows the liquid to flow into the radiator.

Liquid Pump: To circulate liquid coolant into the system.

Fan: It draws air and blows it over the radiator.

1.4 RADIATOR INDUSTRIES – A SURVEY.

Radiator is an integral part of IC Engine, Refrigerator and Air Conditioning System. The cost of radiator in an IC Engine system may be about 1-3 % of the engine cost depending upon quality, size and material. However its role is critical. Failure of radiator means failure of complete system. As such radiator industry has grown up simultaneously with IC Engines, automobile, refrigeration and air conditioning systems. Various industries manufacturing radiators, to name a few are:

a) **Tata Toyo Radiators**, Pune – 412108.
Established in 1998, having about 1000 employees. Their Products & Services are: Heat Exchanger, Industrial Heat Exchanger, Oil Heat Exchanger, Plate Heat Exchanger, Tube Heat Exchanger, Aluminum Brazed Radiator, Intercooler, Heater Core, Condenser, Heat Exchangers up to Core size of 1.0 sq.m., Heat Exchangers up to 200 KW heat, dissipation, For automobiles, DG Sets & agricultural machinery etc.

b) **Poona Radiators And Oil Coolers**, Pune – 412
It is established in 1970., their Products & Services: Heavy Duty Industrial Radiators, Mobile Applications, Radiators for Railway Application, Shell and Tube Type Heat Exchangers and After coolers, Compressor Coolers etc.

Their Products & Services: Automatic hydraulic radiator, Steel radiator, Radiator components, Flange type pressed steel radiator, Flange type Radiator, Radiator engine fan
d) Salim Radiator, Pune- 411030

It is a good old company, manufacturing Radiators for various Automobiles (three and four wheelers).
e) India Radiators And Oil Coolers, Pune - 412308

Manufacturing Radiators, Heat Exchanger, Condensers for various automobiles, DG Sets etc.
f) Sabri Radiators, Belgaum, Karnataka.

Manufacturer of Automotive Radiators, Clutch Plates, pressure plates, brake linings etc.
g) Sharp Technosystems, Sangli-416416.

It is a good old company, manufacturing various educational equipments, experimental setups of all kinds, including necessary Radiators, Heat Exchangers etc.

1.5 POWER CONSUMED BY FAN

The automobile radiator sometimes needs additional airflow through it to prevent the engine from overheating. This usually occurs at idle and slow speed. At higher vehicle speeds, the air flows through the radiator by the forward motion of vehicle provide all the cooling that is needed. An engine fan or cooling fan pulls the additional air through the radiator. The fan may be either a mechanical fan or an electric fan.

Engines mounted longitudinally in rear-drive vehicles usually have a mechanical fan that mounts to the water pump shaft. The fan is made of sheet steel or molded plastic. It has four to seven blades and turns with the water pump impeller. A fan shroud around the fan directs the airflow. This increases the efficiency of the fan.

Transverse engines in front-drive vehicles usually have an electric fan. An electric motor turns the blades. A thermostatic switch turns on the fan only when needed. Generally, the switch turns on the fan when the coolant reaches 700 – 800 C. It turns off the fan if the coolant drops
below this temperature. The fan is turned ON and OFF by the electronic control module (ECM) in many vehicles with an electronic engine control system. Necessary power is supplied by the battery. Most fans, mechanical and electric, are pull – type fans. They mount behind the radiator and pull air through it [44].

On the experimental trial setup of Petrol Engine and Diesel Engine, trials are conducted in the college laboratory with fan and without fan. It is observed that power consumed by the fan is of considerable magnitude and is about 2% to 5% of total power developed by the engine [45]. Any saving in the fan power is directly the saving of precious fuel.

Also BHP of the engine will be mentioned by the manufacturer or it can be calculated. Fan HP can be calculated from the formula.

\[ P_{hp} = Q \times \Delta P \times S / 6355.827 \]  \( \ldots(1) \)

Where,
- \( P_{hp} \) = Horse Power of air
- \( S \) = Specific gravity of air. \((=1.0)\)
- \( \Delta P \) = total change in pressure

\[ P_{BP} = Q \times \Delta P / \eta \times 6355.827 \]  \( \ldots(2) \)

Where \( \eta \) = efficiency.

It is observed that,

1) For open air engine – For power consumption 2 to 4% of engine power.
2) In case of closed engine – power consumption is 4 to 6% of engine power.

Also it is observed from following examples that,

a) Cummins engine make,
   1645 BHP required 42 HP for fan i.e. 2.55% of engine power.

b) Cummins engine make,
   600 BHP required 17 HP for fan i.e. 2.83% of engine power.

1.6 COST OF RADIATORS

Smaller radiators may cost less but will consume more power; hence we have to optimize the design. Cost of radiators, heat transferred per unit area by radiator varies according to size, capacity and materials used for radiator and fins. Standard materials generally used are aluminum, copper, steel, alloys etc. as per the cost and capacity.
1.7 FACTORS AFFECTING RADIATOR PERFORMANCE

a) Air Turbulence: Increased air turbulence improves the heat convection process.

b) Air velocity: Increasing the velocity of the air over the radiator improves heat dissipation.

c) Radiator Tubes: Making smaller tubes and increasing the total amount of tubes, decreases the time taken to transfer the same amount of heat by increasing the surface area of tubes.

d) Surface Area (Fins): Increased surface area of the fins improves heat transfer process.

e) Surface Area (Total): Increase the overall surface area of the radiator for better heat transfer.

1.8 EXISTING RECTANGULAR / SQUARE AND OTHER RADIATOR

a) Rectangular Radiator

Fig. 1.3 : Rectangular Radiator
This existing design is most popularly used in the current applications. As shown in Fig. 1.3, hot water is allowed to flow through the inlet port, to upper tank where the hot water is distributed through a system of tubing. These tubes are surrounded and connected by a number of fins along the entire length of said tubes as shown. A fan is mounted on a shaft which causes a circulation or draught of air through the radiator and the fins. A shroud is adopted to regulate the flow of air from the fan so that it minimizes the quantity of air flow to escape. The atmospheric air collects the heat from the hot water as it flows over said system of tubes. The fins provided over the tubes increases the heat transfer area. The water entering through the inlet is allowed to flow the system of tubing before it gets cooled by the air and ultimately it comes out through an outlet port, after passing through the lower tank as shown.

b) Heat exchanger for air conditioner

![Heat Exchanger Diagram]

**Fig. 1.4 : Heat exchanger for air conditioner**

Fig. 1.4 shows a heat exchanger used in air conditioner, where the refrigerant enters the heat exchanger through an inlet port and it passes through a system of tubing. The flow of refrigerant takes place through the tubing. The tubing transfer heat to the air through a series of fins attached to the tubings. The refrigerant ultimately escapes out through an outlet port. As shown fig.1.4, in
this case also a fan is provided to facilitate the air flow for enhancing the cooling / heating of refrigerant.

c) Square Shaped Heat Exchanger

This also is one of the constructional types of radiator existing in current market [24]

Fig. 1.5 shows a square-shaped heat exchanger with a fan provided to deliver air in a circular area. If the length and breadth of the heat exchanger is equal to D, the effective area of such heat exchanger will be equal to \(D^2\). While the flow of air from the fan (without shroud) will be of area \((\pi/4)D^2 = 0.76 D^2\). The difference in the area of the square and the circle would be \(D^2 - (\pi/4)D^2\) = 0.24 \(D^2\).

![Image of Air-Cooled Square Shaped Heat Exchanger]

**Fig. 1.5** : Air-Cooled Square Shaped Heat Exchanger

1.9 REVIEW OF PAPERS

Review of available literature since 1995 to 2013 has been extensively carried out and from this it is accomplished that no significant research has been carried out for proposed shape radiators. Reference paper [34] provides general technical experience but limited specific knowledge of heat transfer equipments. Heat exchanger design consists of specifying a design, heat transfer area and pressure drop and checking if the assumed conditions are met with. This
paper demonstrates how to design an oil cooler (heat exchanger), especially for shell-and-tube heat exchanger which is mainly used for liquid-to-liquid heat exchange. General design procedures and considerations are illustrated and a flow diagram is provided to aid the design procedure. MATLAB and AutoCAD are used for the design calculations. Fundamental concepts of heat transfer are also presented in this paper.

Reference paper [13] gives the design of concentric tube heat exchanger in order to study the process of heat transfer between two fluids through a solid partition. Concentric tube heat exchanger is designed for counter-flow arrangement and logarithmic mean temperature difference (LMTD) method of analysis is adopted. The fluid used for experimentation is water. Temperatures of hot and cold water in the equipment are $87^\circ\text{C}$ and $27^\circ\text{C}$ respectively and the outlet temperatures of water are $73^\circ\text{C}$ for hot and $37^\circ\text{C}$ for cold water. The results of the experiment are given in the form of a table and a graph for the mean temperature.

Reference paper [20] numerical parametric studies on automotive radiator in detail. The modeling of radiator is done by two methods – finite difference method and thermal resistance concept. For evaluation of performance, the radiator is installed into a test set-up and various parameters like mass flow rate of coolant, inlet coolant temperature etc. are varied. A comparative analysis of different coolants is also given in this paper. The coolants used are water and water in propylene glycol in 40:60 ratio.

Reference paper [39] evaluates the heat exchanger performance in an automotive HVAC which is critically influenced by the uniformity of flow through the core face on the air side. In this paper, the performance is measured in terms of Core Duty and Pressure Drop. It is shown in this paper how vanes or baffles may be used to achieve flow uniformity upstream of heat exchanger in automotive HVAC. CFD is used to capture the impact of design changes on performance objectives. Reference paper [31] analyzes through the Finite Element Analysis Method (FEM) and dimensionally optimizes the frontal radiators of cooling system for electric power transformer in terms of maximum heat transfer. FEA tool used in this study is Solid-Works 3D CAD Design and COSMOS Flow Works 2008 Software. The proposed in significantly reducing the cost of manufacturing transformer.
Reference paper [32] focuses on developing a system model for a space-cooling system with a focus on the finned-tube condenser. The refrigerant used is a new environmentally friendly working fluid. To find the optimum design for a 10 condenser design using various constraints, an optimization algorithm is implemented. System efficiency is taken as the Fig. of merit. The study found a much better design than what is used in current practice.

Reference paper [37] applies Parallel Evolutionary Algorithms (PEA) and the Finite Element Method (FEM) to optimize the shape of heat radiators. Coupled thermoelasticity modeled by MARC/MENTAT software is used to compute the fitness function. Script language implemented in MENTAT is used to create geometry, mesh and boundary conditions. The shape of the structure is modeled by using Bezier curves to reduce the number of design parameters in evolutionary algorithms. The paper also includes numerical examples for some shape optimizations.

Reference paper [5] designs low power consumption, small-size smart antenna called Electronically Steerable Parasitic Array Radiator (ESPAR). Tuning the load reactances at the parasitic elements surrounding the active central element is done for beam forming. A fast beam forming algorithm based on simultaneous perturbation stochastic approximation with a minimum cross correlation coefficient criterion is proposed in this paper. Simulation and experimentation is done to validate the algorithm.

Reference paper [16] presents the heat transfer performance of a newly-designed heat exchanger which can endure several freeze/thaw cycles without undergoing any noticeable damage. This heat exchanger design can also continuously turn up or down the heat rejection according to the load. These heat exchangers are used in Portable Life Support Systems (PLSS) carried by astronauts.

Reference paper [22] assesses and selects individual and combined reliability, availability and maintenance software packages applicable to heat exchanger networks (HENs). To make a proper choice, it is necessary to consider the tools and features required. The analysis done from the software packages provide the reasons why and when to apply them and the main features that need to be considered. A case study is done to Fig. out the efficiency of complex reliability software’s in the optimization of Hens.

They have varying applications ranging from increasing of heat transfer applications to chemicals reactions and evaporation of liquid applications. This paper addresses an engineering approach for modeling the heat and mass transfer processes in micro heat exchangers. This approach takes into consideration the dimensional analysis and principles of theory of similitude that allow the modeling of microscale systems making use of a physical system at miniscale.

Reference paper [3] comments on various aerodynamic sidepod designs and their effect upon radiator heat management. Various features analyzed are inlet size, sidepod shape and size, presence of an under tray, suspension covers, gills and chimneys etc. Computational Fluid Dynamics (CFD) analyses are performed in the FLUENT environment, with the meshing done in GAMBIT meshing software and SolidWorks modeling.

Reference paper [2] explores the concepts of next generation radiators which can accommodate high performance fluids. Advanced nanofluids have better conduction and convection thermal properties and they present an opportunity to design a high energy efficient, lightweight radiator. But, the current designs of radiator have limitations due to the air side resistance requiring a large frontal area to meet the cooling needs. This study strives to design an advanced concept for a radiator for use in automobiles. The chosen design is tested by the use of a demonstration test rig.

Reference paper [17] proposes graphite foam developed at the Oak Ridge National Laboratory (ORNL) having a density of 0.2 to 0.6 g/cm³ and a bulk thermal conductivity of 40 to 187 W/m.K to be used in heat exchangers to recover some of the energy that is wasted as heat. The foam has a very accessible surface area (> 4 m²/g) these heat exchangers can be up to two orders of magnitude greater than conventional heat exchangers. As a result, the heat exchangers can be reduced considerably in size.

Reference paper [29] carries out the mechanical design of a shell and nozzle reinforcement pad of kettle type heat exchanger along with Finite Element Analysis (FEA) using ANSYS. The reinforcement pad is required due to the weakening effect of the nozzle and shell junction. This study carries out the analysis of eccentric cone that is welded with the shell on both sides with nozzle. FEA is used to study the stresses induced in the shell and nozzle and the effects of pad on the stress intensity at nozzle shell junction.

Reference paper [27] goal of this paper is to have a circular radiator which is compact made with minimum material, that is less costly and more efficient, that will work with minimum
power consumption of fan and maximum air flow utilization. The study proposes three different types of radiators and the results of one rectangular and two circular radiators are compared. The concept is validated through manufacturing and mathematical calculations.

1.10 REVIEW OF PATENTS:

Review of related available patents has been extensively carried out and from this it is accomplished that no significant research has been carried out for proposed shape radiators.

1.11 OBJECTIVES OF PRESENT WORK

1. To optimize the fan assisted heat exchanger (radiator) by improvement in design.

2. To provide a heat exchanger that will be more efficient and compact.

3. To provide a heat exchanger that will work with minimum power consumption for the fan and with maximum utilization of air flow.

4. To have a heat exchanger with minimum material and will thus be less costly.

5. Excluding the central hub area, the material saving is @ 24%, saving in the cost of production on mass scale basis once the dies are manufactured will be about 20%.

6. Considering the number of vehicles, refrigerators and air conditioners used at national and international levels, slight improvement in efficiency and reduction in cost will add to the economy to a great extent.

7. CFD analysis of radiator fins is proposed to be carried for evaluation of different velocity profile at various zones. Same will be validated using experimentation.
### 1.12 APPROACH

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<td>Literature Review of the earlier research work and Study of standard testing procedure required for testing of the Fan assisted heat exchanger/radiator</td>
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<td>B</td>
<td>Design of new geometry for the fan assisted radiator</td>
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<td>C</td>
<td>Market survey of the manufacturers Of radiators around Pune</td>
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<td>D</td>
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<td>I</td>
<td>Testing of leakage of inlet and outlet water connection pipes.</td>
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<td>J</td>
<td>Testing of the thermal performance of new radiator.</td>
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<td>Part A- for mass flow rates of 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200 lph and at constant 1500 RPM various temperature and velocity readings are taken</td>
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<td>Part B- at constant mass flow rate of 100 lph and 1600, 1700, 1800, 1900, 2000 rpm various temperature and velocity readings are taken.</td>
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<td>Part C- at constant mass flow rate of 120 lph and 1600, 1700, 1800, 1900, 2000 rpm various temperature and velocity readings are taken.</td>
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<td>Part D- at constant mass flow rate of 140 lph and 1600, 1700, 1800, 1900, 2000 rpm various temperature and velocity readings are taken.</td>
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<td>Part E- at constant mass flow rate of 160 lph and 1600, 1700, 1800, 1900, 2000 rpm various temperature and velocity readings are taken.</td>
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<td>Part F- at constant mass flow rate of 180 lph and 1600, 1700, 1800, 1900, 2000 rpm various temperature and velocity readings are taken.</td>
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<td>Q</td>
<td>Part G- at constant mass flow rate of 200 lph and 1600, 1700, 1800, 1900, 2000 rpm various temperature and velocity readings are taken.</td>
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<td>R</td>
<td>Graphs of temperature Vs radial distance and velocity Vs radial distance for the above readings are plotted.</td>
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<td>Comparison and analysis of results obtained for thermal performance</td>
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<td>Analysis of above readings &amp; results is carried out by using CFD software.</td>
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<td>It is observed that, low velocity zones (high temperature or low heat transfer regions) are observed in the corners and hence may be eliminated and proposed to have circular radiator for maximum efficiency, low cost.</td>
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<td>Report preparation</td>
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