

Numerical Study of Heat Transfer Performance of Pin Fin by Shape Modification

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Abstract. Rate of heat transfer is an important parameter of heat exchangers, mostly it is affected by fins geometry. To achieve maximum heat transfer, shape of the fins plays a major role. In the present work an attempt is made to study the heat transfer performance in terms of temperature difference and pressure drop of pin fin heat sink with constant base heat flux is studied using commercial CFD software (ANSYS). Three geometries of pin fin have been designed by keeping the same cross-sectional area. CFD analysis have been carried out in both free and forced convection with transient formulation. Results have been compared with circular shape fin.

1. Introduction

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows. Computers are used to perform the calculations required to simulate the free-stream flow of the fluid, and the interaction of the fluid (liquids and gases) with surfaces defined by boundary conditions.

Chaitanya and Rao have studied the temperature difference and pressure drop in a pin fin heat sink and has investigated to find out if drop shape and staggered arrangement gives better results in comparison with the circular shape. Whole process been tested by using CFD. Here heat sink design modified with two different Drop shapes with same cross-sectional area, the main cause to introducing drop shape is to increase surface area of air contact region. The process studied in transient condition for better results. Finally, comparison of results of Drop Shape with Circular Shape is employed here. CFD analysis showed that drop fins are more reliable than the circular-shaped fins and they have a better heat transfer rate mainly due to the increased surface area.

Gupta et al. [2] has done a CFD analysis to identify a cooling solution for a desktop computer which uses a 5W CPU. CFD analysis is performed using different geometric parameters and design of the heat sink. This paper considers cylindrical pin fins and rectangular plate heat sinks with aluminium base. The design should be able to adequately cool the chassis of the CPU. Results show that the heat transfer rate of rectangular pin fins is better than the cylindrical fins and hence they are more efficient.

Gupta et al. [3] studied to test various V-array models with varying included angles and to find out the angle giving the maximum heat transfer rate among the models chosen. Results show that V-array models have better heat transfer rates than the circular ones.

Rajole et al. [4] deals with study to find an optimum cooling solution for a desktop computer which uses an 80W CPU, and for the forthcoming desktop systems which may use 70-120W CPU. This paper considers the optimal plate fin heat sink design with variable copper base plate and the control of CPU heat sink processes. To have a better heat dispersion performance, a computational fluid dynamics



analysis is utilized to search for an optimal set of plate fin or cylindrical fin shape parameters. Base plate thickness, fin thickness, fin profile and fin material parameters are to be handled together due to the frequently encountered space limitations. Three different thickness plates and cylindrical heat sink designs with 2.5mm to 5mm thickness copper base plates are analysed by using CFD software packages Gambit and Fluent. The results are then compared with the experimental data. The results show that replacing Aluminium with copper as the material of the base plate improves the performance. Further, the rectangular plate heat sink models perform better than all the cylindrical fin heat sink models. It was also found that the heat sink with 1.5mm thick plate performs better than other heat sinks with different thicknesses.

This paper aims at investigating the heat transfer rate that is achieved by different shapes of the cross-section of the pin fin. The shapes chosen are square, circular and drop shape. Even though the shape is varied, the cross-sectional area of the nozzles is kept the same. In this project, the different shapes of pin fins are designed first, then the analysis is performed on those shapes. Theoretical calculations are done and the results obtained from the CFD analysis is validated with the theoretical results. The heat transfer rate is analysed under both forced and free convection conditions.

2. Geometric and CFD Modelling

2.1. Geometric modelling

A 3-D model of the circular pin fin is designed using CATIA software. This model can now further be used to analyse the required parameters on the computer. Fin shapes considered are circular, square and drop shaped. All pin fins have the same cross-sectional area.

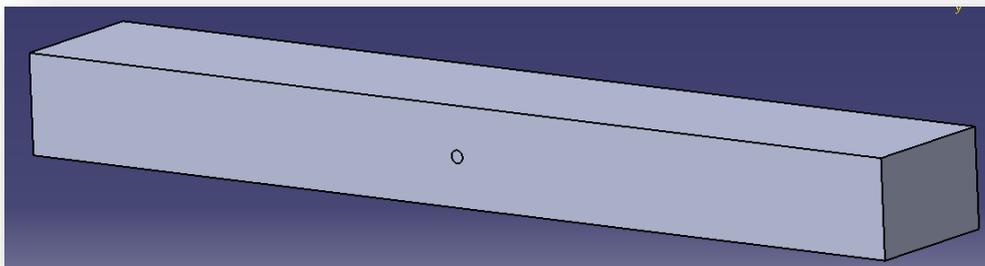
Figure 1 represents the geometric model of the pin fin inside the CFD domain having cross-section 150 x 100 mm with a length of 1000 mm. The circular fin has a diameter of 12 mm with a length of 120 mm. The square fin has a length of 120 mm with each side being 11.5 mm. The drop shape fin has a length of 120 mm with major and minor diameter being 16.2 and 10.4 mm. All the fins have a cross-sectional area of 132.66 mm².

2.2. CFD Modelling

After designing using catia software the model is imported into ansys workbench for meshing in any of the supported formats like IGS, Step and Parasolid. Fins of different cross sectional namely circular, square and drop shape are meshed with a relevance of 50. Figure 2 represents the meshed model of given geometry. Table 1 gives the mesh statistics for various pin fins.

Table 1. Mesh Statistics

	No. of Nodes	No. of Elements
Circular pin fin	101277	334027
Square pin fin	82802	350427
Drop pin fin	81757	327518



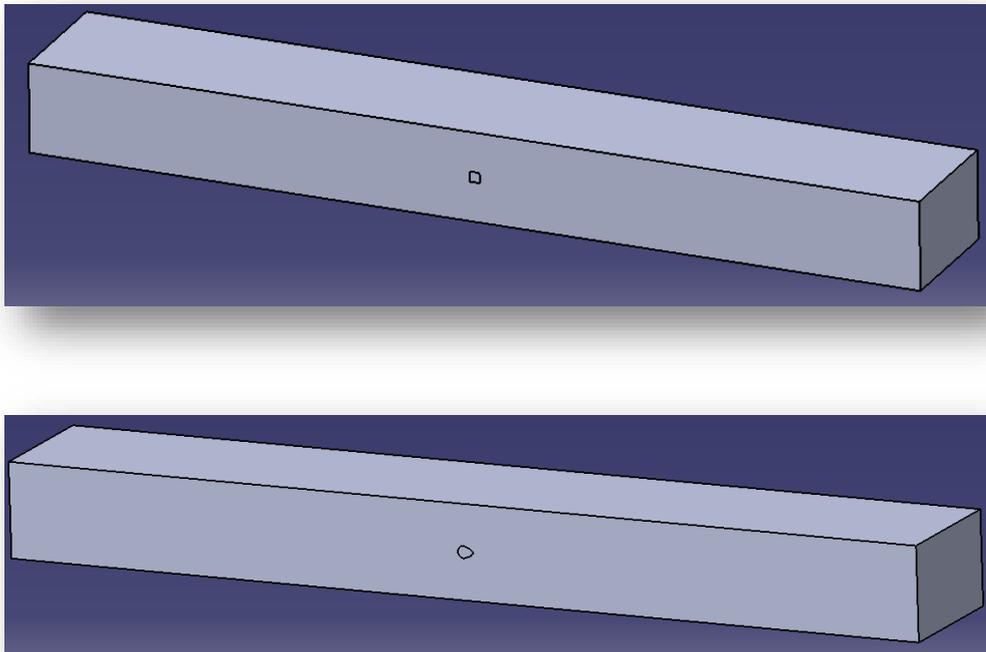


Figure 1. Computer Aided Surface Modelling of Pin fin with various shapes using CATIA v5

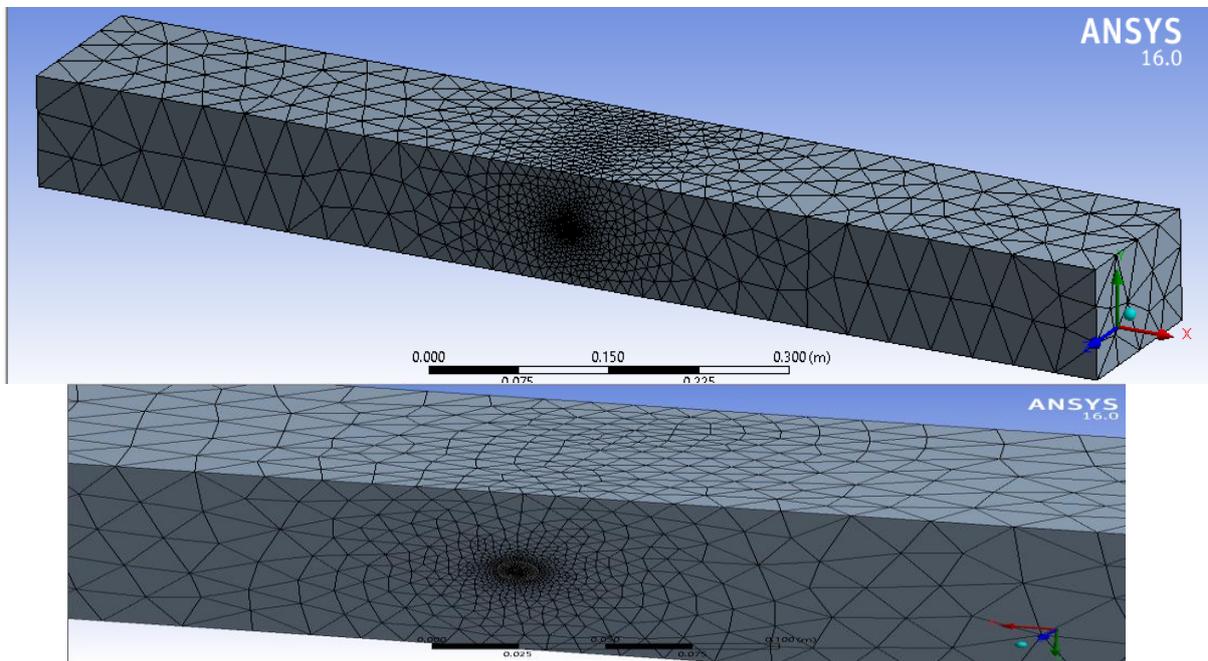


Figure 2. Structured Meshed model of Circular Pin Fin of CFD Domain

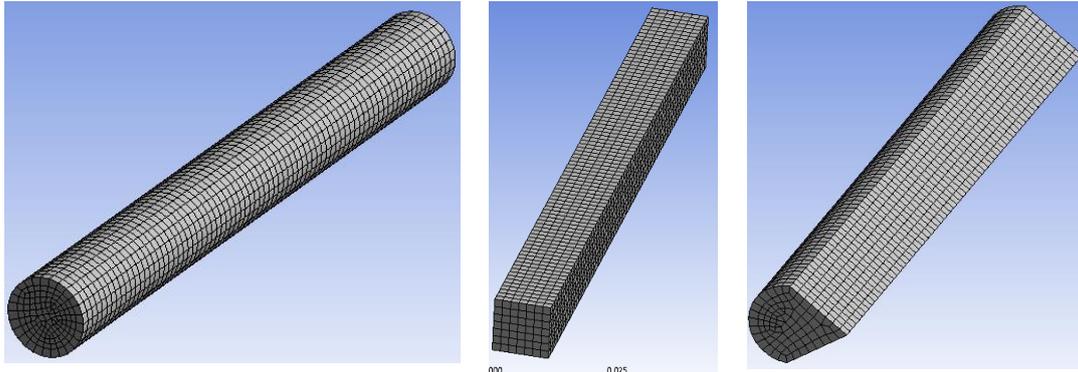


Figure 3. Structured Meshed model of the various shapes considered

3. Mathematical Modelling

3.1. Fin efficiency

It is defined as the ratio of actual heat transfer rate taking place through the fin and the maximum possible heat transfer rate that could occur through the fin i.e. when the entire fin is at its root temperature or base temperature. The entire fin will be at its root temperature only when the material of the fin has infinite thermal conductivity.

$$\eta_{\text{long fin}} = \frac{Q_{\text{act}}}{Q_{\text{max. possible}}} = \frac{\sqrt{hPkA_c} (T_o - T_{\infty})}{h(A_{\text{fin}}) (T_o - T_{\infty})} = \frac{1}{L} \sqrt{\frac{kA_c}{hP}} = \frac{1}{mL}$$

$$\eta_{\text{insulated tip}} = \frac{Q_{\text{act}}}{Q_{\text{max. possible}}} = \frac{\sqrt{hPkA_c} \theta_o \text{Tanh } mL}{h(A_{\text{fin}}) (T_o - T_{\infty})} = \frac{\text{tanh } mL}{mL}$$

3.2. Fin effectiveness

It is defined as the ration between heat transfer rate with fin and the heat transfer rate without fin.

$$\epsilon_{\text{long fin}} = \frac{Q_{\text{fin}}}{Q_{\text{without fin}}} = \frac{\sqrt{hPkA_c} (T_o - T_{\infty})}{h(A_r) (T_o - T_{\infty})} = \sqrt{\frac{kP}{hA_c}}$$

$$\epsilon_{\text{insulated tip}} = \frac{Q_{\text{fin}}}{Q_{\text{without fin}}} = \frac{\sqrt{hPkA_c} \theta_o \text{Tanh } mL}{h(A_r) (T_o - T_{\infty})} = \text{Tanh } mL \sqrt{\frac{kP}{hA_c}}$$

4. Results and Discussions:

4.1. Temperature Contours

Figure 4 represents the temperature contours of circular, square and drop shape pin fins. In circular fin, the temperature is varied from 559.9K to 495.4 K from root the tip of the pin fin. The same is found to be 552 K to 482.8 K in case of square fin and that of drop-shape it is 600.8K to 599.6K. It can be clearly noted that the temperature in case of square fin is comparatively less.

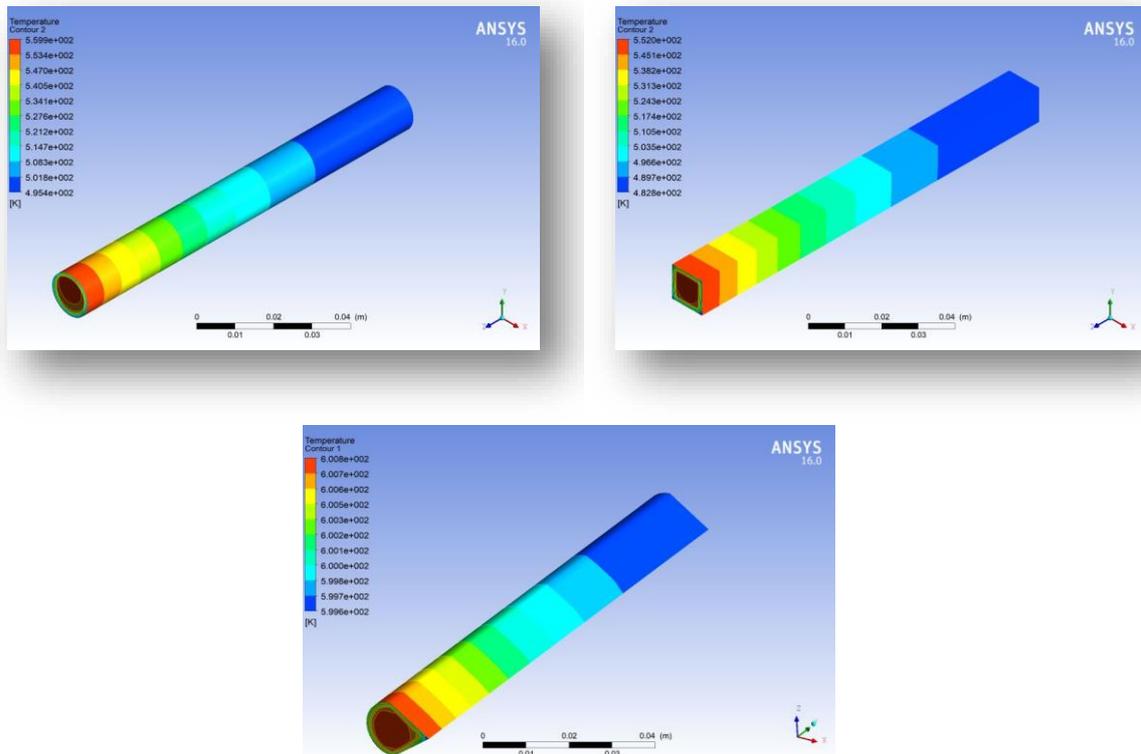


Figure 4. Temperature contours of various pin fins

4.2. Theoretical results

4.2.1 Free convection

$$\frac{T - T_{\infty}}{T_0 - T_{\infty}} = \frac{\cosh m(L - x)}{\cosh mL}$$

$$\text{At } x = l; \frac{T - T_{\infty}}{T_0 - T_{\infty}} = \frac{\cosh(0)}{\cosh mL} = \frac{1}{\cosh mL} \leftrightarrow \frac{486 - 300}{560 - 300} = \frac{1}{\cosh(m \times 0.12)} \leftrightarrow m = 7.2075 = \sqrt{\frac{hP}{K_{AA}}}$$

$$h = \frac{51.94 \times 110 \times \frac{\pi}{4} \times 0.013^2}{\pi \times 0.013} = 18.56 \text{ W/m}^2\text{K}$$

$$\text{Efficiency of fin, } \eta_{fin} = \frac{\tanh(mL)}{mL} = \frac{\tanh(7.2075 \times 0.12)}{7.2075 \times 0.12} \leftrightarrow \eta_{fin} = 80.79\%$$

$$\text{Effectiveness of fin, } \varepsilon = \frac{Q_{with \text{ fin}}}{Q_{without \text{ fin}}} = \frac{16.2}{18.56 \times \frac{\pi}{4} \times 0.013^2 \times (560 - 300)} = 25.29$$

4.2.2 Forced convection

$$\frac{T - T_{\infty}}{T_0 - T_{\infty}} = \frac{\cosh m(L - x)}{\cosh mL}$$

$$\text{At } x = l; \frac{T - T_{\infty}}{T_0 - T_{\infty}} = \frac{\cosh(0)}{\cosh mL} = \frac{1}{\cosh mL} \leftrightarrow \frac{58 - 32}{113.7 - 32} = \frac{1}{\cosh(m \times 0.12)} \leftrightarrow m = 15.098 = \sqrt{\frac{hP}{K_{AA}}}$$

$$h = \frac{227.94 \times 110 \times \frac{\pi}{4} \times 0.013^2}{\pi \times 0.013} = 80.49 \text{ W/m}^2\text{K}$$

$$\text{Efficiency of fin, } \eta_{fin} = \frac{\tanh(mL)}{mL} = \frac{\tanh(15.098 \times 0.12)}{15.098 \times 0.12} \leftrightarrow \eta_{fin} = 52.32\%$$

$$\text{Effectiveness of fin, } \varepsilon = \frac{Q_{\text{with fin}}}{Q_{\text{without fin}}} = \frac{16.2}{81.49 \times \frac{\pi}{4} \times 0.013^2 \times (113.7 - 32)} = 18.34$$

4.3. Temperature vs length of the pin fin

4.3.1 *Free convection.* Figure 5 represents the variation of temperature across the length of pin fin in case of free convection. From figure 5, the temperature of drop shaped fin varies from 581.85 K to 541.098 K while the circular fin varies from 534.49 K to 480.855 K and the square fin varies from 519.58 K to 479.16 K.

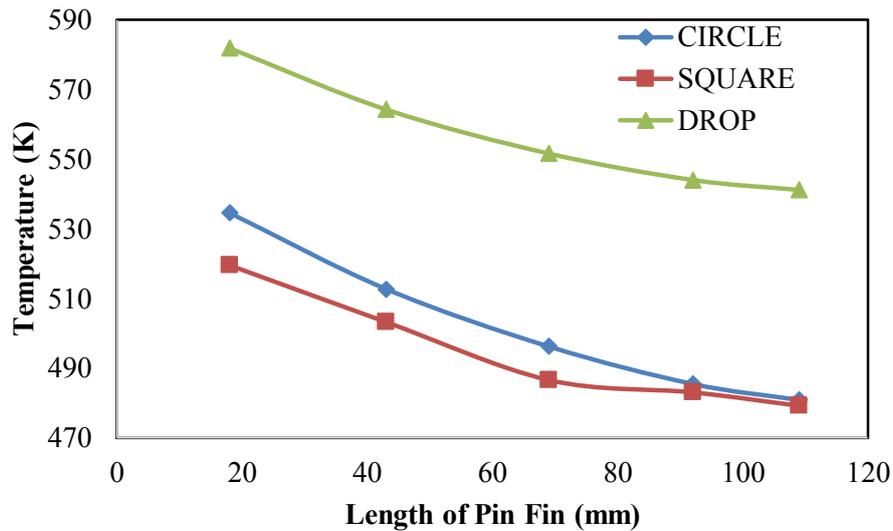


Figure 5. Temperature vs Length of pin fin in free convection

4.3.2 *Forced convection.* Figure 6 represents the variation of temperature across the length of pin fin in case of forced convection. From figure 6, the temperature of drop shaped fin varies from 379.35 K to 334.925 K while the circular fin varies from 376.033K to 331.79K and the square fin varies from 367.717 K to 326.722 K. It can be seen that the square fin transfers the heat much faster compared with other two. When compared to free convection, in forced convection the temperatures are very less, due to the fact that it will have more convective heat transfer coefficient.

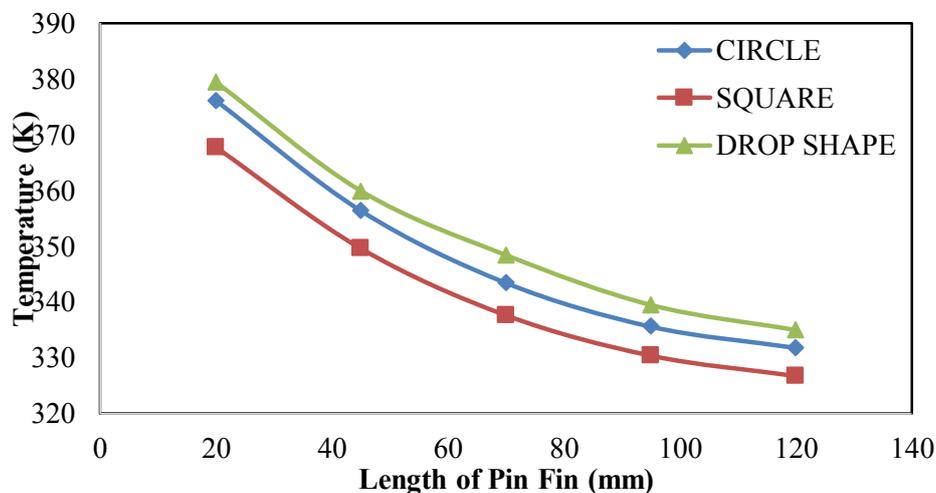


Figure 6. Temperature vs Length of pin fin in forced convection

5. Conclusions

In the present work an attempt is made to study the performance of pin fin with circular, square and drop shaped arrangements by keeping the cross-sectional area constant. The following conclusions are made from the present work.

- In free convection, the temperature of drop shaped fin varies from 581.85 K to 541.098 K while the circular fin varies from 534.49 K to 480.855 K and the square fin varies from 519.58 K to 479.16 K.
- In forced convection, the temperature of drop shaped fin varies from 379.35 K to 334.925 K while the circular fin varies from 376.033K to 331.79K and the square fin varies from 367.717 K to 326.722 K.
- Square shaped pin fin is preferred when compared with drop or circular shape as it gives a very less temperature in both free and forced convection.

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