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Numerical Simulation of the Thermal Performance of a Wavy Fin Configuration of a Straight Fin

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ABSTRACT

Fins over the years have been used as heat exchangers for exchanging heat generated in engineering machines or systems, between the system surface and the ambient air. But the challenge of thermal design for the best geometry of heat fin prompted the study to determining the performance of a wavy and straight fin projecting vertically from a horizontal base, by comparing their rate of heat transfer. In this study a free convection steady state numerical analysis was carried out using Solidworks 2018 flow simulation application, which is based on Computational Flow Dynamics (CFD) based on finite volume method. Three fin arrays were modeled with Solidworks 2018, such as the straight and wavy fin of fin height, 35mm and spacing, 14.2mm. the third fin was a straight fin of height, 50mm equivalent of the effective wavelength of the wavy fin, but of same fin spacing. Aluminum metal was selected as the material, and the simulation was done using air as the fluid, of temperature, and convective heat coefficient, 27^0C and 20W/mK. Simulation was carried out at different temperatures for each geometry, ranging from, 45^0C-120^0C. The results showed that the difference in the rate of heat transfer for the wavy fin and straight fin were close at low temperature but significantly increased to about 28% at higher temperatures in favor of the wavy fin. The third fin had an insignificant 9% heat transfer rate higher than the wavy fin but 43% additional height, thereby occupy more space.Keywords:

Keywords: Heat transfer, wavy fin, Simulation, Temperature, fin height.

1 INTRODUCTION

One measure and common occurrence in engineering systems/machines is the generation of heat due to its operations. This sometimes lead to overheating of this system (May & Almubarak, 2017). The end effects of this overheating if not effectively dissipated out of the system may give rise to malfunctioning and sometimes total damage of the system as well as reduction in machine efficiency and effectiveness. Therefore, heat generated within a system must be dissipated to its surrounding in order to maintain the system at its recommended working temperatures and functioning effectively, efficiently and reliably.

The application of fins otherwise known as extended surface are applied to this system as a heat sink or heat exchanger to enhance the steady and effective dissipation or transfer rate of this heat from the system to the environment either by force convection or free convection.

Extended surfaces according to Mathiazhagan & Jayabharathy, (2014) are specially used to enhance heat transfer rate between a solid and an adjoining fluid. The heat transfer from fins is simply a combined effort of both conduction and convection heat transfer and temperature distribution along the geometry of the material (Incropera et al. 2007)

Extended surfaces are numerously applied as heat sinks or heat exchangers in Engineering or electronic systems such as; power compressors, electrical pumps, air conditioner, refrigerators, power transformers, energy plants, as well as radiators in cars, engine cylinders, CPU heat sink, heat exchangers in power plants,

An extended surface is most times incorporated into the system to increase the surface area of the system over which the convective heat transfer takes place. This is because according to Newton's law of cooling, the rate of heat transfer is a function of the convective heat transfer coefficient (h), the surface area (A) of the system and the temperature gradient $(ts - tf)$ between the solid temperature and the environmental temperature. See equation below.

$$Q = hA\,(ts - tf) \quad (1)$$

several researchers have studied the problem of optimizing the shape of the finned surfaces in order to increase heat transfer effectiveness and decrease the dimensions as a function of limited space, and the weight of heat sinks and exchangers and as such several experimental and numerical investigations have been conducted for various kinds of shape of the fin; such as straight, plate, wavy fin and others.

When calculating the heat transfer rate from an extended surfaces the following assumptions need to be made such as; steady state heat transfer, the properties of the material are constant (independent of temperature), there is no internal heat generation. The heat conduction happens in one dimension only. The material has uniform cross-sectional area. Convection occurs uniformly across the surface area.

The heat transfer from extended or finned surfaces to the ambient atmosphere occurs by convection and radiation. But as a result of relatively low values of emissivity of the fin materials such as aluminum, duralumin and steel alloys, the effect of radiation on the heat transfer may be neglected (Yardi, Karguppikar, Tanksale, & Sharma, 2017). Convection heat transfer is therefore the mode of energy transfer between a solid and it adjacent fluid in motion. The faster the motion of the fluid the greater the convection heat transfer rate from the surface.

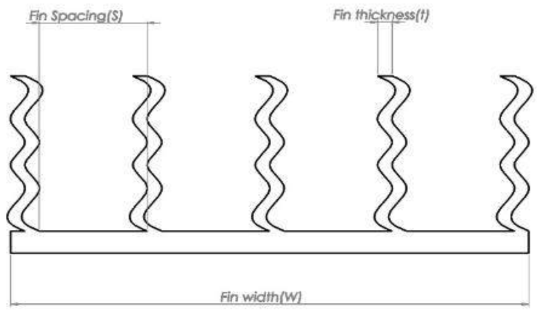
Convection can take place in two forms; Natural convection and forced convection. The former takes place as a result of the fluid flow that is caused by density difference, otherwise known as Buoyancy forces. While in the later (forced convection) fluid is forced to flow over the surface by the use of external means such as fan, pump, compressors etc. The wavy fin surface is popular because it can increase the length of the airflow in the heat exchanger by improving or enhancing the air flow mixing and increasing heat transfer performance (Moorthy, Nicholas, & Oumer, 2018). The wavy fin is one of the most popular fin types in plate fin heat exchangers, particularly where superior heat transfer performance is demanded.

This study is aimed at numerically determining the performance of a straight fin and a wavy fin by comparing their rate of heat transfer. It is limited to a steady state and convective heat transfer.

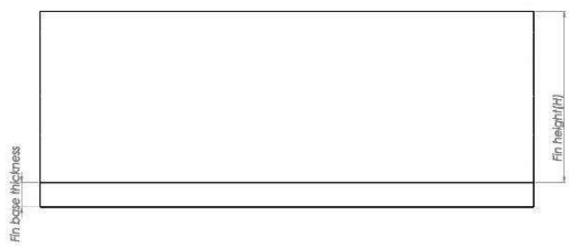
2 METHODOLOGY

2.1 DESIGN OF THE FIN SAMPLE

The fin array model was modeled into three (3) different configurations using Solidworks 2018 version. This models are the straight fin of fin height (H) = 35 mm, the wavy fin of fin height, H = 35 mm and a straight fine equivalent of the wavy fin effective length as though been stretched, H = 50 mm. The base length (L), base width and the base thickness, fin wavelength (λ) and fin thickness (t) was taken generally to be 110 mm, 95 mm, 5 mm, 7 mm, and 3 mm respectively throughout the whole configurations. The fin spacing (s) of the three fin array model were kept constant at (S) = 14.2 mm. The fins were designed to protrude vertical from a rectangular base. See some of the different fin array configurations in the figures 1 through 3 below. The fins where modeled to be integral with the base.



(a) Fin side view Schematic Diagram of the wavy fin



(b) Fin front view Schematic Diagram of the wavy fin

Figure 1: Schematic Diagram of the wavy fin

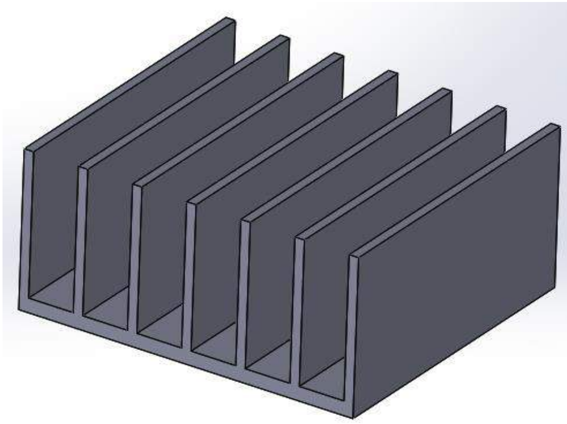


Figure 2: Straight fin @ H=35 mm, S= 14.2 mm

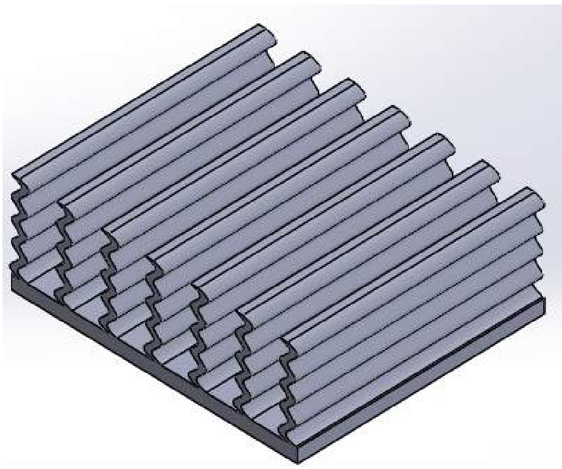


Figure 3: Wavy fin @ S= 14.2 mm, λ= 7 mm.

2.2 SIMULATION PRROCEDURES

A steady state numerical simulation analysis for each of the configuration was carried out using solidworks flow simulation, version 2018. The material selected was aluminum metal because of it high thermal conductivity and strength and low emissivity. The simulation was carried out at four different base temperature; 45^0C, 60^0C, 90^0C and 120^0C respectively. The simulation procedures are; modeling of the fin array configurations, selection of material, selection of boundary conditions, creating Meshing on the model, running the study and display/processing of results. See the initial and boundary conditions summary used in Table1.

TABLE 1: SIMULATION AND BOUNDARY PARAMETERS

Fluid	Air
Fluid or Ambient temperature, T_a(^{0}C)	**27**
Fluid or ambient Pressure (Pa)	**101325**
Boundary condition	**Real wall**
Wall temperature, T_w(^{0}C)	**45, 60, 90, 120**
Heat transfer coefficient, h(W/m^{2}k)	**20**
Material applied	**Aluminum metal**
Analysis Type	**External**

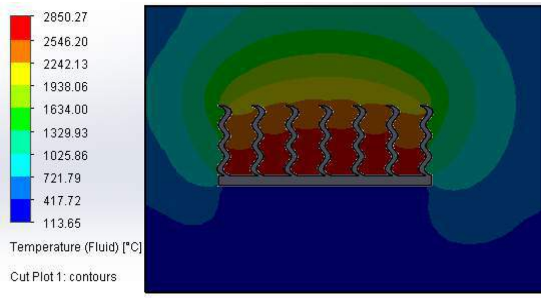
The boundary conditions were chosen such that; the fin and base plate was assigned as solid domain and the enclosure (that is the computational domain) automatically becomes the fluid domain. The back surface of the base plate was taken as real wall 1 with temperature value assigned to it. The remaining surfaces of the fin and base plate assembly were taken as real wall 2 with a convective heat transfer coefficient and air duct temperature assigned to it. Solidworks flow simulation automatically assigns the inlet and outlet pressure, the surrounding fin temperature and the adiabatic condition to the walls of the computational domain.

3 RESULTS AND DISCUSSION

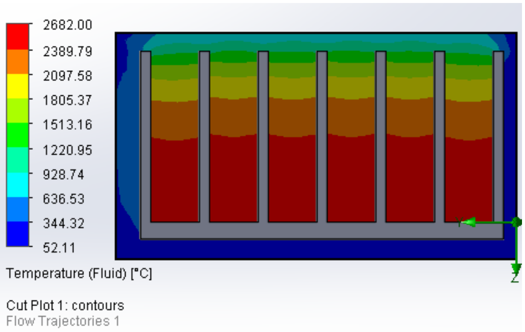
A numerical analysis was carried out for each of the fin geometrical configuration using Solidworks flow simulation, 2018 version. The results obtain are presented in figure 4 through 5, as well as discussions made about them.

Figure 4a and 4b shows the cut plot of the fluid temperature distribution over the entire two fin geometry. The fluid closer to the base where the heat is applied has the highest temperature, but reduces toward and above the tip of the fins, signifying a progressive heat transfer by convection between the solid and the surrounding fluid.

The rate of convective heat transfer with respect to base-to-ambient temperature difference can be seen in Figure 5, for both wavy fin and straight fin array configuration of H = 35 mm and a wavy fin stretched into a straight fin array, whose stretched height becomes 50 mm, all of this configurations having the same fin separation distance of S = 14.2 mm.



. (a) H= 35 mm, S= 14.2 mm at Tw= 1500C



(b) H= 35 mm, S= 14.2 mm T_w= 150°C

Figure 4: (a) and (b), Cut plot showing fluid temperature

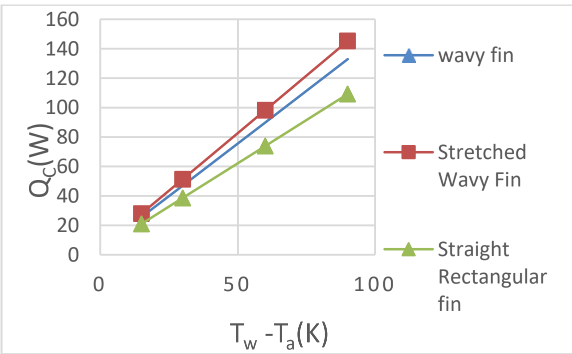


Figure 5: Heat transfer rate of different fin

In Figure 5, it is observed that stretched wavy fin array into a straight rectangular fin array has the highest Convective heat transfer rate greater than the original wavy fin array by 9.25%, which is an insignificant percentage difference. It is also observed that the convective heat transfer rate for the wavy fin array is greater than that of the straight rectangular fin array of the same fin height and fin spacing by about 28% at higher base-to-ambient temperature difference. This percentage difference can be considered reasonable. Though when also observed from the graph, at lower base-to-ambient temperature difference the convective heat transfer rate seems to be so close to each other.

In conclusion, it is established from this study that wavy fin array possesses higher convection heat transfer potential than the straight fin. Therefore in a bit to achieve high performance heat transfer with limited space a Wavy fin array is recommended.

4 CONCLUSION

A numerical analysis was carried out on three different fin configurations, all of the same fin spacing or separation distance. Based on the simulation results shown, the following conclusions were made as follow;

Consequent of the significant percentage difference in the heat transfer rate the wavy fin had, higher than the straight fin, (about 28%), it is strongly concluded that the wavy fin geometry has greater performance in heat transfer rate. Also in terms of area occupied by the fin, it was discovered that when the wavy fin was assumed stretched out to a straight fin it increases by 43% in height, though 9% higher than the wavy fin in heat transfer rate, which is insignificant if space conservation in thermal system design must be taken into consideration.

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