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A Review on Convection Heat Transfer in Extended Surfaces-Fin

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Abstract:

The convection heat transfer plays an essential role to many heat transfer situations by different ways. Convection comprises both the fluid flow as well as heat flow. Computational fluid dynamics is very useful to determine the behaviour of heat flow and fluid flow. Fins are employed in situation where it is desirable to increase the heat transfer. Fins may be stationary or moving as in case of electric motor and bike engines. The heat transfer depends on heat transfer coefficient of medium, thus the correlation for Nusselt number and Reynolds number with respect to location of the body has been studied. Fin heat transfer is either steady state or transient according to situations and involves natural convection and forced convection to enhance heat transfer. The aim of this paper, to review the work carried out in the field of fin heat transfer. Literature reviews of research work pertaining to heat transfer analysis in fins of various profiles are described.

Keywords — **Convection, Exponential, Biot number, Fin, Heat Transfer**

I. INTRODUCTION

The rate of thermal energy that transferred across a boundary of a system is known to us as heat. The three mechanisms are to study to understand the physics of heat with the help of basic calculus, thus to design the various devices/machines that are employed to optimise heat transfer like vehicles radiators, power generation units, electronic devices etc. The tasty meal is the result of required thermal energy to the raw material and time required for cook the meal. The heat transfer between a solid surface and adjacent layer of fluid is known as convection heat transfer, which is the combined effect of conduction and fluid motion. The fluid with some velocity over the solid surface enhance the rate of heat transfer, termed as forced convection and if the fluid is at rest is known as natural convection due to density difference. In real problems, all the modes of heat transfer are encountered simultaneously. Many engineering applications are non linear and complicated and the material property and heat transfer coefficients are functions of temperature [1].phase change materials are used to enhanced the heat transfer rate[2]. Various types of fins are used in problems of heat transfer like longitudinal, circular, annular, plate fins, pin fins [3], pin fin heat sinks[4,5] and fins of tree shape[6]. A lot of research has conducted by numerous researchers and the role of different fins effectively.

This review paper focuses on convection heat transfer, heat transfer coefficient and various configurations of fins. The shape profile of fins, the temperature distribution along the fin and efficiency of extended surface is studied.

II. NEWTON'S LAW OF COOLING

The foundation of convection heat transfer is based on Newton's law of cooling. It states that the rate of cooling of a warm body at any moment is proportional to the temperature difference between the body and its surroundings and expressed as [7],

$$\frac{dT}{T} = const$$

$$\frac{dT}{dt} \propto (T - T_a)$$

Where T is temperature at any time t and T_a is ambient temperature, $T_o at, t = 0$, λ is any constant. The solution of given equation [8],

$$T(t) = T_o e^{-\lambda t}$$

$$T(t) = T_a + (T_o - T_a) e^{-\lambda t}$$

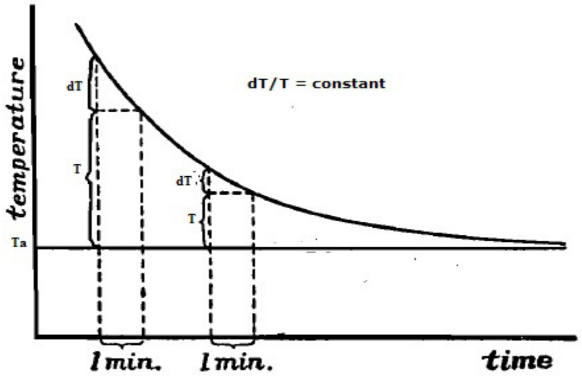


Fig.1: Newtons Cooling Curve [9]

Fourier formulation for the propagation of heat in solids with the associated convective boundary condition as [10],

$$\frac{\partial T}{\partial t} = \alpha \nabla^2 T$$

$$-k\left(\frac{\partial T}{\partial x}\right) = h(T - T_a)$$

The concept of coefficient of heat transfer *h* from solid surface of thermal conductivity to free air in case of fin as [11],

$$A\frac{\partial \theta}{\partial t} = \frac{kA}{\rho c}\frac{\partial^2 \theta}{\partial x^2} - \frac{hP}{\rho c}\theta$$

For steady state, equation converts to,

$$\frac{d^2\theta}{dx^2} = \frac{hP}{kA}\theta \quad \text{and} \quad \theta = \theta_o e^{-mx}\text{, where } m = \sqrt{\frac{hP}{kA}}$$

Where θ is dimensionless temperature, A is cross-sectional area and P is perimeter for fin thermal conductivity k

III. ASSUMPTIONS

The extended surfaces or fins are such ideal effective tools like air conditioning, aircooled craft engines, and computer equipments, see for instance, the leading books by Kraus et al. [12] and Kalpakjian [13]. Recent research in the active field exhibits that moving fins of different profile sections [14] are significant as well as when they are exposed to a heat source [15]. The assumptions are made for analysis the fin heat transfer as,

- Heat conduction in the fin is steady and one-dimensional.
- The fin material is homogeneous and isotropic.
- The fin material has constant properties, and fin surface is diffused.
- The heat transfer coefficient over fin surface is uniform.
- The heat transfer at fin tip is negligibly small.
- The temperature of the fluid inside the pipe is constant; the ambient temperature and environment temperature around the fin are also uniform.
- The radiative interaction between the base wall and fin is neglected.
- The curvature effect of the fin is negligible.
- There is no heat generation inside the fin.

IV. ANALYSIS OF EXPONENTIAL FIN

From literature recent study by Kundu and Lee [16], an analytical analysis was presented to determine a minimum envelop shape of porous fins for a constraint heat transfer rate over the fin surface. It was fascinatingly concluded that the optimum fin shape is inclined to have trapezoidal or exponential geometry instead of a triangular or rectangular one. The helical fin on hydrothermal analysis in a water to air heat exchanger was recently examined both numerically and experimentally by Sheikholeslami and Ganji [17]. Simple configurations of fins are rectangular and exponential profiles along one-dimension with length as shown in Fig. 2:

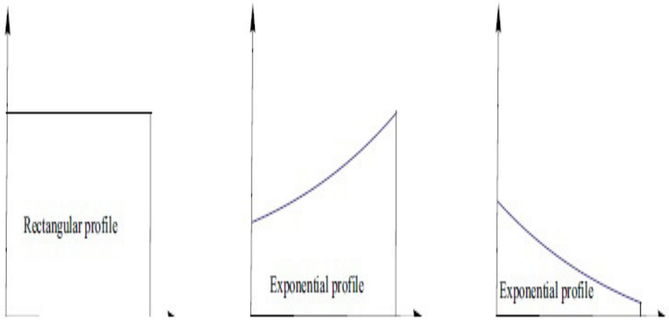


Fig. 2: Fin Profiles

The local shape of exponential fin is given by,

$$f(x) = e^{2\alpha^* x}$$

Where α^* is the dimensional fin shape parameter [18,19]

If α^*=0, the fin is rectangular type. The fin shape parameter for the fin length L is given by,

$\alpha = \alpha^* L$, and the dimensionless length, $X = x / L$

The governing equation for dimensionless temperature distribution over exponential fin without any heat generation in fin is expressed as [20,21]

$$\frac{d}{dX}\left(e^{2\alpha X}\frac{d\theta}{dX}\right) - Bi^2(\theta - \theta_a) + Pe \times e^{2\alpha X}\frac{d\theta}{dX} = 0$$

As $\theta'(0) = 0, \theta(1) = 1$, where θ is dimensionless temperature and $\theta = T / T_b, and \theta_a = T_a / T_b$ and T_a is ambient temperature and T_b is fin base temperature. Bi and Pe are Biot number and Peclet number respectively.

Fin efficiency, which is the ratio of total heat transfer to the maximum possible heat transfer from fin, is given by,

$$\eta = \frac{e^{2\alpha}\theta'(1)}{Bi^2(1 - \theta_a)}$$

Analysis of various fin shapes, it was concluded that Straight rectangular fins have lower temperature values than the growing type but higher values than the decaying type exponential fins, Biot number reduces the temperature variation over the fin surfaces and The growing shaped fin profiles thermally perform better and thus they are potential alternatives to commonly used rectangular fins in industrial instruments. [22]

The variation of fin temperature along its length by analytically determined according to the relationship,

$$T - T_a = T_0 - T_a \frac{\cosh m(L - x) + (h / km)\sinh m(L - x)}{\cosh mL + (h / km)\sinh mL}$$

Motor are using now a day's everywhere from small appliance to high industrial purpose. Electrical energy converts to mechanical energy and losses. Fins are provided on electric motor fins to serve its purpose. The variation of temperature is shown in Fig. 2 for a typical motor fins, motor runs at ideal conditions [23].

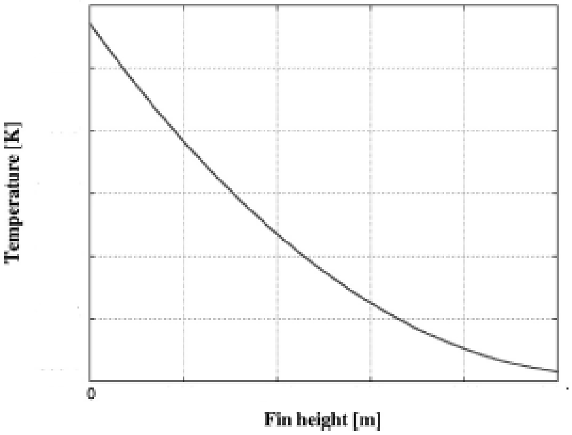


Fig. 3: Typical Temperature variation along fin

V. ANNULAR (CIRCULAR) FIN

Annular fins are used extensively in heat exchanging devices. The heat transfer depends on the different shapes and geometry. Numerous studies have been presented on the performance of circular fins of constant cross-section having uniform base end and side conductance [24] and for coated annular fins [25]. Variable profile like exponential are investigated for optimum heat transfer [26]. A simple annular fin is shown in Fig. 4 of constant cross-section area.

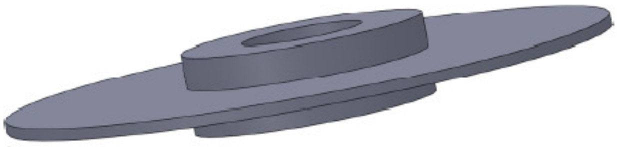


Fig. 4: Typical Circular Fin

Considering an annular fin as shown in Fig. 4, the fin is of uniform thickness, it may be of exponential form. A general fin profile function is expressed by [27] ,

$f(r) = \frac{\delta}{2}\left(\frac{r_2}{r}\right)^n$, n =1 for straight fin

The energy transfer from the fluid in pipe to the interface of pipe and fin is given by,

$$-k_f \frac{dT}{dr} = \frac{T_c - T}{\frac{r_2}{r_1 h_c} + \frac{r_2}{k_w}\ln\frac{r_2}{r_1} + R_{tc}}$$

Where k is thermal conductivity, suffix f for fin and w for pipe wall, T_c temperature of fluid inside pipe, and h_c corresponding heat coefficient, R_{tc} is thermal contact resistance between pipe and fin.

Heat transfer in pipe for cylindrical coordinate system,

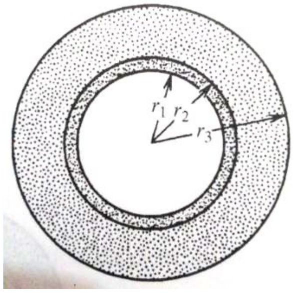
$$\frac{d}{dr}\left[rk_w\frac{dT_w}{dr}\right]=0\, for-->r_1\le r\le r_2$$

And for circular fin,

$$\frac{d}{dr}\left[k_f A\frac{dT_f}{dr}\right]=h_o S(T_f-T_a)$$

$$for-->r_2\le r\le r_3$$

The radius for pipe, thickness of pipe and radius of fin is shown in Fig. 5(a) and side view with coordinate system in (b).



(a) Top View

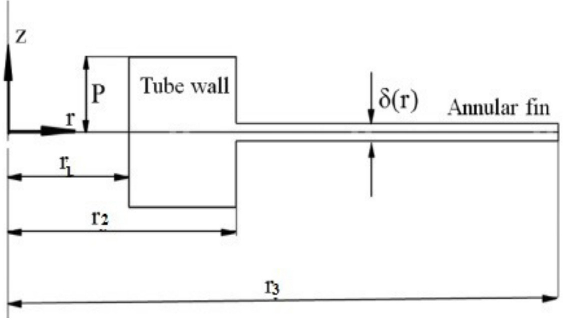


Fig. 5: (b) Side View [28]

And at $r = r_3$

$$\left[-k_f\frac{dT_f}{dr}\right]=h_o(T_f-T_a)$$

Where h_o and T_a are heat transfer coefficient and temperature for ambient air.

The dimensionless form equation is,

$$\left[-k_w P\frac{d\theta_w}{dr}\right]=(P-\delta/2)Bi\theta_w-\frac{1}{2}k_f\delta\frac{d\theta_f}{dr}$$

$$for-->r=r_2$$

And, for $r = r_3$

$$\left[-k_f\frac{d\theta_f}{dr}\right]=Bi\theta_f$$

Where, P is pitch, Bi is Biot number.

Circular fin design problems are explained by numerous methods and to optimize fin shape is studied in this paper. It was found that exponential fin profile was more efficient than rectangular and hyperbolic profile [1].

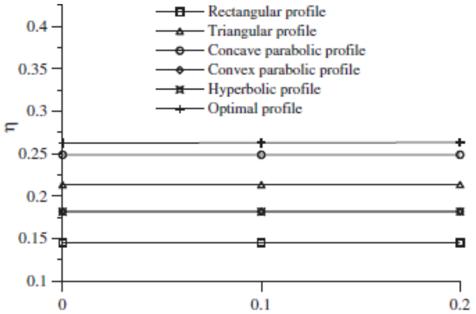
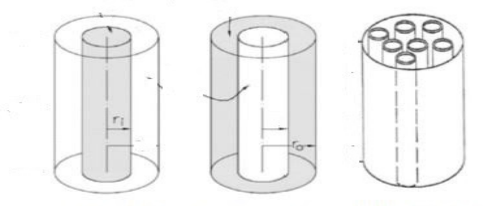


Fig. 6: Efficiency vs Fin slope

VI. FIN MATERIAL AND CYLINDRICAL FINS

Different methods and techniques are taken into consideration to improve the thermal performance of a system. The material selection for fin includes: thermodynamic property, mechanical property, chemical reliability and economic factors to design a fin. Thermal conductivity of fin material must be selected properly to keep Biot number in a specific range to reduce thermal resistance of fin. Some commertial devices such as heat exchangers and cooling topwers have cylindrical geometries like shell and tube and concentric tubes as shown in Fig. 7.



a) Pipe model b) Cylinder model c) Shell and tube model

Fig. 7: Cylindrical Configurations

Fin length is very significant geometrical parameter, fin efficiency decreases with increases in length of fin due to the decrease in fin temperature. The ratio of actual heat transfer rate to an ideal heat transfer rate for the same fin is termed as fin efficiency.

VII. CONCLUSIONS

In recent years, a lot of systems are designed from an electronic device to big machinery. The heat is generated during its operation; hence it is very important to optimize the design of such systems to overcome heat loss or to enhance the heat loss for smooth functioning of the system. This review targets to provide significant information on convection heat transfer. Newton's law of cooling is presented to heat loss from a hot body to its surrounding as exponential decay of body temperature, which further enables to understand the analysis for extended surface heat transfer. Heat transfer coefficient is very important parameter for heat loss. Dimensionless numbers imparts help to simplify the problem. Numerous types of fins like rectangular, exponential, concave type, convex type, circular and fins for ducts are studied. The geometrical parameter must be selected properly and the dimension should be keep to reduce the mass of the system with optimum heat transfer. For future, it is a vast area to research and to find the ways to enhance heat transfer with less material requirement and different more types of configuration.

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