Heat transfer analysis on different pin fin types using Solid Works

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Abstract. A fin is an extended part of an object whose purpose is to raise the rate of heat transfer mainly by convection. The heat flow in any object depends on the surface area, temperature difference, and convection coefficient. As convection coefficient cannot vary after a certain limit and temperature difference depends on the process, the way to increase the rate of heat transfer is to increase surface area which was done by adding fins. In this study, steady-state thermal analysis is performed on different types of fins and fins of different heights by using Solid works simulation. Different materials of fins are also used to verify results as the rate of heat transfer is independent of material. Aluminum 6061 and Copper is used as material for rectangular and cylindrical pin fins. In comparison, rectangular pin fin has a high rate of heat transfer as compared to copper pin fin, and also the rate of heat transfer is directly proportional to the height of the fins irrespective of the profile.

Keywords: Heat transfer analysis; Pin fin efficiency; Pin fin configuration; Solid Works; Fins

1. Introduction

In machines, a fin is an extended surface from an object that is used to increase the rate of heat transfer to and/or from the environment by increasing convection. On adding a fin the surface area of the object increases and can also be an economical solution for heat transfer problems. The rate of heat transfer from a solid surface to the atmosphere is given by Newton’s Law of Cooling

\[ Q = hA\Delta T \]  \hspace{1cm} (1)

Where Q=Heat transfer

h=Heat transfer coefficient

A=Heat transfer surface area

\( \Delta T \)=Difference in heat transfer from a surface at a temperature and surrounding medium

where the value of h cannot be increased beyond a certain limit and the value of \( \Delta T \) depends upon the process and having process limitations. So, to increase the value of Q the possible option we have is to increase the surface area of the object. The extended surface used to increase the surface area is known as the fin. Therefore, fins are used when the surface area which is available is insufficient for required heat transfer with already accessible temperature gradient and heat transfer coefficient [1, 2]. By using thermal analysis, the rate of heat transfer can be figured out. Different objects require a different amount of heat transfer and hence require different types of fins. While selecting a proper fin the following factors are considered:

• The longer the fin, the larger is the surface area available for heat transfer, and hence higher is the rate of heat transfer from the fin.
- The larger the fin, the higher is the mass and the higher is the cost of the material.
- On increasing the fin length, efficiency decreases because of decreasing fin temperature with length.

Heat flux also referred to as Heat flux density is defined as the flow of energy per unit of area per unit of time. It's unit is W/m$^2$. It is a vector quantity as it possesses both magnitude and direction. It is calculated by

$$\phi = h \Delta T$$

Where $\phi =$ Heat flux

$h =$Heat transfer coefficient

$\Delta T =$Difference in heat transfer from a surface at a temperature and surrounding medium

1.1. Heat Transfer:
Heat transfer is the domain of thermal engineering dealing with the generation, conversion, use, and exchange of heat energy between physical systems by different methods. It is classified into various mechanisms Thermal Radiation, Thermal Convection, Thermal Conduction, The transfer of energy by phase changes. Thermal radiation takes place across a vacuum or a transparent medium. Energy in radiation is transferred by means of photons in electromagnetic waves. Thermal convection occurs when a fluid flowing in bulk transfers heat along with the flow matter, either naturally or with some external force. Thermal conduction implies the direct exchange of heat due to the exchange of kinetic energy of particles through the boundary of two systems. According to the second law of thermodynamics the conduction heat flows from high temperature to low temperature.

1.2. Types of Fins
Fins are of various shapes. As the surface area will increase in different types of fins, that type of fin will be better in performance than other fins [3, 4]. Figure 1 indicates various types of fins.
1.3. General Materials used in Manufacturing of fins:
The manufacturing of fins is done by using some selective material. The name and properties of such materials are mentioned in Table 1.

**Table 1. Materials and their properties used in manufacturing of fins [5]**

| MATERIAL             | PROPERTIES                                                                 |
|----------------------|-----------------------------------------------------------------------------|
| Aluminium            | Provides the best overall value [4]                                          |
| Copper               | Provides the best heat transfer because of high thermal conductivity        |
| 304 Stainless Steel  | Thermal conductivity is comparatively low but better than 316 Stainless steel and this provides great resistance from corrosion. |
| Copper Nickel        | Good thermal conductivity, resistant to seawater corrosion but expensive in cost. |
| Heresite P413-coated aluminum fins | Results differ only 1% from Aluminium and copper but comparatively cheaper and can be used effectively in coastal and marine areas. |
| 316 Stainless Steel  | Thermal conductivity is even lower than the 304 Stainless steel and this provides great resistance from corrosion. This is preferred because it is cheap in cost. |

1.4. Application of fins
Fins are used for the enhancement of heat transfer rate because they increase the surface area when added as extra material to a device without any preventive maintenance and are the cheapest way of doing so [6]. Some of the applications of fins include:

1. Cooling of electronic equipment;
2. Dehumidification of surrounding air.
3. Used in heat-exchanging devices such as radiators in cars, computer CPU heat sinks, etc.
4. Used in recent technological advancements such as hydrogen fuel cells.
5. Used as heat exchangers in power plants [7].

2. Methodology
In the paper “Heat transfer analysis on different pin fin types using Solid Works” experimental analysis of heat transfer in fins of different shapes and materials was performed on the software Solidworks. The quantitative data of measurements and temperature was required for the experiment. Experimental data required has been gathered by observation and research.

The experimental data was gathered from existing research papers and the criteria to select the method was data range. The authors read few research papers and collected data ranges for measurements of the fin and temperature and finally, the collected data was scrutinized by the authors, and repeatedly occurring data range was used to experiment.

2.1. Modelling and Simulation
SolidWorks is used for modelling and simulation. SolidWorks is a solid modelling computer-aided and computer-aided engineering program that was developed by Dassault Systèmes in the year 1995. Models of different types of fins were made in SolidWorks and thermal analysis and meshing to figure
out the rate of heat transfer between different types of fins was done by using simulation in SolidWorks.

2.2. Experimental Analysis
The thermal analysis of two types of PIN FINS was done by using SOLIDWORKS SOFTWARE. Models of Rectangular pin fin and cylindrical pin fin were constructed by using SOLIDWORKS and the following are the measurements of the model

For Rectangular Pin Fin:
Length=l=0.02m,
Breadth=b=0.015m,
Height=h=0.08m

For Cylindrical Pin Fin:
Diameter=d=0.02m,
Height=H=0.08m

2.3. Calculations
For Rectangular Pin Fin
Surface Area= 2(l*b) + 2(b*h) + 2(h*l) = 0.0062m²
Volume of rectangular fin=l × b × h = 0.000024m³

For Cylindrical Pin Fin
Surface Area= (π * d * H) + (πd²/2) = 0.005654m²
Volume of cylindrical fin= πd²×H/4 = 0.000025m³

Table 2. Description of surface area and volume of fins

| FIN TYPE           | SURFACE AREA  | VOLUME       |
|--------------------|---------------|--------------|
| Rectangular Pin Fin| 0.0062m²      | 0.000024m³   |
| Cylindrical Pin Fin| 0.005654m²    | 0.000025m³   |

From the material section on the left-hand side of solid works, different materials were selected (1st Aluminum 6061 and 2nd Copper). The simulation was done under the thermal study section. The maximum temperature and thermal conductivity of each material were selected as input and the results were analysed.

Before analysis, the numerical data was gathered and checked manually and the results obtained were compared with existing results. For these general formulas of heat transfer, and perimeter and area were used. Finally, the data was put in Solid Works for respective shape and material of fins, and results obtained were compared with manually calculated and observed results. For simulation, two materials were taken, Aluminium alloy 6061 and Copper [8]. According to Newton's Law of cooling Q=hAΔT, it is clear that heat transfer depends on the Surface area. Alongside the heat transfer also depends on the height of the fins. In the simulation, the base plate temperature is taken as 2000K and convection coefficient as 20 W/K for both the types of fins of both materials. The ambient temperature is taken as 300K and we considered cooling down by using air.
2.4. CAD model of fins

**Figure 2.** Rectangular pin fin of height 0.08\( m \)

**Figure 3.** Cylindrical pin fins
2.5. Meshed model of fins

Figure 4. Rectangular pin fin of height 0.10m

Figure 5. Rectangular pin fin of height 0.08m
Fine meshing improves the quality of results, hence meshing done in all the cases are finest.

2.6. Iteration-1 (Fins of Aluminum 6061)
In first study, two types of fins were taken of Aluminum 6061. First study was done with respect to different surface areas [9].
2.7. Iteration-II (Fins of Copper)
In second study, two types of fins were taken of copper. Second study was also done with respect to different surface areas but here material is different [10].
In third study, two Rectangular Pin Fins of Aluminum 6061 alloy were taken. Third study was done with respect to different heights of fins.
Figure 12. Rectangular pin fin of Aluminum 6061 with height 0.08m

Figure 13. Rectangular pin fin of Aluminum 6061 with height 0.10m
### Table 3. Description of Simulation of different types of fins

| FIN CONFIGURATION | MATERIAL             | MINIMUM TEMPERATURE (K) | MAXIMUM TEMPERATURE (K) |
|-------------------|----------------------|--------------------------|--------------------------|
| RECTANGULAR       | ALUMINIUM 6061       | 1829                     | 2000                     |
| CYLINDRICAL       | ALUMINIUM 6061       | 1849                     | 2000                     |
| RECTANGULAR       | COPPER               | 1922                     | 2000                     |
| CYLINDRICAL       | COPPER               | 1931                     | 2000                     |

### Table 4. Description of Simulation of rectangular pin fin of different heights

| FIN CONFIGURATION | MATERIAL             | HEIGHT OF FIN (m) | MINIMUM TEMPERATURE (K) | MAXIMUM TEMPERATURE (K) |
|-------------------|----------------------|-------------------|--------------------------|--------------------------|
| RECTANGULAR       | ALUMINIUM 6061       | 0.08              | 1829                     | 2000                     |
| RECTANGULAR       | ALUMINIUM 6061       | 0.10              | 1754                     | 2000                     |

#### 3. Manual Calculations for heat flux

Heat flux is calculated by $\phi = h \Delta T$

For Iteration 1:
- Rectangular shape pin fin: $\phi = h \Delta T = 20 \times (2000 - 1829) = 3420 \text{ W/m}^2$
- Cylindrical shape pin fin: $\phi = h \Delta T = 20 \times (2000 - 1849) = 3020 \text{ W/m}^2$

For Iteration 2:
- Rectangular shape pin fin: $\phi = h \Delta T = 20 \times (2000 - 1922) = 1560 \text{ W/m}^2$
- Cylindrical shape pin fin: $\phi = h \Delta T = 20 \times (2000 - 1931) = 1380 \text{ W/m}^2$

For Iteration 3:
- Rectangular shape pin fin with height 0.08 m: $\phi = h \Delta T = 20 \times (2000 - 1829) = 3420 \text{ W/m}^2$
- Rectangular shape pin fin with height 0.10 m: $\phi = h \Delta T = 20 \times (2000 - 1754) = 4920 \text{ W/m}^2$

#### 4. Result and Discussion

1) The surface area of rectangular pin fin is greater than that of cylindrical pin fin (Table 2). It affects the rate of heat transfer.

2) The difference between minimum and maximum temperature in rectangular fin of Aluminum 6061 (Figure 8) is greater than that of cylindrical pin fin of Aluminum 6061 (Figure 9) (Table 3). As high the temperature difference will be there between maximum and minimum temperature, rate of heat transfer will be more, as heat flows from high temperature to low temperature. The order of rate of heat transfer:
   - Rectangular pin fin > Cylindrical pin fin

3) The difference between minimum and maximum temperature in rectangular fin of Copper (Figure 10) is greater than that of cylindrical pin fin of Copper (Figure 11) (Table 3) [11, 12]. The order of rate of heat transfer:
   - Rectangular pin fin > Cylindrical pin fin
4) The difference between minimum and maximum temperature in rectangular fin of Aluminum 6061 of height 0.08m (Figure 12) is less than that of rectangular fin of Aluminum 6061 of height 0.10m (Figure 13) (Table 4).

5) The heat flux computed by manual calculations of Iteration 1 is greater for rectangular pin fin than that of cylindrical pin fin.

6) The heat flux computed by manual calculations of Iteration 2 is greater for rectangular pin fin than that of cylindrical pin fin.

7) The heat flux computed by manual calculations of Iteration 3 is greater for rectangular pin fin of height 0.08m than that of rectangular pin fin of height 0.10m.

8) The heat flux is greater for rectangular pin fin than the cylindrical pin fin.

9) The heat flux is greater for rectangular pin fin of greater height.

5. Conclusions

The following points were concluded from this research work:

1) On changing the surface area, the rate of heat transfer is changing. Surface area is directly proportional to rate of heat transfer.

2) Rectangular pin fins have greater heat transfer rate than the cylindrical pin fins for both materials.

3) Temperature at the end of rectangular fins is low which results in better heat transfer rate.

4) From Iteration I, the heat transfer in rectangular pin fins is greater than the cylindrical pin fins for Aluminum 6061.

5) From Iteration II, the surface area is directly proportional to rate of heat transfer for Copper. Alongside, the heat transfer in rectangular pin fins is greater than the cylindrical pin fins of copper.

6) From Iteration III, as the fins height increases, the rate of heat transfer also increases as the temperature difference between minimum to maximum.

7) The rectangular pin fins have greater heat transfer than cylindrical pin fins in all the Iterations irrespective of the materials employed and also the rate of heat transfer is directly proportional to height of the fins.

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