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PERFORMANCE OPTIMIZATION OF INTERNALLY FINNED HEAT EXCHANGER USING CFD: A REVIEW

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ABSTRACT

This work reports numerical simulation for 3D laminar convection heat transfer in an internally finned elliptical tube heat exchanger with constant heat flux. The most common shape of tubes used in finned tube heat exchanger (FTHE) is the circular tube. The elliptical tubes can offer significant advantages over the circular ones because of smaller wake region and lower profile drag on the air-side. Therefore, it is reasonable to expect a reduction of air-side pressure drop and an increase in heat transfer by replacing circular tubes in FTHE with elliptical ones. The performance of elliptical finned tube heat exchanger optimize with the changing of fin geometry like fin shape, fin height, fin spacing, number of fin and air velocity. It has been found a comparison between the FTHE and the similar heat exchanger without fins indicates that the proposed FTHE has a significant potential to improve the comprehensive heat transfer performance. The numerical results agree well with the reported experimental data proving that CFD is an effective tool for predicting the behaviour and performance of a wide variety of heat exchangers.

Keywords: CFD-computational fluid dynamics, numerical, analytical work and experimental work.

I. INTRODUCTION

heat exchangers is quite complicated, as it needs exact analysis of heat transfer rate, efficiency and pressure drop apart from issues such as long- term performance and the economic aspect of the equipment. In recent years, the use of commercial CFD codes for analyzing the flow and thermal fields in industrial applications has been dramatically increased due to their advanced computational capacity and analytic algorithm. In addition, many optimization techniques have been developed to obtain the optimal solutions. Therefore, much attention has been paid to the optimization of fluid/thermal systems by combining the CFD and optimization algorithm

The objective of this work is to present numerical results for flow in a curved duct of elliptic cross-section. The thermally developing laminar forced-convection flow and heat transfer characteristics in elliptic tubes with four longitudinal internal fins is numerically investigated in this article via the boundary-fitted coordinate system. The elliptical tubes are maintained at a uniform heat flux peripherally. Since the fins are considered to be continuous and of same thickness, the results presented are in terms of isotherms, variation of bulk temperature and Nusselt number in the entire thermal region of the elliptic duct for various values of relative fin heights. Also studied and graphically illustrated is the effect of fin geometry with same perimeter in the elliptic duct with internal fins on the fully developed and developing heat transfer characteristics.

II. LITERATURE REVIEW

There are number of investigation available in the area of finned tube heat exchanger.

Kern and Kraus [1] in 1972, have studied longitudinal, radial and pin fins with straight profile as main fin geometries in external finned heat exchange. Kundu and Das [2] in 2002, later proposed straight taper fins with better heat transfer coefficients to weight ratio. It has been seen that the ratio of base to tip heat transfer coefficient has a profound effect on the fin performance. In general, the efficiency of all the three types of fins increases with the increase of heat transfer coefficient. However, the rate of increase is higher in the intermediate range of heat transfer coefficient. For a given fin volume the rate of heat dissipation increases also from an optimally designed fin for higher values of heat transfer coefficient. Micro fins offer effective heat transfer and are more suitable as better heat exchanging medium than twisted tubes. Smit and Meyer [3] IN 2002, performed an experiment to compare three different (micro fins, twisted tapes and high fins) heat transfer enhancement methods to that of smooth tubes using the geotropic refrigerant mixture R-22/R-142b. The results corroborated the effectiveness of micro fins over twisted tubes. The fins existing in annuli affect the flow pattern, temperature distribution and heat transfer rate. Arslanturk C [4] in 2004 , For non-symmetric convective boundary conditions, the solution of two dimensional heat transfer equation is obtained analytically ,which helps in to obtaining temperature profile in a finned tube He concluded that. There always an optimum fin ratio of a fin with an insulated tip. For an annular fin with heat transferred the tip, first a minimum and then maximum heat dissipation is obtained on increasing the fin ratio. The fin ratio of an optimum fin decrease with increasing heat transfer coefficient at the fin tip. The thermal analysis in the paper also be employed to analysis the fin with variable base temperature. For a given volume, the optimized variables like the fin thickness and ratio of outer radius to inner radius of a fin have been determined.

Mon and Gross [5] in 2004, examined the effects of fin spacing on four-row annular-finned tube bundles in staggered and in-line arrangements. The heat transfer and pressure drop for various fin spacing were computed using FLUENT. According to the flow visualization results, the boundary layer developments and horseshoe vortices between the fins are found to be substantially dependent on the fin spacing to height ratio and Reynolds number. Akkoca and Tutar [6] in 2005, studied time-dependent laminar flow over single e and multi-row plate fin-and-tube heat exchangers. The effects of fin spacing, Reynolds number (300-7000), number of tube rows, and tube arrangement on the heat transfer and flow characteristics were studied.

Malekzadeh et al. [7] in 2007, optimized the shape of non-symmetric annular fins based on two nonlinear dimensional heat transfer analysis. The thermal conductivity of the fin is considered to vary as a linear function of the temperature. The effects of a convective–irradiative condition at the fin tip and effective convective condition at the fin base are considered. The optimization of fins with uniform and step cross-sections is investigated They compared the results obtained through both differential quadrature method and finite difference method. Brien and Sohal [8] in 2005, investigated experimentally forced convection heat transfer in a narrow rectangular duct fitted with a circular tube and/or a delta-winglet pair. They obtained a comparison of local and average heat transfer distributions for the circular tube with and without winglets and found at higher Reynolds numbers the enhancement level is close to 50%. Moreover, the combined effect of heat transfer rate and pressure drop depends on the enhancement of baseline winglet pair. Aziz and Fang [9] in 2010, proposed an alternate solution for the energy equations for one-dimensional steady conduction in the longitudinal fins of three different cross sections namely rectangular, trapezoidal, and concave parabolic profile. The temperature and the heat flux is specified at the base of the fin and the temperature distribution in the fins are provided for these conditions. While fins offer solutions to augment heat exchange problems, they also result in pressure drop of flow. Experimental investigations show that the heat transfer characteristics and flow friction is greatly influenced by the fin spacing, size and shape of the fin. D.Taler [10] in 2007, accomplished a numerical study to determine heat transfer coefficient in cross flow heat exchangers with extended heat exchange surfaces. Heat transfer coefficient on the liquid and air-side were examined using a nonlinear regression method. The exit temperature of the fluid leaving the heat exchanger was determined using the analytical model of the heat exchanger. The developed method in this study was suggested to be used in various types of heat exchangers. Experimental investigations show that the heat transfer characteristics and flow friction is greatly influenced by the fin spacing, size and shape of the fin.

Bilir L, Ozerdem B [11] in 2010, investigated effects of vortex generators on heat transfer and pressure drop characteristics on fin-and-tube heat exchanger with three different types of vortex generators. The cumulative effect of vortex generators offers a better heat exchange solution with moderate drop in pressure. Hussein and Salman [12] in 2007, conducted an experiment to study pressure drop and heat transfer characteristics of water flow in a horizontal tube with or without longitudinal fins and found that heat transfer enhancement is 16 times more and friction factor is 4.5 times more of a finned tube than a bare tube having Re < 4000. The fins existing in annuli influence the flow pattern, temperature distribution and heat transfer rate. Zhu Y [12], focused on model and simulation of four types of basic fins (plain fin, strip fin, offset fin, perforated fin, wavy fin) considering fin thickness, thermal entry effect and end effect for 132.3<Re< 1323. For determining the values of heat transfer and pressure drop, the vortex generators were placed at four different locations on the fin surfaces. After the determination of the best location for a vortex generator of each type, two different models with all three types of vortex generators are created and analyzed numerically. The investigation of the cumulative effect of three different vortex generators is the novelty of the study. It is observed that the heat transfer rate is increased with the marginal increment in the pressure drop, when the three vortex generators together were used. They also verified the experimental data with the simulation model. Ha MY, Kim JG [13] in 2004, presented the solution for the natural convection in internally finned horizontal annuli which he obtained by using a numerical simulation of time-dependent and two-dimensional governing equations. The fins present in annuli affects the temperature distribution, flow pattern and heat transfer rate. The variation of the fin configuration decelerates or accelerates the natural convection effect compared to those of smooth pipe. The effect of fin configuration number of fin and ratio of annulus gap width to inner cylinder radius and demonstrated by distribution of velocity vector, isotherms and stream line.

Tatsumi K [14] in 2010, examined experimentally and numerically parallel cut fin array for the purpose of enhancing the fluid mixing and heat transfer and also reducing the pressure loss. They found that the heat transfer coefficient remained almost constant in the plain-fin case but increased in the cut-fin case. Sakalis and Hatzikonstantinou [15] in 2001, studied numerically the effect of non-dimensional fin height (fin height/ tube radius) on friction numbers and found that the friction factor and Nusselt number are directly related with the fin height and reached critical value at 0.85 and 0.73 respectively. The use of computational methods has been done to predict the performance of heat exchanger for both external and internal fins under different boundary conditions. Haldar SC, Kochhar GS [16] in 2007, numerically analyzed laminar free convection about a horizontal cylinder with external longitudinal fins of finite thickness and suggested that among the various fin parameters, thickness plays the most influential role in determining the performance of the fins. Duplain and Baliga [17] in 2009, had formulated and demonstrated a computational methodology for optimization of fin shapes of steady, laminar, fully-developed forced convection in a straight duct of circular cross-section, with air as the fluid and non-twisted, uninterrupted, longitudinal internal fins made of steel, aluminum, and copper, Liu and Jensen.[18] in 2001, has investigated of turbulent flow and heat transfer characteristics of an internally rectangular finned tube. They concluded that the effects of fin profile, fin number, fin width and fin height has a significant effect on Nusselt number and friction factor.

S. K.Rout, D.N.Thatoi [19] in 2012, accomplished parametric study by using a computational fluid dynamics (CFD) program named FLUENT to evaluate the performance of the heat exchanger with different fin numbers, sizes and shapes. The results endowed from the study for a steady and laminar flow of fluid under mixed flow convection heat transfer condition shows that there exist an optimum number of fins to keep the pipe wall Temperature at a minimum. The wall temperature optimises at a particular fin height beyond which, it is insensitive to any height variation. Moreover, amongst the three different shapes considered for fin, results represent that wall temperature is found to be minimum for triangular shaped fins, compared to T-shaped and rectangular fins. It is also seen from the present examination the top wall temperature distribution is higher compared to the bottom wall due to buoyancy effect.

Harun and Stephen [20] in 2013, performed numerical investigation of annular finned tubes by using the computational fluid dynamics (CFD) software ANSYS FLUENT. The effects of fin height, fin spacing, fin material, and fin thickness on the overall heat transfer coefficient and pressure drop were determined for a single row of finned tubes in cross flow. As fin height increased, the predicted overall heat transfer increased. The magnitude of the increase in overall heat transfer was larger for smaller fin spacing and also concluded that the effect of the fin thickness was less significant than the fin spacing and fin height. Hossain Nematic and Moghimi [21] in 2014, studied turbulent flow passing over a four-row finned tube heat exchanger by using nine different turbulent models. Annular fin has a complex geometry and as a result, very complex phenomena such as flow separation, horseshoe vortices, generated wakes, etc. may be observed and shows that the numerical solution may be used as a new tool to visualize flow passing a tube bundle. In spite of some discrepancy between results, it is still a reasonable method in comparison with the experimental methods.

III. GOVERNING EQUATION

The governing equation used natural convection heat transfer problem for the solution.

Continuity equation

The equation states that mass of fluid is conserved

The rate of increase of mass in fluid element = net rate of flow of mass into fluid element

For time dependent 3-D equation is

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0$$

For 2-D, incompressible and steady flow equation is

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$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

Momentum equation

Momentum equations are based on newton's second law which states that the rate of change of momentum equals the sum of forces on the fluid particle. The time dependent and 3-D momentum equation in X- direction is

$$\frac{\partial(\rho u)}{\partial t} + u\frac{\partial(\rho u)}{\partial x} + v\frac{\partial(\rho v)}{\partial y} + w\frac{\partial(\rho w)}{\partial z} = -\frac{\partial p}{\partial x}$$
$$+\mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) + \rho f_x$$

In Y–axis:

$$\frac{\partial(\rho v)}{\partial t} + u\frac{\partial(\rho v)}{\partial x} + v\frac{\partial(\rho v)}{\partial y} + w\frac{\partial(\rho v)}{\partial z} = -\frac{\partial p}{\partial x}$$
$$+\mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) + \rho f_y$$

In Z – axis:

$$\frac{\partial(\rho w)}{\partial t} + u\frac{\partial(\rho w)}{\partial x} + v\frac{\partial(\rho w)}{\partial y} + w\frac{\partial(\rho w)}{\partial z} = -\frac{\partial p}{\partial x}$$
$$+\mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) + \rho f_z$$

Where f_x ,f_y ,f_z are the body forces in X ,Y and Z direction.

Energy equation for fluids

$$\rho c_p\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\right) = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right)$$

Diffusion equation

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = 0$$

Equations and dimensionless number used in convection problem

$Q = hA\Delta T$, Newton law of cooling Nu = $\frac{hd}{k}$, Pr = $\frac{\mu c_p}{k}$, Gr = $\frac{l^3 g\beta\Delta t}{\nu^2}$, $\beta = \frac{1}{\nu}(\frac{\partial V}{\partial t})_p$, Ra = Gr* Pr , Nu = c (Gr * Pr)^m

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IV. FIGURES

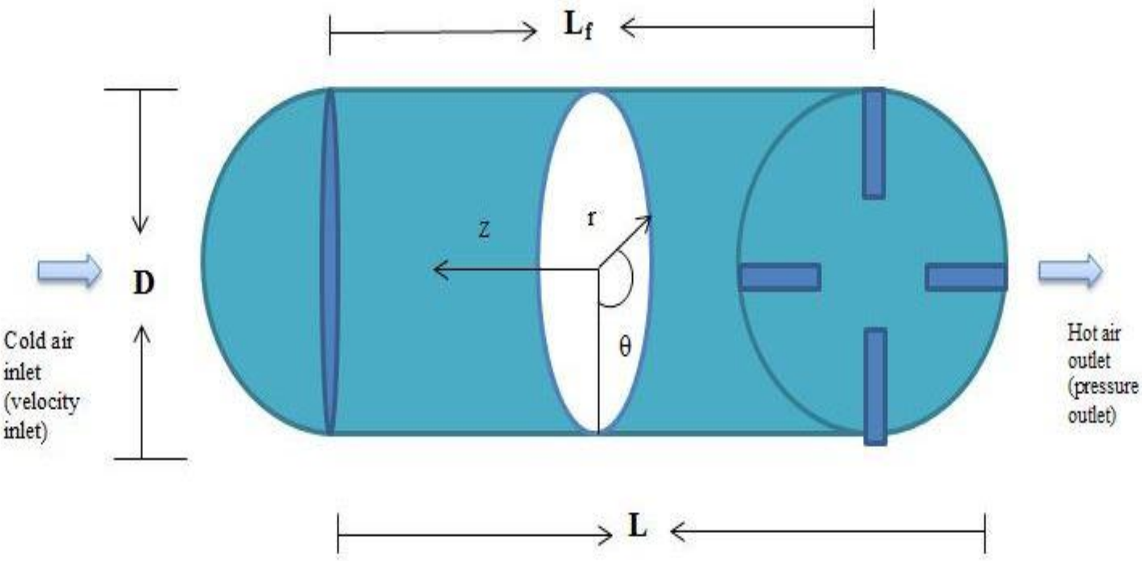

Figure 1: Schematic diagram of internally finned tube and the boundary condition applied to it.

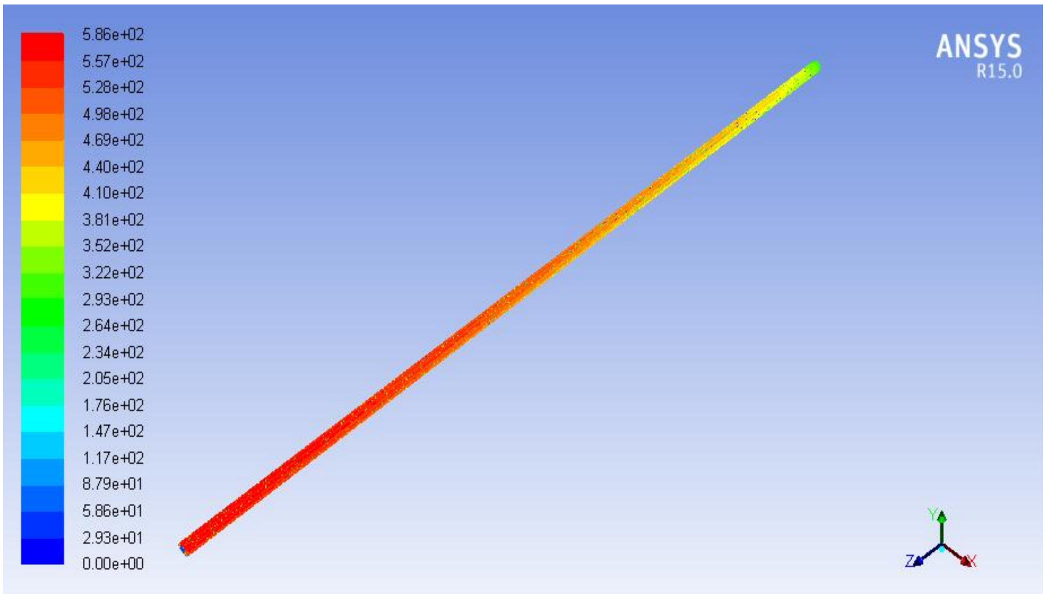

Figure 2: Wall temperature profile for of finned tube

V. CONCLUSION

The present work gives a comprehensive overview of number of research papers related to CFD application in finned tube heat exchanger. Conventional methods used for the design and development of heat exchangers are largely tedious and expensive in today's competitive market. CFD has emerged as a cost effective alternative and it provides speedy solution to heat exchanger design and optimization. It has been concluded that fin geometry and number of fins are the key factor for optimization the performance of finned tube heat exchanger.

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