ANALYSIS OF PERIODIC HEAT TRANSFER THROUGH EXTENDED SURFACES

by

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This article is concerned with the review of periodic heat transfer through extended surfaces known as fins. In this review, we bring out the detailed study of heat transfer of different type variation through extended surfaces. Heat transfer has remained a warm responder to various conditions for the researchers in last many decades. In the current analysis, an attempt is appointed to study, analyze and summarize the result of the periodic heat transfer and flow in various fins. Further, we are carried out the analysis for the periodic heat transfers through various kinds of extended surfaces also called fins in the presence of periodic base and ambient temperature. The performance of the extended surface is expressed in terms of the fin effectiveness and its efficiency. The heat transfer process is regulated by three experimentally determined dimensionless parameters such as the frequency parameter, w, the convection fins parameter, N, and the amplitude parameter, A. Further the fins performance and efficiency are demonstrated through several examples. On basis of comparison rectangular fins are good for heat transfer due to their extended surfaces.

Key words: *periodic heat transfer, extended surfaces, surface temperature, conduction and convection*

Introduction

For the last few decades, the uses of fins (also known as extended surfaces) have been proved to be the inexpensive and powerful sources of enhancing the heat transfer rate between hot solid surfaces and their surroundings fluids. The said surfaces have been utilized increasingly in various electronic accessories like compressors, internal combustion engines, control systems and heat exchangers. Many types of heat exchangers are used in industrial processes. Different surveys have been focused on various kinds of extended surfaces for the periodic heat transfer and flow. It is remarkable that for the first-time the rate of heat transfer was defined by Newton in [1] which is called Newton's law of cooling. The aforesaid law states that *The time rate of heat transfer from a surface is directly proportional to the difference between the surface temperature,* T_b, *and the surrounding fluid temperature,* T_∞. The aforesaid law is mathematically represented:

$$\frac{\mathrm{d}}{\mathrm{d}t}[Q_{\text{conv}}] = hA_s(T_b - T_\infty) \tag{1}$$

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On the basis of convective heat transfer analysis, the aforementioned law is the first rule for heat transfer formulation. Further on the aforesaid area further work has been done in 1922, 1929, and then in 1998, for detail see [2, 3]. Later on the cooling law was modified by Fourier [4] in 1822 also called Fourier law of heat conduction given:

$$\frac{\mathrm{d}}{\mathrm{d}t}\left[Q_{\mathrm{cond}}\right] = -kA_c \frac{\mathrm{d}T}{dx} \tag{2}$$

After the Fourier law, several theories have been developed to model heat transfer in various fins. The conclusive steps in the foundation of convective heat transfer coefficient in natural and forced convection heat transfer were given by Nusselt in 1916. Because Newton's law of cooling is applicable only for forced convection with some constant physical properties. Various models of conduction and convection of heat transfer analysis have been developed. Until 1950, the model proposed by Fourier was extensively applied in the fundamental equation governed by the first law of thermodynamics, which describes the conduction mode of heat transport mechanism, we refer [5].

For the first-time heat transfer through extended surfaces has been studied by Hyper and Brown. It was a well-designed work to analysis the relationship between convection and conduction in an extended surface and provided a mathematical description by them. Further they also introduced the idea of heat exchange. Hyper and Brown [6] called the aforesaid surface *cooling fin* which later became simply a fin. Further, Batchelor [7] published his work as a mathematical analysis of extended surfaces. In the case of periodic heat flow and transfer in an extended surface that occurs from a periodic base temperature or an oscillatory ambient temperature, many analytical and numerical methods have been established like frobenius method, perturbation techniques, finite elements and differences methods. Here we remark Cattaneo in [8] and Allan [9] has been investigated the hyperbolic non-Fourier wave model of conduction heat transfer equation (CHTE) in 1948. Further the said authors have also utilized their investigation study the heat transfer problems in fins.

The features related to heat transfers in various straight longitudinal fins with periodic variation of base temperature were analytically concluded by Yang [10]. Eslinger and Chung [11] have been introduced a finite element solution for the periodic heat transfer and flow in convective and radiative extended surface. Aziz and Na [12] have been analysis the periodic heat transfer in convective fins with temperature dependent thermal conductivity and co-ordinate dependent heat transfer coefficient using the perturbation analysis technique in 1981. Further the detail investigations about heat transfer analysis in different fluids were recorded during 1983. For the mentioned study we refer the work of Vick and Ozisik [13] , Yuen and Lee [14]. Sanea and Mujahid [15] have been applied a finite-volume numerical model to describe the heat transfer properties of longitudinal fins with rectangular profile subjected to periodic and step change base temperatures. Lin [16] numerically analyzed the periodic heat transfer process arising from a periodic base temperature in convective longitudinal fins. Li *et al.* [17] studied and analysis the enhancement of heat transfer in fins having irregular shape. Ahmadikia and Rismanian [18] analytically studied the problem that had been presented numerically by Lin in 2011. Azimi *et al.* [19] brought out analysis for unknown base temperature circulation in various non-Fourier fins during 2012. They considered 1-D general formulation of the non-Fourier model for longitudinal fin with arbitrary profile such as convex parabolic, concave parabolic and triangular. Further they have been used various methods for solution, like implicit finite difference method and adjoint conjugate gradient method.

Huang and Lee [20] studied and analysis the importance of considering the non-Fourier effects in heat transfer problems through annular fins. They solved the non-Fourier CHTE and investigated the thermoelastic wave propagation in annular fins by using a hybrid numerical method. Kundu and Lee [21] analytically determined the fin temperature response with volumetric heat generation for both Fourier and non-Fourier heat transfer mechanisms applying separation of variables method. After they have also analyzed temperature dependent heat generation problem. Further, for the required solution they used least square method. Non-linear temperature distribution equation in porous and solid longitudinal fins with temperature dependent internal heat generation has been explained and solved using differential transform technique [21].

Mosayebidorcheh, *et al.* [22] have been designed various kinds fins and they also discussed which one is more favorable for heat transfer. Ma *et al.* [23] have been studied the convective, conductive and radiative heat transfer through porous fins having trapezoidal type shape. They have been used spectral element method to solve various problem in porous fins. Further they also have been used the spectral collocation method for the solution of unsteady thermal process in the moving plate with temperature dependent properties and heat generation. They observed high accuracy in this problem [24]. Two straight walls and quarter circular enclose with two sinusoidal wavy walls were proposed and analyzed by Tang *et al.* [25].

Fins under periodic thermal condition have been extensively studied under various conditions. The physical parameters which manage heat transport process are defined. The effects of periodic variation of the base temperature on the rate of heat flow, fin temperature distribution, fin efficiency and fin effectiveness have been demonstrated through several examples.

Fins have large numbers of applications which are used to increase the heat transfer from a hot body to ambient. Normally the fins material has high thermal conductivity. The performance and applications of fins are utilized in various fields, such as in automatic control mechanisms, cylinders of air-cooled aircraft, electronic equipment, nanotechnology, storage devices and also use in base heating. Further in engineering system fins are used in a large number of applications for example fins are attached to electronic components to enhance the periodic heat transfer from the hot surface.

In this article our aims and objectives to bring out the comprehensive review for the periodic heat transfer through extended surfaces (fins). Here we describe some parameters as heat transfers from different extended body depend on the environmental temperature, T_∞, fins temperature, T, fins thickness, fins pattern, fins alignment, fins outside dimeter, thermal conductivity, heat transfer coefficient, h, fin surface area, A_s. Further, the enhancement of heat transfer also depends on the ambient fluid properties. Here we remark that the heat transfer through the mentioned surfaces can be increased by extending the concerned surfaces up to sufficient degreee. The concerned process depends also on the nature of materials and heat transfer coefficients. It also depends on the velocity of the wind, the temperature of the surrounding and the geometry of the surfaces

Heat transfer from extended surfaces (fins) and applications

Different kind of fins are utilized mostly to enhance the heat transfer rate between a hot solid body and an ambient fluid. From fig. 1 we see extended surfaces (also known as a cooling fins, combined conduction-convection system or simply known as fins) is a solid in which heat transfer in the form of conduction is consider to be 1-D. Further heat is also transferred from finned surfaces by other two modes which is convection and radiation.

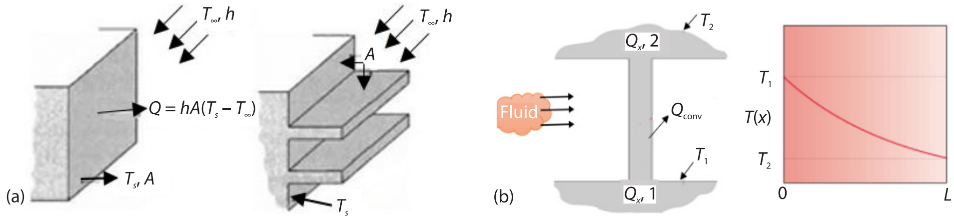

Figure 1. The fin configuration [25]

From fig. 1 it is recognized that the convection heat transfer coefficient, h, changes along the fin's length as well as its perimeter. Experimentally it is observed that the value of h is mostly much less at the fins base as compared to the fin tip. Near to the fins base there is more resistance to the fluid motion which is surrounded by the surface, because fluids are more contact with the surface. Further, along the fins the interaction of fluid is decreasing and there exist less resistance to fluid motion and resulting the heat transfer rate increase. Consequently, fixing several fins on a surface decrease the overall heat transfer rate. The implementation and performance of the extended surface is expressed in terms of the fins effectiveness which is defined as the ratio of heat transfer rate from the extended surfaces having base area and heat transfer rate from the surface area if no fins are fixed to the surface.

Periodic heat transfer from finned surfaces and use of numerical method

When heat transfer form extended surfaces under thermal conditions, experimentally it has been observed that the transfer of heat from a surface is naturally periodic. In a periodic transient state temperature undergoes periodic change within the system which are either regular or irregular but definitely cyclic and in steady condition no periodic component. Many researchers studied and worked on periodic heat transfer through extended surface and developed many numerical and analytical techniques, method to solve the periodic heat transfer problem through fins and define the parameter which are manage and enhance the heat transfer rate having periodic nature from different surfaces. Aforementioned numerical and analytical methods containing the method of finite element, finite difference, straight line, perturbation expansion and boundary element method.

Finite element technique is used for heat transfer form radiation and convicting fins or a series of fins. Researcher have been worked and analyzed by changing the temperature periodically. It has been experimentally proved that heat transfer rate is increase if surrounding in black and surface are gray color and the ambient fluid is less viscosity and the fluid is transparent.

Periodic heat transfers from various kind of extended surface

Different type of extended surfaces have been utilized to increase the periodic heat transfer rate from the surface of a system. Therefore, various extended surface (fins) are used commonly in different kind of heat exchanging equipment such that used in computer CPU heatsink, power plant and also used in radiator of different cars and other motors. Further these are also used in heat exchanger, automatic control device and used in nanotechnology. Latest technology also used fins such that in hydrogen fuel cell. Further all physical things that we see in our surrounding take advantage from fins.

Periodic heat transfers from longitudinal straight rectangular fins

Longitudinal straight rectangular fins are utilized to enhance the periodic heat transfer from a hot solid surface of the fins which are fixed to a surface of a system to the environment.

Analytical and numerical solutions for heat transfer in one and 2-D model for both rectangular type and wedge-shaped fins having uniform thickness is presented by Hyper and Brown [6]. The numerical solutions are concluded in terms of fins efficiency and effectiveness of the longitudinal straight rectangular profile. A paper was published by Ghai [26] in which he studied an experimental analysis of heat transfer through rectangular type fins. Various problem of the longitudinal fins of triangular profile, rectangular profiles with heat transfer coefficient that varied linearly over the fin length has been analyzed and studied by Melese [27]. Fourier proposed diffusion model and illustrates the relationship between the temperature gradient and heat flux. Cattaneo in [8] and Allan [9] investigated thermal wave model which describes temperature propagating as a wave, having thermal diffusivity acting as a damping effect in heat transfer and propagation. Allan [9] and Cattaneo in [8] have used a modified heat flux to explain and solve heat transfer problem in rectangular fin with time-dependent boundary conditions. Han and Lefkowitz [28] considered the rectangular fins. For the temperature excess the general differential equation with heat transfer function taken as a function of the distance from the fins base. Chen and Zyskowski [29] applied an exponential variation of the convection heat transfer coefficient by choosing the concern equation.

Ueda and Harada [30] numerically studied the overall convective heat transfer coefficient and also carried out analysis for the friction factors of rectangular profile fins in cross-flow. The effect of fins spacing and height, fins material and channel height all ware considered as a function of Reynolds number. Ueda-Harada [30] studied and done analysis in the first to show the greater variation in the ambient fluid temperature, which had, until now have been assumed as a constant. This was visualized by graph which displayed the variation of the fluid temperature in the direction of the fin height and the gaps between these fins.

Myers [31] has been done analysis for the periodic heat convection and conduction in rectangular shape fin, and also explained various problem by using the complex combination technique. Yang [10] has been made a research and analysis on the periodic heat transfers in straight longitudinal fin, further he also studied the effect of various environmental parameters on the temperature variation. Campo [32] considered the longitudinal fin of rectangular profile in fig. 2 and studied the unsteady state response of rectangular fin with simultaneous convection and radiation. In radial fins of rectangular profile in fig. 3 under steady-state periodic heat conditions but with radiation has been analysis by Campo [32] in 1977. Further using the perturbation technique, Aziz and Na [12] performed a detail study on periodic heat transfer through convicting fins which has dependent thermal conductivity they were dependent on temperature, space co-ordinate and also depended on heat transfer coefficient.

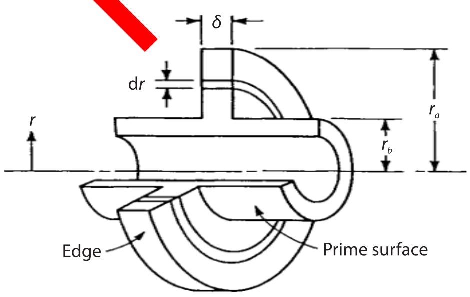

Figure 2. The rectangular fin configuration [30]

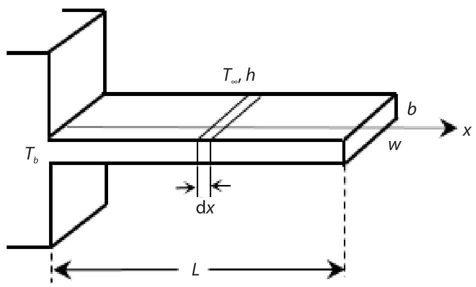

Figure 3. Radial fin of rectangular profile [30]

The aforementioned authors have been studied in 1975 for the first time in this area and extended the analysis of the periodic heat transfer through radial and rectangular fins. In this case the solution existed in terms of modified Bessel function of complex arguments. On separated the real and imaginary parts of the function and they calculated the oscillating components by using the series expansions for these functions. For base heat flux the numerical results, temperature distribution and time-average fin efficiency showed fundamentally the same performance as a result for the straight longitudinal fins.

Aziz and Na [12] studied the problem of oscillating base temperature with two additional effects. They analyzed the change in convection heat transfer coefficient with changing the velocity of the adjacent fluid, thermal conductivity, fin height co-ordinate to change with temperature. Al Mujahid [33] studied and used the complex combination method to obtain the analytical solution for rectangular fins with both base heat flux and environmental temperature oscillation simultaneously. Eslinger and Chung [11] studied periodic heat transfer through various fins and groups of fins with simultaneous radiation and convection. Further the phenomena of periodic heat transfer have been investigated by Houghton *et al.* [34] during 1992, 1993, respectively. He also extended the study of heat conduction in 2-D rectangular fin. In rectangular fin the loss of heat to environment by pure convection. Chu *et al.* [35] used the Fourier transformation technique to eliminate the time variable in 1982. The resulting differential equation gave rise to a series type of solutions which were solved by using the method of separation of variables. Further for one and 2-D case, the convergence of such a series solution slow for smaller time values. The same problem was analyzed by Chu and Wong [36]. They used numerical technique to obtain the Laplace inverse method instead using of separation of variables methods. The numerical result has some shortcoming Ju [37] recognizing these shortcomings and took different approach. They recognized the ratio of fin thickness to the fin height as a very small perturbation parameter and created a 2-D unsteady equation. Later on, using the perturbation analysis, they removed the 2-D effect by averaging the quantities along the fin thickness. Further unsteady problem in 2-D was reduced to 1-D by using that method and finally solved the problem by using linear operator method. Wang *et al.* [38] used hyperbolic heat conduction theory and built a thermo mass gas model that describe the fluid-flow in a medium like heat conduction process. Further using the concept of thermo mass Wang and Guo [39] introduced a new governing equation for non-Fourier heat conduction in nanomaterials.

Periodic heat transfers through triangular fins

Heat is thermal energy which is transfer from hot solid surface to cold surface as a result of temperature difference. Heat transfer consists in three modes that is convection, conduction and radiation. Naturally the transfer of heat is periodic in transient state. Therefore, some researcher analysis different type of fins for heat transfer and flow, for this purpose they utilized triangular fins and attached to a hot surface to enhance the periodic heat transfer and further they define some constant environmental physical parameter. The uses and performance of triangular fins can be measured in term of fin efficiency, effectiveness and thermal resistance. This type of fins consists less material and minimum weight and low cost. The triangular fins are large number of applications that is uses in industrial process, air cold cylinder or jet engine of air craft and outer space and further use in engineering system. Hamid *et al.* [40] performed an analysis and present the mods of heat transfer in his book. He studies triangular fins and analysis the boundary condition. Minkler and Rouleaus [41] in studied and worked on triangular fins and consider the effect of heat transfer from triangular profile with a constant convection heat transfer coefficient on the fin surfaces and further the fin tip become insulated such that no heat loss. After Nakamura *et al.* [42] investigate and utilized the numerical technique to remodel a triangular co-ordinate system to solve various dimensional problem in triangular fins. Papadopoulos *et al.* [43] investigated the response of straight and circular fins to fluid temperature changes in 1990. Aziz and Nguyen [44] and look has also been analysis the 2-D conduction problem in a triangular shape fin. Further, sued the method of separation of variable and consider a fin with identical conduction and conviction from bottom to top faces and a constant base temperature.

Nain [45] in his book presented an introduction abut triangular type fins and analysis the boundary conditions and give detail information about it. Incropera [46] discussed 2-D fins analysis contributing in heat transfer and planned a relationship for triangular fins. Mahesh his book presented practical applications of triangular fins. Kumar *et al.* [47] give experimental analysis to calculate the performance of heated up triangular fins, fig. 4.

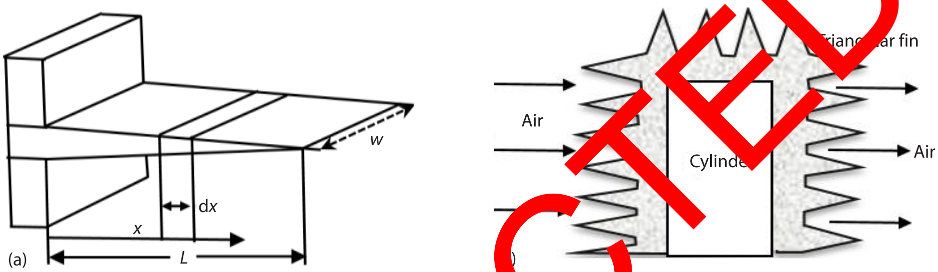

Figure 4. (a) Triangular fin attached to cylinder and (b) air cooled cylinder with triangular fins [47]

Teerakulpisut [48] study in his paper and introduced the modified Bessel function application in the investigation of fins used for enhance the heat transfer. Further conviction and conduction heat transfer are formulated by differential equation. Khaled and Gari [49] analysis heat transfer and flow through a wall containing triangular type fins which are partially implanted in its volume. Further he used an iterative finite volume technique to solve numerically heat diffusion equation. In his paper he attained the analytical and numerical result.

Many researchers see that the heat flow and transfer rate is maximum from triangular rooted-finned surfaces therefore, they recommended to use this type of fins which are exposed to highly convective fluid-flows. Narve *et al.* [50] study in his paper and deliberate the characteristic of heat transfer and flow in natural-convection through triangular fin arrays which are design vertical. He experimentally analyzed the results and compared the result with equivalent rectangular fin arrays. Further they calculated some dimensional quantities such that Average and Grashoff number and base Nusselt number to define a relationship between in these dimensional quantities. They noted that average and base Nusselt number are increases with increase in Grashoff number.

Periodic heat transfers from annular fins

Normally, annular fins have been test, study and design such that the fin thickness is to be consider very less or ignore as compared to the fin radius. Sparrow *et al.* [51] explain and utilized annular fin for heat transfer and construct a model for annular type fin with blackbody surface and include the fin and base radial interface. Many researchers analysis and studies and show that for a comparable fin thickness the result of 2-D experiment give effective result and show good performance instead of 1-D study. This type of extended surface are commonly utilized in commercial and industrial implementation and useful application we find such as air-cooled electronics devices and compact heat exchanger.

Concerning the insufficiency of works and study affecting thermal performance of orthotropic annular extended surface in two-dimensions. Mustafa *et al.* [52], Yovanovich *et al.* [53] analysis and study the temperature circulation and heat transfer flow for orthotropic

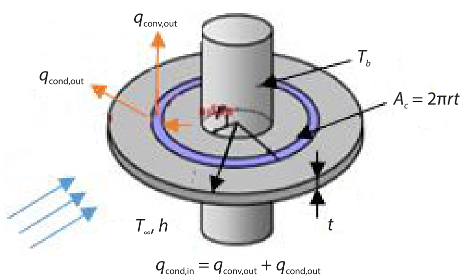

Figure 5. Fin of non-uniform cross-sectional Area: annular fin [60]

2-D, annular fins subject to convective-tip boundary condition. Further dimensionless heat transfer is described throughout annular fins and further fins efficiency ratio are calculated and plotted as a function of constant value of geometric parameters and biot numbers. Campo and Acosta-Iborra [54] have been stated the thermal solutions of metallic, composite fins of varying thickness.

Aziz and Beers-Green [55] and Gaba *et al.* [56] provided a detail information about the thermal performance of rectangular annular fin which are organized functionally. Aziz and Fang [57] analyze the study the heat transfer process in a rod having variable thermal conductivity which enhance heat transfer by radiation and convection in at the same time. Further, they analysed the heat transfers through annular fins in moving state and developed analytical solution for heat transfer.

Mujahid and Abu-Abdon [58] analysis and study the functionality and the performance report of annular type fins when its base is subject to the ambient temperature periodically. After the two researcher Kang and Look [59] study 2-D symmetric radial fins consider several values of different slope and consider non-dimensional fins length for heat loss and discuss the relationship among different parameter in annular fins. Many calculations and result show that when the slope increase the heat transfer rate decrease. In recently Gaba *et al.* [60] analysis and reported the parametric study of well-designed and categorized rotating annular fins and investigate the efficient of rotating fins and categorizing the material in the performance of annular fins. The flow chart of the said fin is given in fig. 5.

Further a convective annular fin is considering for heat transfer having uniform cross-sectional area. Consider the ambient temperature constant, take annular fin which is displayed and subject to a periodic heat transfer rate near the base. This case accrues and developed in various engineering system and use in a large number of applications. The separation of variable method cane be used to get the resulting solution in the form of series by using the convicting fins with linear cooling law. Chapman [61] have been reported such solution in an annular fin. In Arpaci book used the complex temperature method to solve many problems for annular fin. In the solution process the Bessel function is also used. Bessel function with complex argument is also studied. Further analysis of the periodic heat transfer through annular fins was investigated by using numerical technique to solve the equation contained Bessel function with complex argument. Further closed form solution for the time average efficiencies and temperature distribution are found which are dependent on the physical parameter of the fins.

Periodic heat transfers through cylindrical fins

Many researchers steady-periodic heat transfers in cylindrical fins which is more important in many engineering applications including annular fins [35, 62]. Such types of fins are uses in rotating machinery such as heat exchanger and electromagnetic equipment, and used in those devices which undergoing periodic thermal contact such as engine exhaust valves [63].

Sparrow and Vemuri [64] experimentally describe to explain the three mode of heat transfer by conduction, natural-convection and radiation of vastly settled arranges of cylindrical like spines or fins. This type of extended surface was placed with in horizontal axes and were fixed to a heated surface at the base. After some researcher's analysis and define heat transfer rate effecting by decrease and increase the number of fins, base surface-to-surrounding temperature difference, further the uses and effect of insulator fins. Various numerical calculation indicated that at small temperature difference the use and contribution of more fins are used for the total heat transfer. Lieberman and Gelhart [65] provide and concerning the dependence of heat transfer coefficient in pin-fin arrangement along parallel cylinders' arrangement and determined geometric parameter. Aihara *et al.* [66] analysis and show heat transfer through cylindrical type fins and produce optimum spacing among horizontal isothermal cylinders.

Further cylindrical pin-fins expressed in fig. 6, with a vertical base plate are study by Bejan *et al.* [67] and provide a relationship for the experimental average heat transfer coefficient in natural-convection. Hatami [68] analysis most favorable shape of wavy wall around the heated cylinder. Agrawal and Bhavsar [69] perform an experimental work to investigate the heat transfer through single finned cylinders consider the heat characteristics for air-flow.

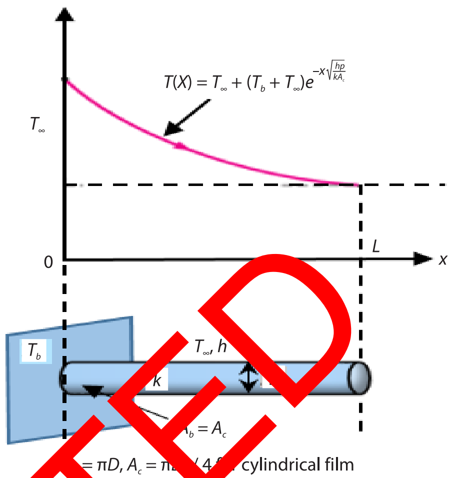

Figure 6. Flow chart of cylindrical pin-fin [67]

Their system contained two identical finned cylinders having different physical materials such that aluminum and brass. The rectangular spiral type spine which lies in and opposite direction and graphically determined the result and show the effect on the heat transfer process.

Metzger and Haley [70] also organized and reported an experiment as well as flow visualization studies for arrangements of short pin-fins. Murthy and Patankar [71] testified on work affecting to heat transfer from rotating longitudinal cylinders operational with radial fins. Kuehn (1984) (analysis a parallel isothermal cylinder fin with infinitely large transverse non-isothermal plate spine and fins. Nusselt [72] defined the physical nature of layered film condensation. Further the result of his study for inclined and vertical sheets and parallel cylinders are in useful arrangement with experiment.

Compression of heat transfer through various kind of extended surfaces

Many researchers have been studied in their literature, that the heat transfer rate is increased by enlarging the heat transfer surface area or enlarge the heat transfer coefficient parameter. Increasing the heat transfers rate in natural-convection we increase the heat transfer area by providing fins. The enhancement ratio of heat transfer rate be determined by on thermal conductivity, geometric parameters of fin arrays and the fins orientations. The most common arrangements of using fins arrays involve vertical or horizontal surface plate to which fins arrays are fixed.

Literature review

Al-Essa and Adullah [73] take rectangular fins implant with equilateral triangular perforations and analysis the enhancement of heat transfer in natural-convection through it. He determined that the perforated fins enhance the heat transfer rate for particular values of triangular dimension. The magnitude of heat transfer enhancement is proportional to its thermal conductivity and the fin thickness. Further increase the fins perforation, the heat transfer rate increase. Beside the cost of fins material is decrease.

Ramdas [74] studied various industries that are using thermal systems in which overheating can harm and damage the components of a system and reduce the function of the system and further cause to failure of the system. To overcome this problem, they attached various fins to manage the thermal systems with effective by enhance the heat transfer rate from the surface. To increase the thermal performance and working of a system, thereby affecting energy material and cost savings has led to development and use of many techniques termed as *Enhancement the heat transfer*. This method also known as *Heat transfer Augmentation* or *Intensification*.

The uses of fins in different heat exchanger the augmentation technique increased convective heat transfer by increasing thermal conductivity and reducing the thermal resistance. Various heat augmentation methods have been studied, these are:
– wave baffle and plate baffle
– surface roughness,
– inclined baffle,
– perforated baffle,
– corrugated channel,
– porous baffle,
– discontinuous Crossed Ribs and Grooves, and
– twisted tape inserts.

Most of these improvement techniques are led to increase in heat transfer coefficient but at the cost of increase in pressure drop.

Mostafavi *et al.* [75], studied natural convection in vertically fixed rectangular fins in steady-state and analysis heat transfer from these extended surfaces. After confirmation of the analytical result for continuous fins by experimental, a systematic numerical and analytical study is performed on the effect of single wall and fin array interruption. Further computational software like COMSOL Multiphysics and FLUENT are applied to develop numerical model in 2-D to investigate the fins interruption effects. Various results indicate that increasing spacing in vertical rectangular spine and fins, decreases the weight of the fin arrays and increase the thermal performance of fins, which lead to lower manufacturing costs.

The *V*-shaped plates (fins) were fixed to the two identical vertical plates with the aim of enhance the heat transfer. They take three different type of fins and study among *V*-fins array and rectangular vertical fins array with bottom spacing design. The performance was observed to increase the heat transfer with increase in the height and thickness of the *V*-plates (fin). Here, some comparision at different heat transferred coefficients has been plotted graphically in fig. 7 and fig. 8.

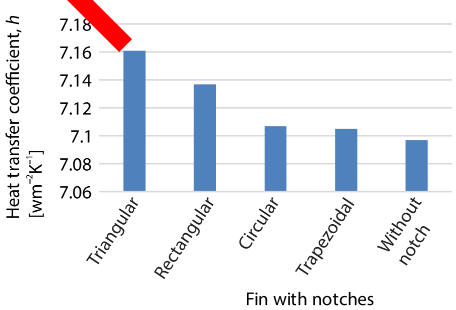

Figure 7. Comparisons of HTC at 100 °C base temperature

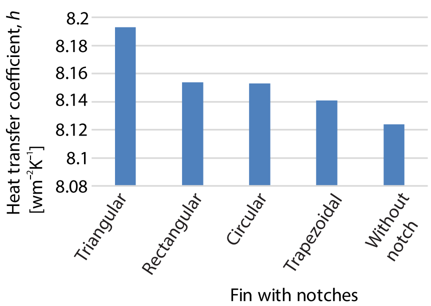

Figure 8. Comparisons of HTC at 70 °C base temperature

Numerical and simulation works

Aziz and Luardini [76] have been analyzed heat transfer rate in various extended surface with periodic base temperature. Further they used many methods to solved various problem by using numerical, analytical and combined numerical analytical technique. These contain the technique of finite differences, Frobenius, finite elements, perturbation expansions, the boundary element method and the straight-line method. Further many equations involving Bessel function with complex arguments are used numerical methods to solve it. They make a comparison of the result for a straight longitudinal rectangular fins and radial fins having different boundary conditions as well as with the same boundary conditions.

Further in the case of periodic heat transfer in various extended surfaces that occurs from a periodic base temperature or an oscillatory ambient fluid temperature, many analytical and numerical studies have also been published. In straight fins the characteristics of heat transfer with periodic variation of base temperature numerically and analytically explained by Yang [10]. Periodic heat transfer in convective and radiative fins a finite element solution has been demonstrated by Eslinger and Chung [11]. perturbation analysis for the periodic heat transfer in various convective fins with temperature dependent thermal conductivity and co-ordinate dependent heat transfer coefficient used by Aziz and Na [12].

Sanea and Mujahid [15] applied a finite-volume numerical model to describe the heat transfer characteristics of straight longitudinal fins with a rectangular profile subjected to periodic and step change base temperatures. Various numerical and analytical studies determine the experimental parameters, which affect the heat transfer rate in various fins. In heat transfer models, both thermal conductivity and heat transfer coefficient which effect heat transfer rate are study. The heat transfer coefficient is depending on fluid properties and ambient temperature and beside the thermal conductivity measure the ability of the material to conduct heat. Further the solutions assumed usually as a linear or non-linear function of the temperature. Various researcher has been study and applied computational software Packages like COMSOL, ABAQUS, ANSYS, MATHCAD and MATLAB to solve graphically the numerical and analytical equation for heat transfer in engineering system.This computational software gives the desired numerical results and also provide colorful and graphical form of the result for impressive presentations.

Nowadays for more accurate approximation of complex physical and mathematical problem are solve by using computational software. Further developing advanced numerical techniques and computing tools using high performance computational software. The COMSOL Multiphysics is a simulation software which is used in the solution of partial differential equation by using finite element technique. Further to be applied these techniques to solve the complicated problem in mechanical, electrical and chemical engineering area. Mujahid [33] has studied the radial extended surfaces with periodic base heat flux and further he explains and show in detail, how the modified Bessel functions of complex argument solution can be separate into two-components such that their real and imaginary parts. Papadopoulos *et al.* [43] study the oscillating ambient temperature with a fixed base temperature and used the Laplace transformation find the solution of heat transfer rate. Some further work in this regards can be seen in [77-79].

Discussion

Aziz and Na [12] published a recently paper in the year, and mad an inclusive and comprehensive analysis which present developed in the area of periodic heat transfer rate through different type of extended surface. Further another paper has been published by Yang

[10] in discuss and examine heat transfer characteristics in various longitudinal straight fins. Further the periodic variation of base temperature in various fins also numerically and analytically determined by Yang [10]. Yang [10] and Aziz and Na [12] study and discuss heat transfer rate in various kind of extended surface which are naturally periodic.

Different type of fins is utilized to enhance the heat transfer from a hot body. Evidently, the first point of attention here was that Ghai [26] published a paper in which he works and reported an experimentally exploration of rectangular type fins. He shows in this research a large difference in convection along the fins in the direction of the air-flow and heat transfer coefficient both from fins base to fins tip. The circular fins are a specific kind of profile, which is utilized for heat transfer in radial direction. In heat exchanger mostly, circular fins are frequently used to increase the heat transfer area. Furthermore, circular-finned tube heat exchangers are commonly utilized for industrial process. Look, Aziz and Nguyen [44] also examined and explain to solve various problem in 2-D convection and conduction in a triangular profile.

The aforementioned investigation indicates that the heat and performance of the extended surface depends on the frequency parameter, amplitude parameter, steady-state fins parameter. Fins surfaces are commonly used in practice to enhance heat transfer and they often increase the rate of heat transfer from a surface several fold.

From the aforementioned review, we concluded that fins have significant applications in real life instruments like radiator, airconditioning.

Conclusion

Due to the important uses of extended surfaces (fins) in the real-world phenomena, we have focused our attention carried out comprehensive review about the periodic heat transfer through different type of extended surfaces (fins). In conclusion we state that basically there are three fundamentals ways to accelerate the heat transfer through the aforementioned extended surfaces. The first one is by enlarge the temperature difference between the ambient fluid and the hot surfaces, the second one is by enlarging the parameter heat transfer coefficient and the third one which is effective, inexpensive and more popular is related to increase the surface area by extended surfaces known as fins. Many researchers propose and mention that the periodic heat transfer through various kind of extended surface may well present a challenging for further exploration, analysis and investigation. That to minimize and decrease the mas, size and volume of extended surface (fins) which are used in different type of heat exchangers (compact heat exchanger). Different kind of extended surface structures, arrangements, process of convection and conditions and further many factors are studied and develop the functioning and performance of various fins for the periodic heat transfer and flow. We expect that for further investigation and research this report will provide a foundation for improving those effects which enhance the periodic heat transfer rate in various kind of fins which are used in heat exchangers. Furthermore, the central objective of this review paper direct to well-designed the fins, effective heat transfer behavior and savings cost. Besides, this work will show and play a significant role in further investigation for getting industrial, engineering, commercialization uses and applications.

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References

[1] Kaye, G. W. C., A Dictionary of Applied Physics, Vol. 1, 1922, pp. 439-442

[2] Greenidge, K. N., Ascent of sap. *Annual Review of Plant Physiology*, *8* (1957), June, pp. 237-56

[3] Cheng, K. C., Fujii, T., Heat in History Isaac Newton and Heat Transfer, *Heat transfer engineering*, *19* (1998), 4, pp. 9-21

[4] Kumar, M. A., Review on Convection Heat Transfer in Extended Surfaces-Fin., *Int. J. of Eng. and Tech*., *4* (2018), 2, pp. 2-26

[5] Aziz, A., Allan, D. K., Transient Heat Transfer in Extended Surfaces, *Appl. Mech. Reviews*, *48* (1995), 7, pp. 317-350

[6] Harper, D. R., Brown, W. B., *Mathematical Equations for Heat Conduction in the Fins of Air-Cooled Engines*, National Advisory Committee on Aeronautics, Washington DC, USA, 1923

[7] Batchelor, G. K., Heat Transfer by Free Convection Across a Closed Cavity between Vertical Boundaries at Different Temperature, *Quarterly of Applied Mathematics*, *12* (1954), 3, pp. 209-233

[8] Cattaneo, Sur une Forme de l'Equation de la chaleur elinant la paradoxe d'une propagation instantance (in French), *Compt Rendu*, *247* (1958), pp. 431-433

[9] Allan, D. K., Sixty-Five Years of Extended Surface Technology (1922–1987), *Appl. Mech. Reviews*, *41* (1988), 9, pp. 321-364

[10] Yang, Y. W., Periodic Heat Transfer in Straight Fins, *Journal of Heat Transfer*, *94* (1972), 3, pp. 310-314

[11] Eslinger, R. G., Chung, B. T. F., Periodic Heat Transfer in Radiating and Convicting Fins or Fin Arrays, *AiAA Journal*, *3* (1979), 3, pp. 1134-1140

[12] Aziz, A., Na, T. Y., Steady Periodic Heat Transfers in Fins of Arbitrary Profile, *Numerical Heat Transfer*, *3* (1980), 3, pp. 331-344

[13] Vick, B., Ozisik, M. N., Growth and Decay of a Thermal Pulse Predicted by the Hyperbolic Heat Conduction Equation, *Journal of Heat Transfer*, *105* (1983), 4, pp. 902-907

[14] Yuen, W. W., Lee, S. C., Non-Fourier Heat Conduction in a Semi-Infinite Solid Subjected to Oscillatory Surface Thermal Disturbances, *Journal of Heat Transfer*, *111* (1989), 1, pp. 178-181

[15] Sanea, S. A., Mujahid, A. A., A Numerical Study of the Thermal Performance of Fins with Time-Dependent Boundary Conditions Including Initial Transient Effects, *Warme-Und Stoffubertragung*, *28* (1993), 7, pp. 417-424

[16] Lin, J. Y., The non-Fourier Effect on the Fin Performance under Periodic Thermal Conditions, *Applied Mathematical Modelling*, *22* (1998), 8, pp. 629-640

[17] Li, J. C., *et al*., An Analysis of Inverse Heat Conduction Problem on Irregular Shape Fins, *Proceedings*, Int. Multi Conference of Engineers and Computer Scientists, Hong Kong, China, 2010, Vol. III

[18] Ahmadikia, H., Rismanian. M., Analytical Solution of Non-Fourier Heat Conduction Problem on a Fin under Periodic Boundary Conditions, *Journal of Mechanical Science and Technology*, *25* (2011), 11, pp. 2919-2926

[19] Azimi, A., *et al*., Inverse Hyperbolic Heat Conduction in Fins with Arbitrary Profiles, *Numer Heat Transf. Part A*, *61* (2012), 3, pp. 220-240

[20] Huang, C. H., Lee, C. T., Inverse Method in Estimating the Base Heat Flux for Irregular Fins, *Journal of Thermophysics and Heat Transfer*, *28* (2014), 22, pp. 320-326

[21] Kundu, B., Lee, K. S., Analytical Tools for Calculating the Maximum Heat Transfer of Annular Stepped Fins with Internal Heat Generation and Radiation Effects, *Energy*, *76* (2014), 1, pp. 733-748

[22] Mosayebidorcheh, S., *et al*., Optimization Analysis of Convective Radiative Longitudinal Fins with Temperature-Dependent Properties and Different Section Shapes and Materials, *Energy Conservation Manag*, *106* (2015), Dec., pp. 1286-1294

[23] Ma, J., *et al*., Simulation of Combined Conductive, Convective and Radiative Heat Transfer in Moving Irregular Porous Fins by Spectral Element Method, *Int. J. Thermal Science*, *118* (2017), Aug., pp. 475-487

[24] Ma, J., *et al*., Spectral Collocation Method for Transient Thermal Analysis of Coupled Conductive, Convective and Radiative Heat Transfer in the Moving Plate with Temperature Dependent Properties and Heat Generation, *Int. J. Heat Mass Transf*., *114* (2017), Nov., pp. 469-482

[25] Tang, W., *et al*., Natural-Convection Heat Transfer in Nainofluid-Filled Cavity with Double Sinusoidal Wavy Walls of Various Phase Deviations, *Int. J. Heat Mass Transfer*, *115* (2017), Dec., pp. 430-440

[26] Ghai, M. L., Heat Transfer in Straight Fins, *Proceedings*, General Discussion of Heat Transfer, Institute of Mechanical Engineers, London, UK, 1951, Vol. 180

[27] Melese, G. B., Efficacite d'une ailette longitudinale avec variation du coefficient d'echange de chaleur le long de l'ailette (in French), *Jornal Nucl. Energy*, *5* (1957), 3-4, pp. 285-300

[28] Han, L. S., Lefkowitz, S. G., Constant Cross-Section Fin Efficiencies for Non-Uniform Surface Heat Transfer Coefficients, ASME Paper, *60* (1960), A17796
[29] Chen, S. Y., Zyskowski, G. L., Steady-State Heat Conduction in a Straight Fin with Variable Heat Transfer Coefficient, *Proceedings*, 6th ASME-AICh Heat Tran., Conf., Boston, Mass., USA, 1963
[30] Ueda, T., Harada, I., Experiment of Heat Transfer on the Surfaces with Transverse Fins for Flow Direction, *Bull. JSME*, *7* (1964), 28, 759
[31] Myers, G. E., *Analytical Methods in Heat Conduction*, McGraw-Hill, New York, USA, 1971
[32] Campo, A., Unsteady Heat Transfer from a Circular Fin with Non-Linear Dissipation, *Waerme Stoffuebertrag*, *10* (1977), 3, pp. 201-210
[33] Al Mujahid, M., A Closed form Solution for Periodic Heat Transfer in Annular Fins, Eine geschlossene Lösung für periodische Wärmeübertragung an ringförmigen Rippen, *Wärme-und Stoffübertragung*, *24* (1989), 3, pp. 145-150
[34] Houghton, J. M., *et al.*, The 1-D Analysis of Oscillatory Heat Transfers in a Fin Assembly, *ASME J. Heat Transfer*, *114* (1992), 3, pp. 548-552
[35] Chu, H. S., *et al.*, Applications of Fourier Series Technique to Transient Heat Transfer Problem, *Chemical Engineering Communications*, *16* (1982), 1-6, pp.215-225
[36] Chu, S., Wong, S., Linear Pulse Propagation in an Absorbing Medium, *Physical Review Letters*, *48* (1982), 11, 738
[37] Ju, J. W., On Energy-Based Coupled Elastoplastic Damage Theories: Constitutive Modeling and Computational Aspects, *International Journal of Solids and Structures*, *25* (1989), 7, pp. 803-833
[38] Wang, M., *et al.*, General Heat Conduction Equations Based on Thermomass Theory, *Frontiers in Heat and Mass Transfer*, *1* (2010), 013004
[39] Wang, M., Guo, Z., Understanding of Size and Temperature Dependences of Effective Thermal Conductivity of Nanotubes, *Physics Letter A*, *374* (2010), 42, pp. 4312-4315
[40] Hamid, R. A., *et al.,* Effects of Joule Heating and Viscous Dissipation on MHD Marangoni Convection Boundary Layer Flow, *Journal of Science and Technology*, *3* (2011), 1, pp. 1-10
[41] Minkler, W. S., Rouleau, W. T., The Effects of Internal Heat Generation on Heat Transfer in Thin Fins, *Nuclear Science and Engineering*, *7* (1960), 5, pp. 400-406
[42] Nakamura, H., *et al.*, Solutions of Two-Dimensional Heat Conduction Problem in Annular Triangular Fins, *Journal of Chemical Engineering of Japan*, *14* (1981), 6, pp. 487-489
[43] Papadopoulos, K. D., *et al.*, The Response of Straight and Circular Fins to Fluid Temperature Changes, *Int. Communication Heat Mass Transf.*, *17* (1990), 5, pp. 587-595
[44] Aziz, A., Nguyen, H., The 2-D Effects in a Triangular Convecting Fin, *Journal Thermophys and Heat Transfer*, 6 (1992), 1, pp. 165-167
[45] Nain, D., Fin Efficiency Analysis in Electronic Devices Considering Temperature, Heat Transfer, Coefficient, Fin Length, *Think India Journal*, *22* (2019), 4, pp. 5056-5064
[46] Incropera, F. P., *Fundamentals of Heat and Mass Transfer*, John Wiley and Sons, New York, USA, 2011
[47] Kumar, G., *et al.*, *Experimental Investigation of Natural-Convection from Heated Triangular Fin Array Within a Rectangular Array*, Research India Publications, Rohini, Delhi, India, 2014, Vol. 2248-9967
[48] Teerakulpisut, S., Application of Modified Bessel Functions in Extended Surface, *Heat Transfer*, *22* (1995), pp. 61-74
[49] Khaled, A. R. A., Gari, A. A., Heat Transfer Enhancement via Combined Wall and Triangular Rooted-Fin System, *Journal of Electronics Cooling and Thermal Control*, *4* (2014), 1, pp. 12-21
[50] Narve, N. G., *et al.*, Natural-Convection Heat Transfers from Symmetrical Triangular Fin Arrays on Vertical Surface, *Int. J. of Scientific and Engineering Research*, *4* (2013), 5, pp. 271-281
[51] Sparrow, E. M., *et al.*, Analysis Results and Intepretation Between Some Simply Arranged Gray Surfaces, *Trans. ASME*, *83* (1961), 2, pp. 207-214
[52] Mustafa, M. T., *et al.*, Thermal Analysis of Orthotropic Annular Fins with Contact Resistance: A Closed-form Analytical Solution, *Applied Thermal Engineering*, *31* (2011), 5, pp. 937-945
[53] Yovanovich, M., Simplified Solutions to Circular Annular Fins with Contact Resistance and End Cooling, *Journal of Thermophysics and Heat Transfer*, *2* (1988), 2, pp. 152-157
[54] Campo, A., Acosta-Iborra, A., Approximate Analytic Temperature Distribution and Efficiency for Annular Fins of Uniform Thickness, *International Journal of Thermal Sciences*, *48* (2009), 4, pp. 773-780
[55] Aziz, A., Beers-Green, A. B., Performance and Optimum Design of Convective-Radiative Rectangular Fin with Convective Base Heating, Wall Conduction Resistance, and Contact Resistance between the Wall and the Fin Base, *Energy Conversion and Management*, *50* (2009), 10, pp. 2622-2631

[56] Gaba, V. K., *et al.*, Thermal Performance of Functionally Graded Parabolic Annular Fins Having Constant Weight, *Journal of Mechanical Science and Technology*, *28* (2014), Oct., pp. 4309-4318

[57] Aziz, A., Fang, T., Thermal Analysis of an Annular Fin with (a) Simultaneously Imposed Base Temperature and Base Heat Flux and (b) Fixed Base and Tip Temperatures, *Energy Conversion and Management*, *52* (2011), 7, 2467-7824

[58] Mujahid, A. A. M., Abu-Abdou, K., Thermal Performance of Annular Fins of Arbitrary Profile Subjected to Periodic Base and Environment Temperatures, *Journal of King Saud University-Engineering Sciences*, *5* (1993), 1, pp. 105-121

[59] Kang, H. S., Jr. Look, D. C., The 2-D Trapezoidal Fins Analysis, *Computational Mechanics*, *19* (1997), 3, pp. 247-250

[60] Gaba, V. K., *et al.*, Parametric Study of Functionally Graded Rotating Annular Fin, *Procedia Engineering*, *127* (2015), 10, pp. 126-132

[61] Chapman, A. J., Transient Heat Conduction in Annular Fins of Uniform Thickness, *In. Chem. Engng. Symp. Ser.*, *55* (1959), pp. 195-201

[62] Wu. S. S, *et al.*, Analysis on Transient Heat Transfer in Annular Fins of Various Shapes with Their Bases Subjected to a Heat Flux Varying as a Sinusoidal Time Function, *Comput. Struct.*, *61* (1996), 4, pp. 725-734

[63] Paradis, I., *et al.*, Thermal Periodic Contact of Exhaust Valves, Journal of Thermophysics and Heat Transfer, *16* (2002), 3, pp. 356-365

[64] Sparrow, E. M., Vemuri, S. B. Orientation Effects on Natural-Convection/Radiation Heat Transfer from Pin-Fin Arrays, *Int. J. of Heat and Mass Transfer*, *29* (1986), 3, pp. 359-368

[65] Lieberman, J., Gebhart, B., Interactions in Natural-Convection from an Array of Heated Elements, Experimental, *Int. J. of Heat and Mass Transfer*, *12* (1969), 11, pp. 1385-1396

[66] Aihara, T., *et al.*, Free Convective/Radiative Heat Transfer from Pin-Fin Arrays with a Vertical Base Plate (General Representation of Heat Transfer Performance), *International Journal of Heat and Mass Transfer*, *33* (1990), 6, pp. 1223-1232

[67] Bejan, A., *et al.*, The Optimal Spacing between Horizontal Cylinders in a Fixed Volume Cooled by Natural-Convection, *Int. J. of Heat and Mass Transfer*, *38* (1995), 11, pp. 2047-2055

[68] Hatami, M., Nanoparticles Migration around the Heated Cylinder during the RSM Optimization of Wavy Wall Enclosure, *Adv. Powder Technol*, *28* (2017), 3, pp. 890-899

[69] Agrawal, D. D., Bhavsar, V. C., Experimental Investigation on Heat Transfer Characteristics of Air-Flow Across Finned Cylinders, *Journal Inst. Eng. (India)*, *57* (1977), Jan., pp. 357-351

[70] Metzger, D. E., Haley, S. W., Heat Transfer Experiments and Flow Visualization for Arrays of Short Pin Fins, *Proceedings*, Int. Gas Turbine Conference and Exhibit., London, UK, 1982, pp. V004T09A007 V004T09A007

[71] Murthy, J. Y., Patankar, S. V., Numerical Study of Heat Transfer from a Rotating Cylinder with External Longitudinal Fins, *Numerical Heat Transfer*, *6* (1983), 4, pp. 463-473

[72] Nusselt, W., The Condensation of Steam on Cooled Surfaces, *Z. Ver. Dtsch. Ing.*, *60* (1916), pp. 541-546

[73] Al Essa, D., Abdullah, M., Augmentation of Heat Transfer of a Fin by Rectangular Perforations with Aspect Ratio of Three, *Int. J. of Mechanics and Applications*, *2* (2012), 1, pp. 7-11

[74] Ramdas, B., *et al.*, A Study on the Heat Transfer Enhancement for Air-Flow through a Duct with Various Rib Inserts, *Int. J. of Latest Trends in Engineering and Technology*, *2* (2013), 4, pp. 479-485

[75] Mostafavi, G., *et al.*, Natural-Convection from Interrupted Vertical Walls, *Journal of Heat Transfer*, *136* (2014), 11, pp. 112-501

[76] Aziz, A., Luardini, V. J., Analytical and Numerical Modeling of Steady Periodic Heat Transfer in Extended Surfaces, *Computational Mechanics, 14* (1994), 5, pp. 387-410

[77] Tolpadi, A. K., Kuehn, T. H., Conjugate Three-Dimensional Natural Convection Heat Transfer from a Horizontal Cylinder with Long Transverse Plate Fins, *Numerical Heat Transfer*, *7* (1984), 3, pp. 319-341

[78] Ganji, D. D., *et al.*, Determination of Temperature Distribution for Annular Fins with Temperature Dependent Thermal Conductivity by HPM, *Thermal Science*, *15* (2011), Suppl. 1, pp. S11-S115

[79] Han, W. S., Rhi, S. H., Thermal Characteristics of Grooved Heat Pipe with Hybrid Nanofluids, *Thermal Science*, *15* (2011), 1, pp. 195-206

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