CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The role of heat exchangers has taken on increasing importance recently as engineers have become energy conscious and want to optimise designs not only in terms of a thermal analysis and economic return on the investment but also in terms of energy payback of system. In Recuperators type of heat exchangers, the hot and cold fluids are separated by a wall and heat is transferred by a combination of convection to and fro from the wall and conduction through the wall. The wall can include extended surfaces such as fins for heat transfer enhancement.

2.1.1 External Fin

Callinan and Berggren (1959) analysed space radiators with single or double active surface design, for obtaining temperature distribution as well as for maximising the heat rejection per unit weight. Sparrow et al (1961) considered mutual interactions between fins but neglected the interaction of the fin with base. The geometry for the analysis was more than two fins arranged on a common base surface and the fin profile was rectangular. Solutions were obtained for angles of 45°, 60°, 90°, 120° between two fins and for emissivities 1, 0.75 and 0.5. Temperature distributions, overall heat loss
and local heat loss and the fin effectiveness were presented along with the conditions under which weight of the fins becomes a minimum.

Sparrow et al (1961) studied heat transfer from fin tube radiator, including longitudinal heat conduction and radiant interchange between longitudinally non isothermal finite surfaces. The fins were considered to be infinitely long and the profile was rectangular. The study concluded that longitudinal conduction did not have any appreciable effect on the thermal performance of the system.

Sparrow (1963) studied a plane –tube radiator in which there was considerable radiation interaction between the fin and base surfaces. The fins were of rectangular profile. Arbitrary radiation from external sources was also included. It was shown that the base heat loss comprises an important part of the total heat loss of the system. Karlekar and Chao (1963), presented an optimisation procedure for achieving maximum dissipation from a longitudinal fin system of trapezoidal fins with mutual irradiation but no base interaction. The temperatures were obtained using the Newton-Raphson method. A new non-dimensional parameter based on the total heat dissipation from the fin system per unit axial length was proposed to characterise the total dissipating capacity of the fin system with mutual irradiation. Optimum fin number and their proportions were determined and charts of dissipation were presented.

Shnurr (1975) studied radiation from an array of longitudinal fins of the triangular profile arranged around a cylinder of isothermal base. The fins were considered to be infinitely long and base interaction was also considered. The effects of external incident radiation were ignored. The results were useful in optimising the design for minimum weight.
Bejan (1979) studied the performance characteristics of annular finned radiators and duct type radiators. A novel feature of this study was consideration of variation of temperature along the length of the radiators.

A thermodynamic optimization study of Nag and Mukherjee (1987) showed that the initial temperature difference between the fluid and wall considered as an important criterion for the design of thermal system.

Chung and Zhang (1991) presented a new approach to minimize the weight of radiating straight fin array. The effect of base interaction was considered and the fins were infinitely long. In this study the fins were arranged symmetrically around the circular tube. The temperature of the tubes surface was considered to be uniform both longitudinally and circumferentially.

Sridhar et al (1994) considered the effect of two dimensionality in radiating-conducting wedges. The base was considered to be isothermal and the fin profile was triangular. They analyzed a space radiator with six rectangular fins interacting with each other and with the environment. The study concluded that two dimensional effects were important only for low aspect ratio fins.

Binesh and Balaji (2001) numerically analyzed a horizontal circular duct with external longitudinal fins, trapezoidal in cross-section with turbulent flow for heat transfer by convection, radiation and entropy generation. The resulting two dimensional fin equations were solved using second order finite difference scheme. The analysis takes into account the variation of base temperature along the duct.

Sasikumar (2001) introduced a holistic approach to optimize fin systems over a rectangle duct considering the effect of thermal convection
and radiation. A convecting radiating fin array, which stands vertically on a horizontal duct, was analyzed for entropy generation and total heat loss per unit mass. The flow was considered to be fully turbulent inside the duct and variation of fluid temperature along the duct was accounted for.

Mohamed Najib Bouaziz et al (2001) aimed to quantify the effects of non-simplified situations on longitudinal fins efficiency. For this purpose a more realistic model, which had been developed based on variable profile and temperature-dependent thermo physical properties in transient two-dimensional fin with internal non-uniform heat generation. An explicit exponential finite-difference method, conditionally stable, was extended in the study for the discretization of the governing equations. The numerical procedure consists in solving series of nodal temperature distribution according to the type of node, in order to reach the steady-state heat exchange. Then, the numerical simulation was used to present the sensitivity of some parameters on efficiency. Numerical results of interest were illustrated for a direct comparison with the traditional solutions. Extensive numerical experiments were conducted and showed that temperature-dependent heat transfer coefficient and generation lead to a significant reduction of fin-efficiency. The simultaneous effects of parameters for this non-linear problem were not negligible.

Sasikumar and Balaji (2002) numerically studied a natural convection heat transfer and entropy generation from an array of vertical fins, standing on a horizontal duct, with turbulent fluid flow inside. The analysis was taken into account the variation of base temperature along the duct. One dimensional fin equation was solved using second order finite difference scheme.

Thermal analysis and optimization of straight taper fins had been addressed by Kundu and Das (2002). With the help of the Frobenius
expanding series the temperature profiles of longitudinal fin, spine and annular fin had been determined analytically through a unified approach. Simplifying assumptions like length of arc idealization and insulated fin tip condition had been relaxed and a linear variation of the convective heat transfer coefficient along the fin surface had been taken into account. The thermal performance of all the three types of fin had been studied over a wide range of thermo-geometric parameters. It had been observed that the variable heat transfer coefficient had a strong influence over the fin efficiency. Finally, a generalized methodology had been pointed out for the optimum design of straight taper fins. A graphical representation of optimal fin parameters as a function of heat duty had also been provided.

Conjugate numerical solution of laminar free convection about a horizontal cylinder with external longitudinal fins of finite thickness had been carried out by Haldar (2007) et al. Fins alone contributed very small to the total heat transfer but they greatly influenced the heat transfer from the uncovered area of the cylinder. Among the various fin parameters, thickness had the greatest influence on heat transfer. For thin fins, there exists a fin length, which maximized the rate of heat transfer. The optimum number and dimensionless length of the fins were obtained as 6 and 0.2 respectively when fin thickness was 0.01.

Dibakar Rakshit and Balaji (2007) had investigated the conjugate convection from a finned channel with vertical rectangular fins being mounted on outside of the channel. The two dimensional governing equation, steady, incompressible, constant property laminar flow was solved for the fluid outside channel. For fluid flowing inside the channel, the flow was assumed to be turbulent with forced convection as the mode of heat transfer.
2.1.2 Internal Fin

Schmidt (1926) suggested the adoption of a parabolic shape as an optimal profile for longitudinal fins. Such a proposition was supported by Duffin (1959) on the basis of a rigorous variational model.

Sparrow et al (1962), analysed the heat transfer characteristics of the annular finned space radiators by a numerical method using finite differences. The shape factors were obtained using a contour integration. Fin and tube heat losses were separately calculated.

Olson (1992) measured heat transfer and pressure drop of three thin, compact heat exchangers in helium gas at 3.5 MPa and with Reynolds numbers of 450 to 36,000. The flow geometries for the three heat exchanger specimens were: circular tube, rectangular channel, and staggered pin fin with tapered pins. The specimens were heated radioactively at heat fluxes up to 77 W/cm². Correlations were developed for the isothermal friction factor as a function of Reynolds number and for the Nusselt number as a function of Reynolds number and the ratio of wall temperature to fluid temperature. The specimen with the pin fin internal geometry had significantly better heat transfer than the other specimens, but it also had higher pressure drop. For certain conditions of helium flow and heating, the temperature more than doubled from the inlet to the outlet of the specimens, producing large changes in gas velocity, density, viscosity, and thermal conductivity. These changes in properties did not affect the correlations for friction factor and Nusselt number in turbulent flow.

Bejan and Morega (1993) reported the optimal geometry of an array of fins that minimizes the thermal resistance between the substrate and the flow forced through the fins. The flow regime was laminar. Two fin types were considered: round pin fins, and staggered parallel-plate fins. The
optimization of each array proceeded in two steps: The optimal fin thickness was selected in the first step, and the optimal thickness of the fluid channel was selected in the second. The pin-fin array was modelled as a Darcy-flow porous medium. The flow past each plate fin was in the boundary layer regime. The optimal design of each array was described in terms of dimensionless groups. It was shown that the minimum thermal resistance of plate-fin arrays was approximately half of the minimum thermal resistance of heat sinks with continuous fins and fully developed laminar flow in the channels.

Heat transfer enhancement in the latent heat thermal energy storage system by using an internally finned tube was presented by Yuwen Zhang and Faghri (1996). The phase change material filled in the annular shell space around the tube, while the transfer fluid flows within the internally finned tube. The melting of the phase change material was described by a temperature transforming model coupled to the heat transfer from the transfer fluid. The heat conduction in the internal fins was an unsteady two-dimensional heat conduction problem and was solved by a finite difference method. The results showed that adding internal fins was an efficient way to enhance the heat transfer in thermal energy storage systems.

The effects of different geometrical parameters, including tube row numbers (14 rows), wavy angles ($\theta = 8.95^\circ$, $17.05^\circ$, $32.21^\circ$) and wavy heights ($S = 0.751$, 1.500 and 3.003 mm) were investigated by Jiin-Yuh Jang and Li-Kwen Chen (1997). For the Reynolds number $Re_H$ (based on the fin spacing and the frontal velocity) ranging from 400 to 1200, Numerical results indicated that the row effect was less important in a wavy-fin as compared to plain-fin counterpart. It was also found that, for equal wavy height, both the average Nusselt number and pressure coefficient were increased as the wavy angle was increased; while for equal wavy angle, they were decreased as the
wavy height was increased. The combination of \((\theta = 8.95'', S = 1.500 \text{ mm})\) gave the highest flow area.

Giampietro Fabbriri (1998), presented the problem of optimizing the geometry of internally finned tubes in order to enhance the heat transfer under laminar flow conditions. The velocity and temperature distributions on the finned tube cross-section were determined with the help of a finite element model, and a global heat transfer coefficient was calculated. A polynomial lateral profile was proposed for the fins and the geometry was optimized in order to make the heat transferred per unit of tube length or surface as high as possible for a given weight and for a given hydraulic resistance. Finally, the optimum fin profiles were obtained by means of a genetic algorithm.

Performance of annular fins of different profiles subjected to locally variable heat transfer coefficient was investigated by Esmail and Mokheimer (2002). The performance of the fin expressed in terms of fin efficiency as a function of the ambient and fin geometry parameters. These curves were essential in any heat transfer textbook, had been obtained based on constant convection heat transfer coefficient. However, for cases in which the heat transfer from the fin was dominated by natural convection, the analysis of fin performance based on locally variable heat transfer coefficient would be of primer importance. The local heat transfer coefficient as a function of the local temperature had been obtained using the available correlations of natural convection for plates. Results had been obtained and presented in a series of fin-efficiency curves for annular fins of rectangular, constant heat flow area, triangular, concave parabolic and convex parabolic profiles for a wide range of radius ratios and the dimensionless parameter based on the locally variable heat transfer coefficient. The deviation between the fin efficiency calculated based on constant heat transfer coefficient and
calculated based on variable heat transfer coefficient, had been estimated and presented for all fin profiles with different radius ratios.

Haw-Long Lee et al (2004) solved two dimensional inverse problem of estimating the unknown heat flux at a pin fin base by the conjugate gradient method. In estimating processes, no prior information on the functional form of the unknown quantity was required. The accuracy of the inverse analysis was examined by simulated exact and inexact measurements of temperature at interior locations of the pin fin. The numerical results showed that good estimations on the heat flux obtained for all the test cases. Furthermore such a technique was applied to determine the heat flux acting on an internal surface, where a direct measurement was not feasible.

Inmaculada Arauzo et al (2005) addressed an elementary analytic procedure for the approximate solution of the quasi-one-dimensional heat conduction equation (a generalized Bessel equation) that governs the temperature variation in annular fins of hyperbolic profile. This fin shape was of remarkable importance because its heat transfer performance is close to that of the annular fin of convex parabolic profile, the so-called optimal annular fin that is capable of delivering maximum heat transfer for a given volume of material. The salient feature of the analytic procedure developed here was that for realistic combinations of the two parameters: the enlarged Biot number and the normalized radii ratio, the truncated power series solutions embracing a moderate number of terms yields unprecedented results of excellent quality. The analytic results were conveniently presented in terms of the two primary quantities of interest in thermal design applications, namely the heat transfer rates and the tip temperature.

An experimental study was conducted by Ugur Akyol et al (2006) to investigate the heat transfer and friction loss characteristics in a horizontal
rectangular channel having attachments of hollow rectangular profile fins over one of its heated surface. The Reynolds number based on the flow averaged inlet velocity and the hydraulic diameter, ranged from 3000 to 32,000. The hollow rectangular profile fins in 10 cm height and a × b = 2 cm × 4 cm dimensions with a thickness of 0.2 cm were mounted on a heating surface vertically. Reynolds number, fin arrangement and fin pitch in the flow direction were the experimental parameters. Both in-line and staggered fin arrangements were studied for one-fixed span wise (Sx/a = 3) and four different stream wise (Sy/b = 1.5, 1.875, 2.5 and 3.75) distances. Correlation equations for Nusselt number and thermal performances were determined for fin configurations and the straight channel case without fins.

2.1.3 Genetic Algorithm

Genetic algorithm was proposed by Giampietro Fabbri (1997) in order to optimize the thermal performance of finned surfaces. The bi-dimensional temperature distribution on the longitudinal section of the fin was calculated by resorting to the finite elements method. The heat flux dissipated by a generic profile fin was compared with the heat flux removed by the rectangular profile fin with the same length and volume. The genetic algorithm was then applied to the case of polynomial profile fins, in order to determine the polynomial parameter values which optimize the fin effectiveness. The optimum profile was finally shown for different polynomial orders.

Genetic algorithms are adaptive search procedures loosely based on the Darwinian notion of evolution. They use rules of natural selection to investigate highly complex, multidimensional problems and have been employed successfully in a variety of search, optimization and machine learning applications in science and engineering where other more traditional methods fail. Genetic algorithms were presented and discussed by Queipo
et al (1994). The exposition focuses on their application to an electronics cooling problem where it was required to find optimal or nearly optimal arrangements of convectively cooled components placed in-line on the bottom wall of a ventilated two-dimensional channel. The power of the methodology rests on its generality of application and an indifference to the source of data (experimental, analytical or numerical) used in the optimization process. The study had shown that genetic algorithms allow a cost-effective approach for investigating highly complex numerical and/or experimental thermo sciences problems where it is desirable to obtain a family of acceptable problem solutions as opposed to a single optimum solution.

Dibakar Rakshit and Balaji (2005) reported the results of numerical investigation of conjugate convection from a finned channel. The computational domain of investigation was a horizontal channel with vertical rectangular fins being mounted on outside of the channel. The equations governing two-dimensional, steady, incompressible, constant property laminar flow had been solved for the fluid flowing outside the channel. Boussinesq assumption was made to be valid for the fluid flowing outside the channel along the fins. For the fluid flowing inside the channel, flow was assumed to be turbulent with forced convection as the mode of heat transfer. From a large volume of numerically generated data correlations had been proposed for (1) Nusselt number and (2) Entropy generated by the system. These correlations were finally used to obtain thermodynamic optimum, by using the state-of-the art Genetic algorithms.

Kenan Yakut et al (2006) studied the effects of the heights and widths of the hexagonal fins, stream wise and span wise distances between fins, and flow velocity on the heat and pressure-drop characteristics were investigated using the Taguchi experimental-design method. Nusselt number and friction factor were considered as performance statistics. An orthogonal
array was selected as the experimental plan for the five parameters mentioned above. While the optimum parameters were determined, the trade-off among goals was considered. First of all, each goal was optimized, separately. Then, all the goals were optimized together, considering the priority of the goals, and the optimum results were found to be a fin width of 14 mm, a fin height of 150 mm, span wise distance between fins of 20 mm, and stream wise distance between fins of 20 mm for a flow velocity of 4 m/s.

2.2 RESEARCH GAP

The literature study reveals that heat transfer performance was studied for the external fin with three different fin geometries and not with the internal fin. The conductivity and viscosity alone were taken as the temperature dependent without considering the specific heat capacity of coolant.

i. Heat transfer analysis for the internal fin with various half included angles was not done.

ii. All the thermo physical properties such as thermal conductivity, density, viscosity, specific heat capacity were not considered as temperature dependent.

iii. Reynolds number and pressure gradient were treated as independent parameters.

iv. The effect of variation of pressure gradient due to change of viscosity of coolant was not considered along the length of the pipe.

v. Genetic programming application for predicting the performance was not found in heat transfer study.
2.3 OBJECTIVES OF PRESENT STUDY

The objectives of present studies are

i. To use fin geometry with three different half included angle for studying heat transfer performance.

ii. To obtain more rigorous solution by considering all the thermo physical properties as temperature dependent.

iii. To compute the enhancement of heat transfer due to internal fin under laminar flow condition.

iv. To find optimal fin geometry for better heat transfer.

v. To predict heat transfer performance using genetic programming.

2.4 SCOPE AND METHODOLOGY

In order to enhance the heat transfer, finned surfaces are commonly used in many engineering sectors. To remove high heat fluxes from very small components, the need to reduce the weight or volume of thermal dissipater system has become even more important, particularly in new applications such as in the compact heat exchanger. Many researchers have studied the problem of optimizing the shape of the finned surface in order to increase the heat transfer effectiveness and reduce the weight of dissipater. In this study the effect of fin geometry in the internal flow through the pipe is studied for increasing the heat transfer performance such as Nusselt Number, bulk temperature and effectiveness. The above objectives are met by the following work.
1. The fin with three different geometries was created by keeping the cross sectional area of the fin as constant.

2. Governing momentum and energy equation for thermal entry region for the fluid and energy equation for the tube with fins are obtained.

3. The above equations are solved using finite difference method by keeping the properties of the fluid and tube as temperature dependent.

4. Bulk temperature and bulk velocity are obtained by Trapezoidal rule.

5. The results obtained from numerical method are validated by conducting experiment.

6. Graphs have been plotted for bulk temperature of the fluid, Nusselt Number (Nu), and effectiveness of the tube against axial distance of the tube.

7. Best geometry was selected by comparing the effectiveness of the fin.

8. Parametric study was conducted for the best fin geometry by varying the Reynolds number, heat flux, conductivity of pipe materials and thickness of the pipe.

9. For the unfinned tube large data are generated by varying the Reynolds number, pipe diameter, pipe material and coolant such as air, water, engine oil.

10. Java code was obtained by using the above data in Discipulus software which works based on genetic algorithm.
11. The formula to evaluate the Nusselt number and Bulk temperature are obtained by decoding the Java code which is got from Discipulus software.

12. The values obtained from numerical method and the formulas are compared and regression coefficient was obtained.

2.5 PROBLEM FORMATION

The internal diameter of the tube and thickness are assumed as 20 mm and 1 mm respectively to select the best fin geometry. The inlet temperature of the fluid is taken as 298 K. The flow is assumed to be fully developed locally, but thermally undeveloped. Water and engine oil are assumed as coolants. The tube/fin material is selected as aluminium and copper. The thermo physical properties such as thermal conductivity, viscosity, density, specific heat capacity of the fluid and the thermal conductivity of tube wall are considered as functions of temperature. The viscous dissipation and natural convection in the fluid have been neglected.

The cross sectional front view as well as the side view of the unfinned tube is shown in the Figure 2.1.

![Figure 2.1 Cross sectional front and side view of circular unfinned tube](image)
The front view as well as the sectional side view of the finned tube is shown in the Figure 2.2. The details of geometry of one of the four identical fins are shown in Figure 2.3.

Figure 2.2 Front and side view of finned tube

Figure 2.3 Geometrical details of one of the four identical fin
2.5.1 Fin Geometry

The main geometrical dimensions of any one fin are

- Fin half included angle ($\alpha$)
- Radial distance from centre to tip of the fin ($r$)
- Lateral length of the fin ($l_1$)

The relation between ‘$r$’ and ‘$\alpha$’ is given by the equation (2.1).

$$\alpha = \left[ \frac{0.00135}{0.01^2 - r^2} \right]$$  \hspace{1cm} (2.1)

Using the above relation between $r$ and $\alpha$, three fin models with different half included angles namely $\alpha=14^\circ$, $\alpha=16^\circ$ and $\alpha=18^\circ$ are obtained.

Each fin model has different fin dimensions and they are given as follows.

**Fin model $\alpha=14^\circ$ has the following dimensions.**

- Half included angle = $14^\circ$
- Radial distance from centre to tip of the fin = 1.9 mm
- Lateral length of the fin = 8.0 mm

**Fin model $\alpha=16^\circ$ has the following dimensions.**

- Half included angle = $16^\circ$
- Radial distance from centre to tip of the fin = 3.9 mm
- Lateral length of the fin = 6.0 mm
Fin model $\alpha=18^\circ$ has the following dimensions.

- Half included angle $= 18^\circ$
- Radial distance from centre to tip of the fin $= 5.0 \text{ mm}$
- Lateral length of the fin $= 5.0 \text{ mm}$

Problem Parameters

- Fin / Tube materials: Aluminium and Copper
- Coolants: Water and Engine oil
- Internal diameter of the tube $= 20 \text{ mm}$
- Thickness of the tube $= 1 \text{ mm}$
- Length of the tube $= 1000 \text{ mm}$

2.6 ASSUMPTIONS

The following assumptions are made to confine the problem and make it possible for the particular application.

- Fin and tube material is homogeneous and isotropic.
- Flow is hydro dynamically fully developed.
- All the fins are identical.
- Flow is steady, laminar and thermally undeveloped
- Reynolds numbers are taken as 500, 1000, 1500 and 2000.
- Radiation heat transfer is negligible.
• Thermo physical properties of tube material and the coolants are assumed as function of temperature.

• Viscous dissipation and natural convection are negligible.

• Outer surface of the tube is subjected to constant heat flux throughout the length of the tube.

2.7 SUMMARY

The detailed literature has been studied for the heat exchangers with internal fin and external fin arrangement. It is identified that the fin with different fin geometry has not been investigated so far. Also, all the thermo physical properties have not been considered as temperature dependent. This has been fixed as objectives and problem parameters like diameter of the pipe with three different fin geometry, coolant used to remove heat, heat flux to be applied have been decided and suitable assumption are made.