Comparison of CFD and Experimental Performance Results of Relation Between Nusselt Number and Reynolds Number in the Analysis of Pin Fins with Different Geometries.

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Abstract

The advantages of numerical modelling compared with experimental studies (e.g. reduced cost, easy control of the variables, high yield etc.) are well known. Theoretical studies where experimental validation is also presented provide an important added value to numerical investigations. In the present paper, CFD and experimental performance results the analysis of Pin Fins with Different Geometries are presented and compared. The Different Geometries were achieved by converting the external periphery of the simple pin into helically grooved and square threaded profiles. Reynolds number is chosen based on the work in Performance analysis of a heat exchanger having perforated square fins. Once an optimum shape of the pin fins is chosen, the flow velocity is varied without changing any other parameters. This arrangement results in a variation in Nusselt number and friction factor while keeping the pin fin height and (Sy/D) ratio constant. The physical model of the project is built according to the experimental model. It consists of three different sections viz. inlet section, test section, and exit section. The fluid and pin fins were modelled as a 'conjugated' computational domain to solve the problem. To calculate the reading, the pin fin cross section in the stream wise direction is modelled, and applied to the domain boundary. The graphs were then plotted for the dependability of Nusselt number on the Reynolds number, and were compared on the basis of results obtained from CFD and actual experimental setup.

INTRODUCTION

Heating of an element under various working applications is a major problem for today's engineering devices therefore rapid heat removal from heated surfaces and reducing material weight and cost has become a major task for design of heat exchanger equipment's. Development of super heat exchanger requires fabrication of efficient design techniques to exchange great amount of heat between surfaces such as external surfaces and ambient fluid. Extended surfaces (fins) are widely used in heat exchanging devices for the purpose of increasing the heat transfer between a primary surface and the surrounding fluid. The compactness of electronic devices leads to smaller size and formation of high amount of heat. Also the globally advance technology in development of high power electronic components and the demand of greater functionality larger storage space and faster rates of information transfer for handy electronic devices have increased significantly resulting into compactness of equipment size and lead to formation of large amount of heat which reduces their life cycle. The design of heat sink device is established on the criterions of maximizing heat dissipation rate. Pin fins provided on a heating surface increase the heat dissipation rate and may cause turbulent mixing of flow results in more heat transfer

EXPERIMENTAL SET UP

The experimental setup is prepared and observations are noted down. The experimental set up consist following parts,1)Rectangular Tunnel 2)Heater 3)Test Plate 4)Data Collection Unit

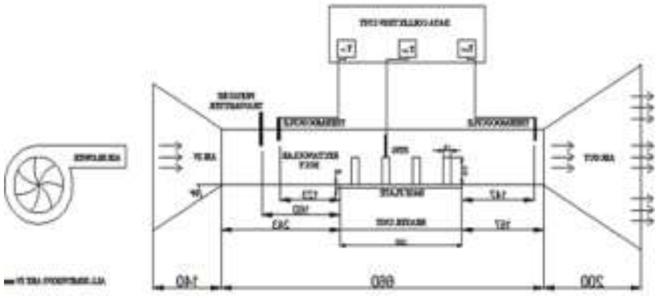

Fig 1: Experimental Set-up

3. COMPUTATIONAL ANALYSIS

CFD has grown from a mathematical curiosity to become an essential tool in almost every branch of fluid dynamics. It allows for a deep analysis of the fluid mechanics and local effects in a lot of equipment. Most of the CFD results will give an improved performance, better reliability, more confident scale up, improved product consistency, and higher plant productivity (Bakker et al. 2001). Some design engineers actually use CFD to analyze new systems before deciding which and how many validation tests need to be performed.

Pin Fin Geometry -circular pin, square threaded & helically grooved pin fins are designed and test is conducted. In the current study the pins all have the same diameter. The diameter of the circular pin is 15 mm. The Square Threaded pin has a major diameter 15 mm and core diameter 9 mm and pitch 6mm (3 x 3 mm square thread) and helically grooved pin fin has a diameter of 15 mm with Sy/D ratio of 3.417.

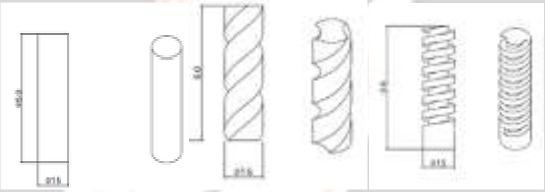

Fig 2: Different Pin Geometries

The constant inter pin fin spacing and staggered arrangement gives constant number of pin fins located at base plate. The table-1 gives the details of number of pin fins and base plate used for experimental performance and setting the numerical control parameters. Advanced CFD software packages have the program to carry out the following operations: defining a grid of points, also volumes or elements, defining the boundaries of the geometry, applying the boundary conditions, specifying the initial conditions, setting the fluid properties

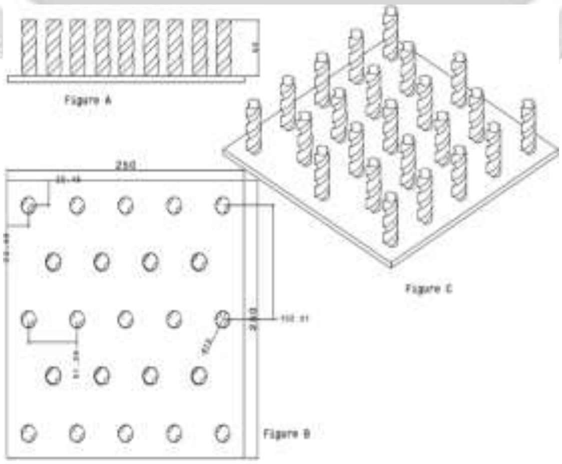

Fig 3: Staggered Helical Pin Fin Setup

Simulation of pin fin model

A commercial finite volume analysis package called FLUENT is used to perform numerical analysis on the model. The models are constructed using ICEM software, and the models data were passed to the fluent software for various analyses. The governing equations solved are the Navier Stokes equations combined with the continuity equation, the energy equation, and constitutive property relationships as described in the previous section. Once the analyses were completed, the resulting data were easily evaluated by the Fluent postprocessor.

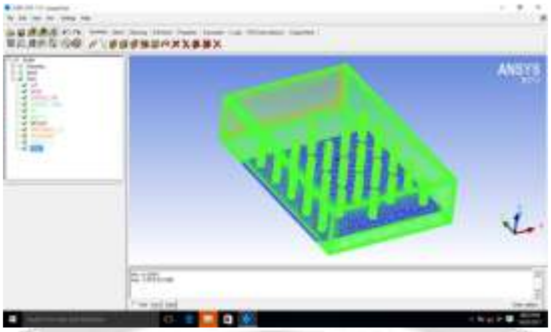

Figure 4: Meshing of rectangular tunnel with square thread pin fins in CFD

Reynolds Number:

The Reynolds number (Re) is an important dimensionless quantity in fluid mechanics used to help predict flow patterns in different fluid flow situations. It has wide applications, ranging from liquid flow in a pipe to the passage of air over an aircraft wing. The Reynolds number is used to predict the transition from laminar to turbulent of flow, and used in the scaling of similar but different sized flow situations, such as between an aircraft model in a wind tunnel and the full-size version. The predictions of onset of turbulence and the ability to calculate scaling effects can be used to help predict fluid behaviour on a larger scale, such as in local or global air or water movement and thereby the associated meteorological climatological effects.

The Reynolds number is the ratio of inertial forces to viscous forces within a fluid which is subjected to relative internal movement due to different fluid velocities, in what is known as a boundary layer in the case of a bounding surface such as the interior of a pipe. A similar effect is created by the introduction of a stream of higher velocity fluid, such as the hot gases from a flame in air. This relative movement generates fluid friction, which is a factor in developing turbulent flow. Counteracting this effect is the viscosity of the fluid, which as it increases, progressively inhibits turbulence, as more kinetic energy is absorbed by a more viscous fluid. The Reynolds number quantifies the relative importance of these two types of forces for given flow conditions, and is a guide to when turbulent flow will occur in a particular situation. This ability to predict the onset of turbulent flow is an important design tool for equipment such as piping systems or aircraft wings, but the Reynolds number is also used in scaling of fluid dynamics problems, and is used to determine dynamic similitude between two different cases of fluid flow, such as between a model aircraft, and its full size version. Such scaling is not linear and the application of Reynolds numbers to both situations allows scaling factors to be developed.

The Reynolds number is defined based on the hydraulic diameter considering pin fin as.

$$R_e = \frac{U_{max} D_h}{\vartheta}$$

Where U_{max} is the maximum flow velocity in a channel embedded with a pin fin array based on hydraulic diameter and ϑ is the kinematic viscosity of the Flowing fluid.

Calculation of Nusselt Number

In heat transfer at a boundary (surface) within a fluid, the Nusselt number (Nu) is the ratio of convective to conductive heat transfer across (normal to) the boundary. In this context, convection includes both advection and diffusion. Named after Wilhelm Nusselt, it is a dimensionless number. The conductive component is measured under the same conditions as the heat convection but with a (hypothetically) stagnant (or motionless) fluid. A similar non dimensional parameter is Biot Number, with the difference that the thermal conductivity is of the solid body and not the fluid.

A Nusselt number close to one, namely convection and conduction of similar magnitude, is characteristic of "slug flow" or laminar flow. A larger Nusselt number corresponds to more active convection, with turbulent flow typically in the 100 to 1000 range. The convection and conduction heat flows are parallel to each other and to the surface normal of the boundary surface, and are all perpendicular to the mean fluid flow in the simple case.

The Nusselt number is calculated for each test configuration. The relation between Nusselt number and Reynolds number for all pin fin configurations is calculated. The data indicate that the Nusselt number can be correlated with the Reynolds number as a power law function. Moreover, it is also apparent that the Nusselt number is sensitive to flow regime and, clearly, this sensitivity is greater for square threaded fins than $N_u=(h*D_h)/k$

$N_{uavg}=(h_{avg*}\,D_h)/k$

Nusselt number based on the projected area will replicate the effect of the difference in the surface area as well as that of the disturbances in the flow due to fins on the heat transfer. But Nu based on the total area will reflect the result of the flow disturbances only. In this study, heat transfer improvement Characteristics can be determined by using Nu based projected area.

RESULTS AND DISCUSSION

The observations are noted down for Computational as well as for experimental results for three different shapes, cylindrical, square threaded and helically grooved pin fin at different Reynolds number ranging from 13500 to 42000. The Clearance ratio (C/H)=1 and (Sy/D)= 3.412 inter pin fin distance. It is summarised as follows

The Nusselt number is calculated for each test configuration. The Figure 5 shows the computational results between Nusselt number and Reynolds number for all pin fin configurations, result shows that the average Nusselt number increases with increase in Reynolds number as high Reynolds number produces the turbulence. Average Nusselt number reaches maximum value at 42000 Reynolds number and gives maximum value for square thread pin fins.

The Table 1 shows the experimental results between Nusselt number and Reynolds number for all pin fin configurations, result shows that the average Nusselt number increases with increase in Reynolds number as high Reynolds number produces the turbulence. Average Nusselt number reaches maximum value at 42000 Reynolds number and gives maximum value for square thread pin fins.

Parameter	***Re***	***Uin***	***Cylindrical***		***Helically Grooved***		***Square Threaded***	
			Exp	***Comp***	***Exp***	***Comp***	***Exp***	***Comp***
havg	13500	2.40214	62.7451	64.2585	69.5652	65.1097	80	78.154
	27750	4.93773	83.1169	85	94.1176	91.62	114.286	112.25
	42000	7.47332	112.281	109.356	123.077	120.743	142.222	139.256
Nuavg	13500	2.40214	205.246	210.197	229.441	214.746	272.586	266.297
	27750	4.93773	271.885	278.045	310.421	302.183	389.409	382.473
	42000	7.47332	367.283	357.716	405.935	398.237	484.598	474.491

Table 1: Details of Average Nusselt Number with different Reynolds Number

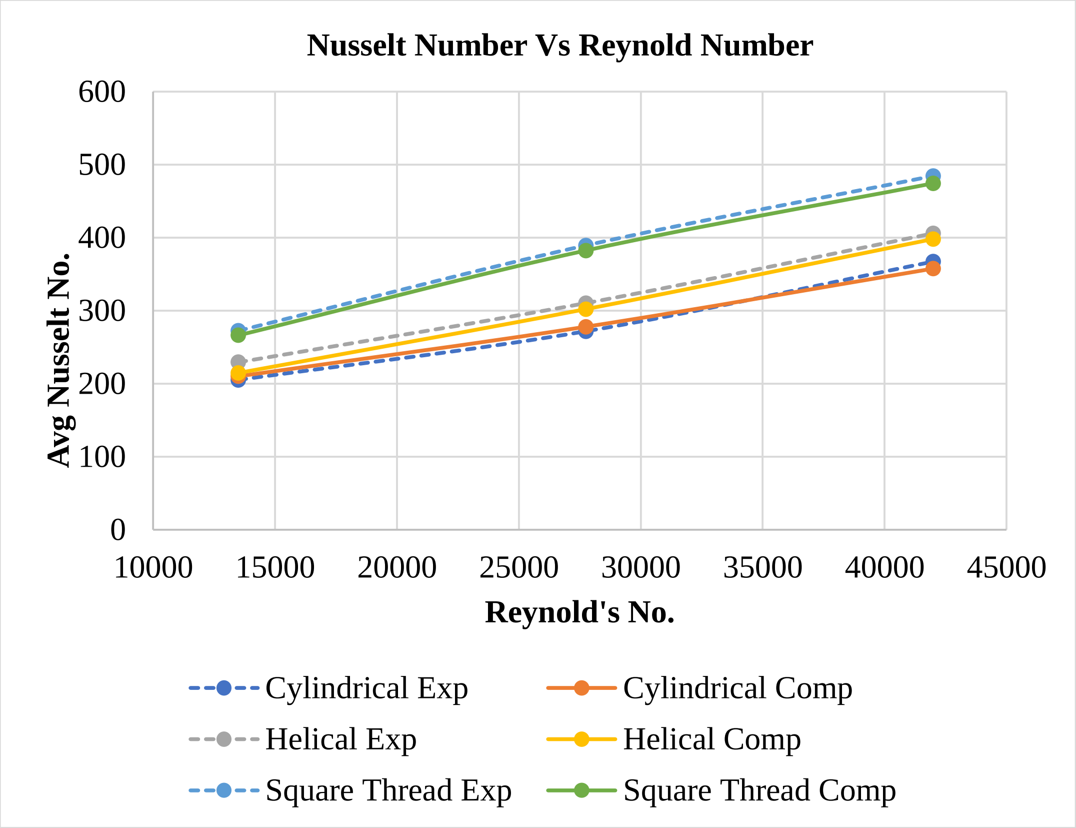

Figure 5 : Experimental and Computational results of $N_{uavg}\ Vs\ R_e$

The Figure 5 shows the combined computational and experimental results between Nusselt number and Reynolds number for all pin fin configurations, the result shows that there is a variation in computational and experimental results about 11%. The data indicate that the Nusselt number can be correlated with the Reynolds number as a power law function. Moreover, it is also apparent that the Nusselt number is sensitive to flow regime and, clearly, this sensitivity is greater for square threaded fins than for helically grooved and cylindrical fins. These observations led to the conclusion that during the flow regime change, there is a sharp increase in Nu for all configurations. The square threaded pin fin has the maximum Nu among all morphologies. The table 4.2 shows the details of average heat transfer coefficient and average Nusselt Number with different Reynolds number and inlet velocities.

In combined experimental and computational work, the effects of different geometrical fin shape on heat transfer characteristics are investigated in rectangular cross section duct. The fluid flow phenomenon is further examined with CFD analysis in Ansys Fluent software.

1. The average increase in Nusselt number of square threaded (32.80%) and helical grooved pin fin (11.78%) is greater than that of circular pin fins as square threaded geometry provides more blockages to fluid flow
2. Nusselt number increases with increase in Reynolds number as it produces more turbulence.

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