NUMERICAL AND EXPERIMENTAL INVESTIGATION OF STAGGERED INTERRUPTED FIN ARRANGEMENT IN A NATURAL CONVECTION FIELD

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Abstract— Steady-state external natural convection heat transfer from vertically-mounted rectangular staggered interrupted fins is investigated numerically and experimentally. FLUENT software is used to develop a 3-D numerical model for investigation of fin interruption effects. A custom-designed testbed was developed and continuous, inline interrupted and staggered interrupted aluminum alloy heatsinks with various geometric dimensions are machined and tested to verify the theoretical results. A comprehensive experimental and numerical study is performed to investigate the effects of staggered interruptions. Our results show that adding staggered interruptions to vertically-mounted rectangular fins can enhance the thermal performance considerably than the inline interrupted fins. The results of this work can be used to improve thermal performance of enclosures in a variety of electronics, power electronics and telecommunication applications.

Keywords— Experimental study, Fin geometry, Heat sinks, Natural convection, Numerical Analysis, Staggered interruptions, Thermal Performance.

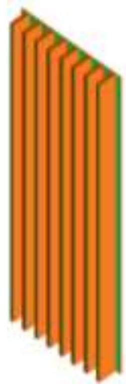
INTRODUCTION

The widely preferred method for cooling electronic and telecommunications devices is passive cooling since it is cost effective and reliable solution. It doesn't need costly enhancing devices. Effectively finned Heat sinks are generally used to enhance the heat transfer rate. Here in this work the focus is staggered interrupted fins. The objective of this work is to enhance the heat transfer rate by providing staggered interruptions. The staggered interruptions are provided on the heat sink. Providing fin interruptions results in considerable weight reduction that can lead to lower manufacturing cost. The staggered interruption pattern improves the thermal performance of heat sink compare to inline interruption pattern. The following paragraphs provide a brief overview on the pertinent literature.

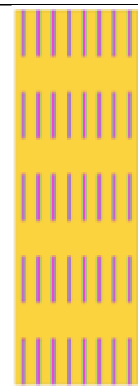
Mehran Ahmadi et al [2] shows that adding inline interruptions to a vertical wall can enhance heat transfer rate up to 16% and reduce the weight of the fins, which in turn, lead to lower manufacturing and material costs. Golnoosh Mostafavi,et al [1] shows that adding interruptions to vertically-mounted rectangular fins can enhance the thermal performance considerably and that an optimum fin interruption exists. A new compact correlation is proposed for calculating the optimum interruption length. G. A. Ledezma et al [3] documents the geometric optimization of an assembly of staggered vertical plates that are installed in a fixed volume and showed that the geometric arrangement of vertical staggered plates in a fixed volume can be optimized such that the thermal conductance between the assembly and the surrounding fluid is maximized. G Guglielmini et al [4] investigated the heat transfer by natural convection and radiation between an isothermal vertical surface, having a staggered array of discrete vertical plates of finite thickness, and the surroundings and showed that for the particular geometry taken into account, the convective and radiant components yield a more efficient heat transfer than that obtained from fins made up of U-shaped vertical channels of the same bulk volume.

PROBLEM DEFINITION

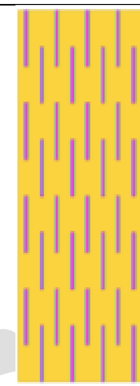
The present work was based on the research carried out by Mehran Ahmadi et al [1] on the rectangular fins for heat removal from a heat source using natural convection. Their work included the experimental and 2-D numerical analysis for the continuous and interrupted fins of inline arrangement. The authors had extensively studied the effects of interruptions on heat transfer rate. However, the present study focuses on staggered interrupted fin arrangement and investigates its impact on the overall system performance by both the numerical and experimental approaches.



Continuous Fins Arrangement



In-line interrupted Fins Arrangement



Staggered interrupted Fins Arrangement

Figure 1 Considered Heat sink Geometries

EXPERIMENTAL SET-UP

Figure 2 Experimental Setup

The tested heatsinks are made from 6063-T5 aluminium alloy with a thermal conductivity of 130 W/m K and emissivity of 0.09 at 20 ^{0}C. A new custom-made setup is designed for measuring natural convection heat transfer from heatsinks as shown in Fig. 2. The set-up includes an enclosure made of wood which is insulated by a layer of dense insulation foam. During the experiments, in addition to the power input to the electric heater, surface temperatures are measured at various locations at the backside of the baseplate. Electrical power is supplied through an AC power supply from Dimmerstat . The voltage and the current are measured to determine the power input to the heater. Six thermocouples are adhered to the back side of the heatsink to prevent disturbing the buoyancy driven air flow. One more thermocouple is used to measure the ambient temperature during the experiments. Temperature is measured at six different vertical positions in order to observe the temperature variation over the heatsink. The average of these six readings is taken as the base plate mean temperature. Since fins height is short, maximum fin height is 17 mm, fins are assumed to be isothermal. The system is allowed to reach a steady-state condition for each power input level, and then temperatures and power are recorded. The steady-state condition is ensured by observing the rate of changes in all thermocouples. For each of the three heatsinks, the experimental procedure is repeated for different power inputs. Recording the temperature values in time, the point where the temperature difference in a 10 min time span became less than the accuracy of the thermocouples, were considered as steady state conditions.

CFD MODELING

In the experiment studies, the fins were placed on a base plate of dimension 305 X 101 mm. The set-up was placed in a room with static conditions. The similar conditions were created for the CFD simulations. As shown in the Figure 3, the fin arrangement was placed in the middle and the bounding box was created. The boundaries of this computational domain were placed sufficiently away from the fins to avoid any flow-reversal during the numerical simulations. The CFD meshing, computational domain discretization was performed using ANSYS ICEM CFD, a well-known commercially available pre-processor. Combinations of tetrahedral and triangular prism elements were used. Due to the high temperature difference between the fin surfaces and the surroundings, the buoyancy currents will be dominant. The triangular prism layers generated surrounding the fin surfaces would help to numerically resolve the thermal boundary layers and this result in the improved accuracy in the overall heat transfer rate predictions.

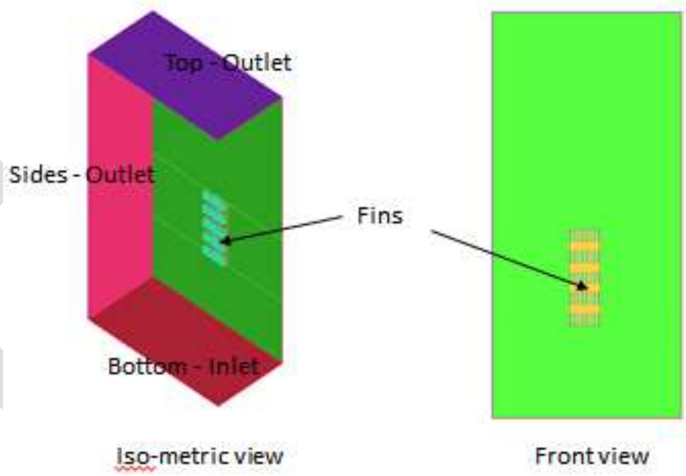


Figure 3 CFD Model

Steady state CFD formulation was employed to model this problem in ANSYS FLUENT. The gravitational forces that were acting in negative Y direction, in this case, were activated. In the reference work [1], the heat transfer from the fin tip areas were neglected. In order to maintain the consistency, the fin tip heat transfer from the simulations was not considered for the analysis. The fins and base plate surfaces were modeled using the Wall boundary conditions. At these walls, the No-Slip and Iso-Thermal conditions were imposed. The radiation effects from the fin surfaces to the atmosphere were not modeled. The bottom surface was specified as pressure-inlet boundary condition to allow the fluid motion inside the domain. The remaining surfaces were specified as outlet boundary conditions. The accuracy of the CFD simulations would depend upon the selection of the spatial discretization schemes. Second order spatial discretization schemes for the Pressure, Momentum and Energy were chosen for the simulation while Green-Gauss Node based scheme was used for the gradient calculations.

CFD SIMULATION RESULTS

In order to compare the results from Mehran et al [1], a validation study was carried out.

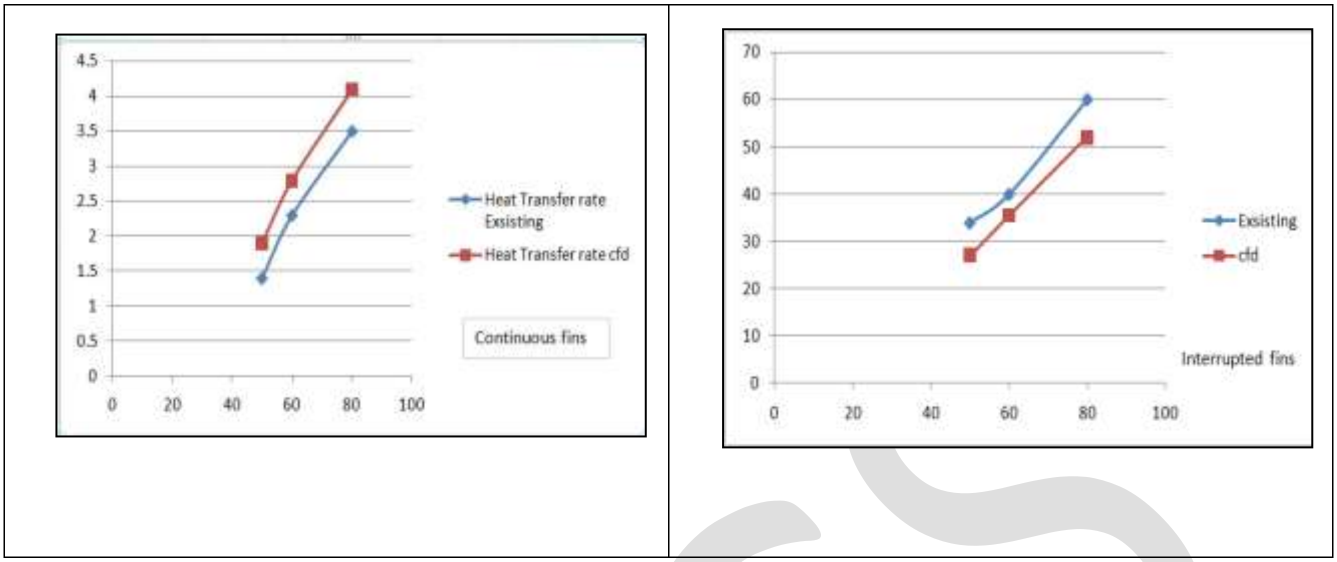
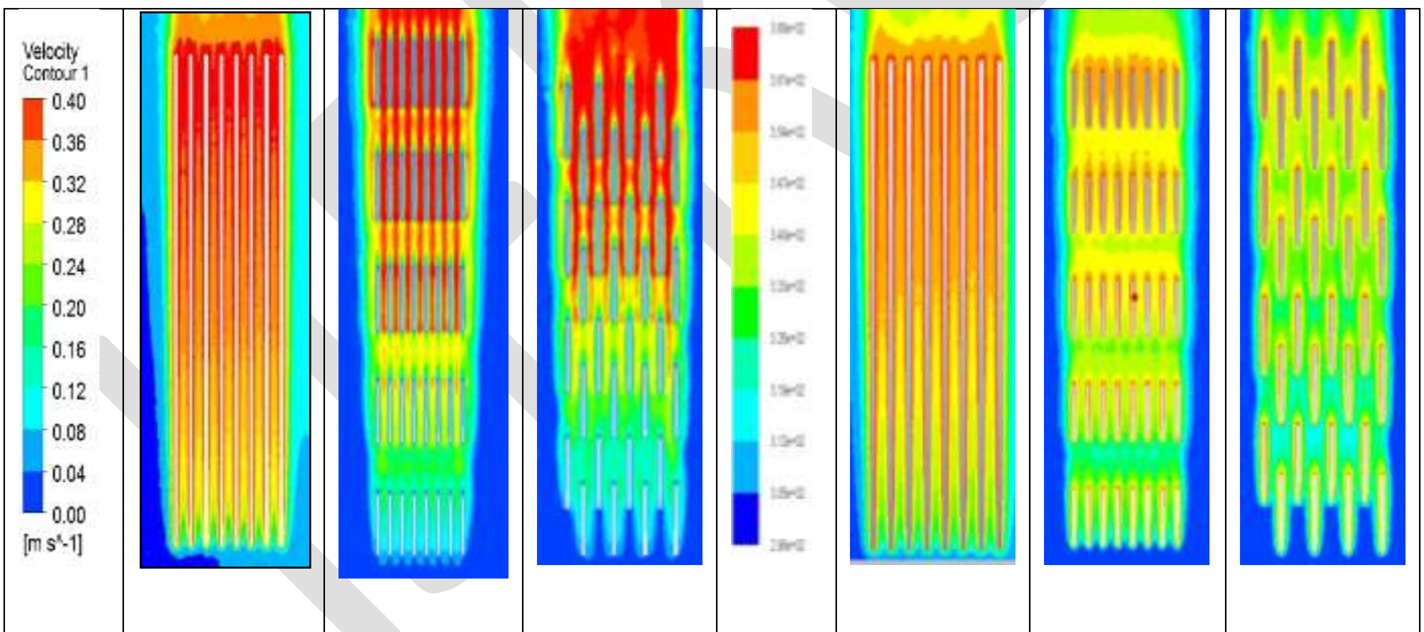


Figure 5 Validation of inline interrupted fins

The results from the CFD simulations by the authors and by Mehran et al were plotted in figure 5. In the present study, the heat transfer rate for the continuous fin arrangement was over-predicted in comparison to the work by Mehran et al. However, in the case of interrupted fins, the heat transfer rate was slightly under-predicted to the experimental results from Mehran et al. However, the variation from the reference journal was found to be less than 10%. In the next phase of the work, the CFD simulations for the actual geometrical configurations were carried out. The staggered fin arrangement was configured as explained in the following image.The CFD simulation settings that were discussed earlier section had been applied for these simulations and the results are discussed below.



Velocity Contours for the dT = 70 C | Temperature Contours for dT = 70 C

Figure 4 Velocity and Temperature contours for thr dT=70 ^{0}C

The contour plot for the flow velocity and the flow temperature at the mid-height of the fin was generated to study the flow and thermal characteristics of the system. The flow velocity was observed to be higher in the case of staggered fin arrangement as compared to the other fin arrangement system. Such fluid flow patterns would also result in enhanced heat transfer rate from the surfaces. The temperature contours in figure indicate high temperature zones at the top region of the fins in the continuous fin arrangement. While in the staggered fin arrangement, the flow temperatures around the fins were much less compared to the continuous fins arrangement. The flow turbulence created by the staggered arrangement enhances higher fluid velocity which in turn improves the heat transfer rate from the surfaces.

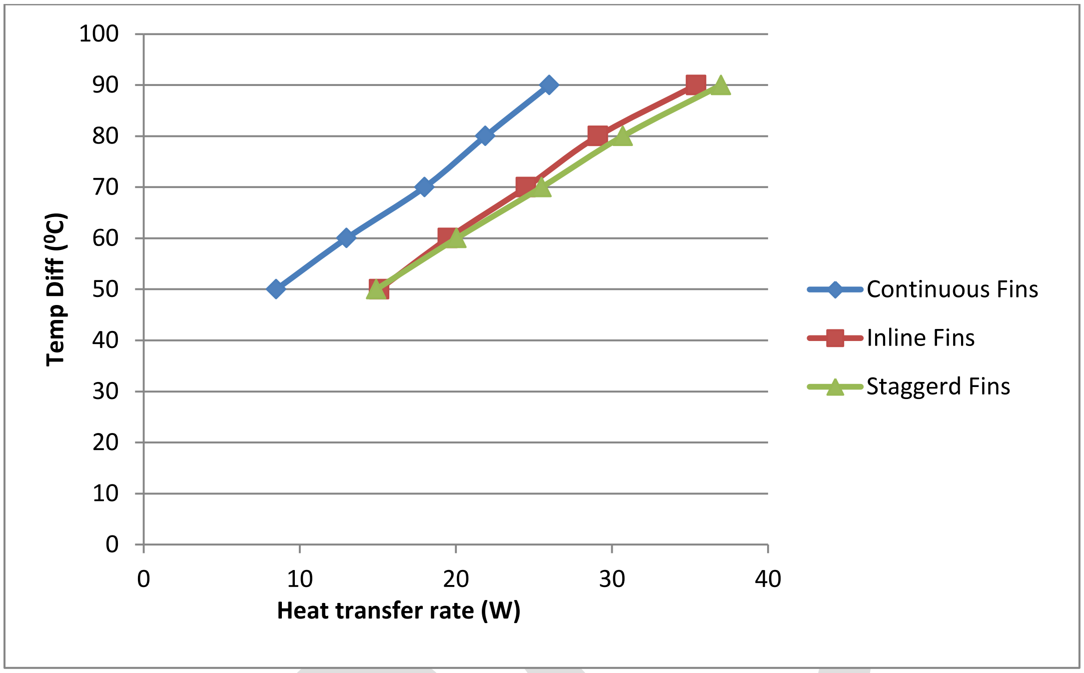


Figure 5 CFD results of Heat transfer rate continuous, inline, and staggered interrupted fins.

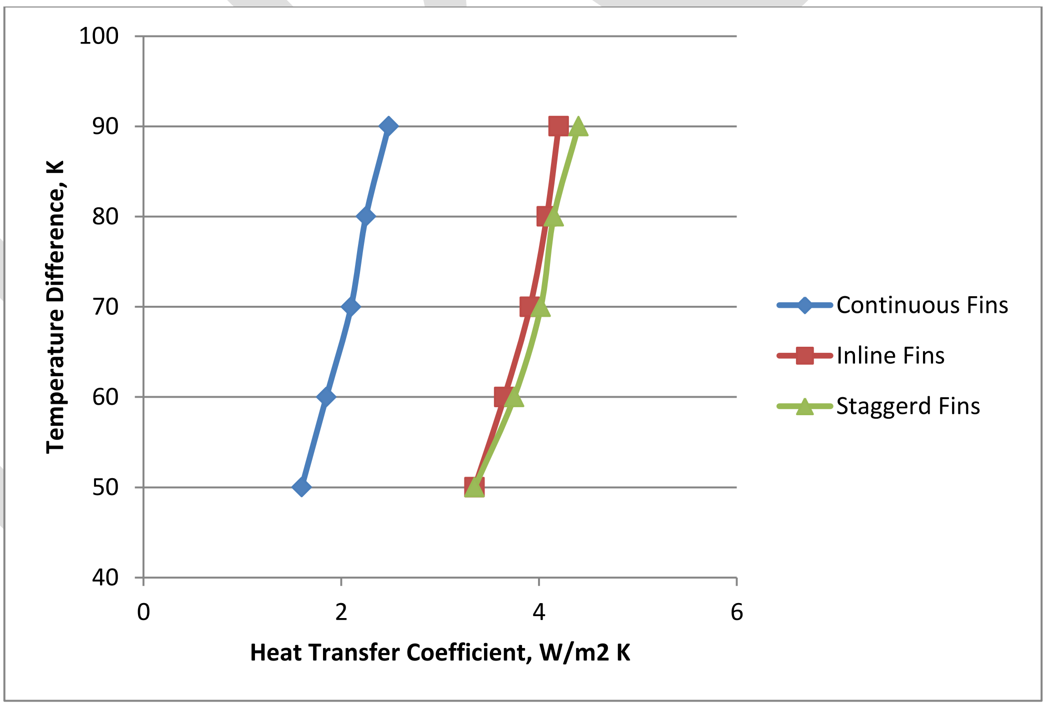


Figure 6 CFD results of Heat transfer coefficient for continuous, inline, and staggered interrupted fins.

This fluid and thermal behaviour was observed when the temperature difference (dT) was changed as well. In the graph, the staggered fin arrangement performs better than the continuous fin and inline interrupted fin arrangement in terms of heat transfer rate. However, the material required constructing the staggered fin arrangement and in-line fin arrangement is similar.

EXPERIMENTAL RESULTS

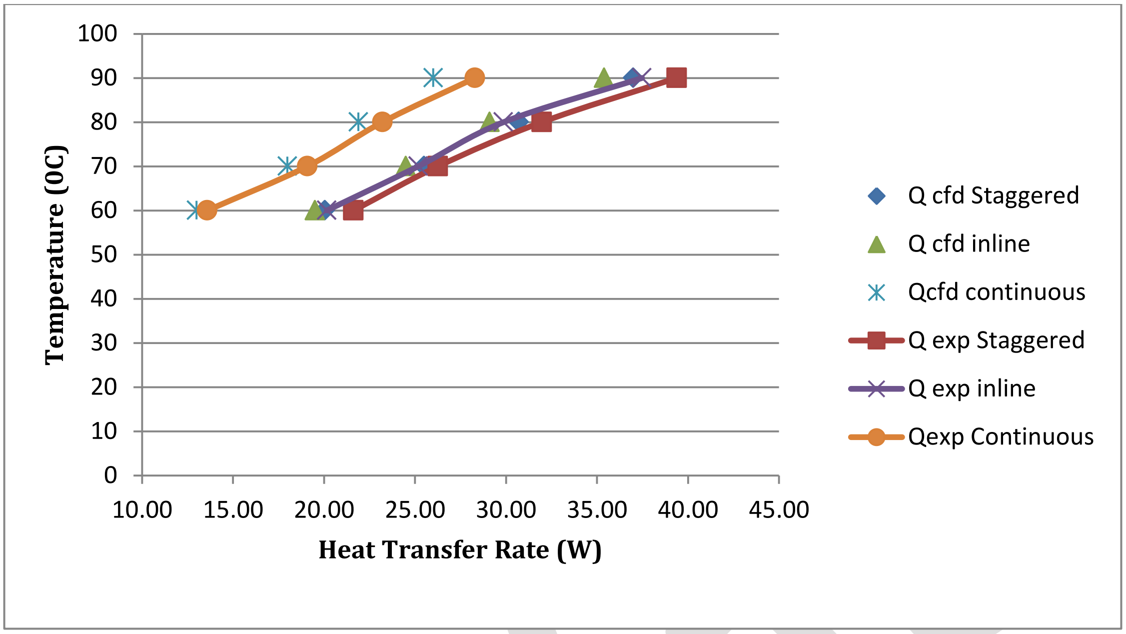


Figure 7 Experiment results of Heat transfer rate for continuous, inline, and staggered interrupted fins.

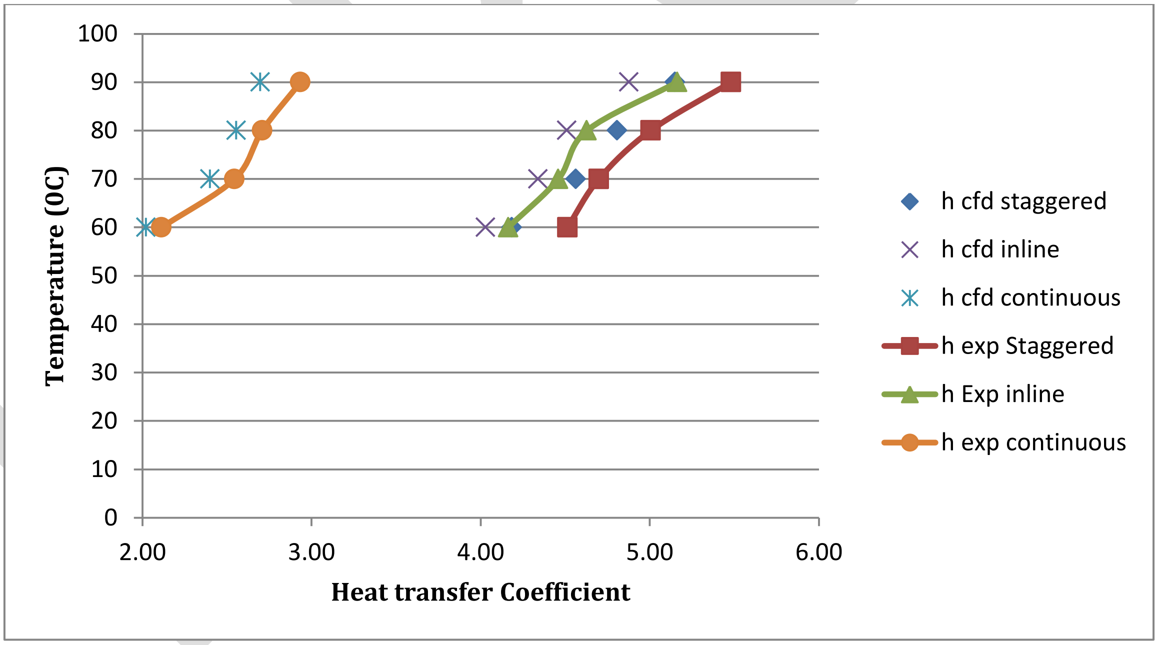


Figure 8 Experiment results of Heat transfer coefficient for continuous, inline, and staggered interrupted fins.

In order to validate the cfd simulation results, Experiment study was carried out by maintaining the same operating conditions. As can be seen from the figure 7 & 8 experiment results are in good agreement with the cfd results with maximum deviation of 10%.

CONCLUSION

- Staggered interrupted fin arrangement and in-line interrupted fin arrangement provided better heat transfer rate in comparison with the continuous fin arrangement.
- In the present operating conditions and for this staggered interrupted pattern of fin arrangement, the thermal performances of the staggered interrupted fins were found to be better.
- The numerical predictions were in good agreement with the experimental results for the operating conditions that was considered for this investigation.

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