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Analysis of Fin Tip Temperature and Fin Efficiency for Different Fingeometries and Materials Using Abaqus

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ABSTRACT

Fins are widely used in various engineering applications to enhance the rate of heat transfer. The effect of fin geometry and its material on the fin efficiency and the amount of heat transferred are investigated in this study. Rectangular and triangular fin geometries have been considered and two fin materials, aluminum and carbon steel, have been selected. It is found numerically that the fin tip temperature and the fin efficiency are decreased with the increase of the convective heat transfer coefficient. ABAQUS has been used to conduct this numerical study.

1. Introduction

Fins are extended surfaces generally employed to transfer heat from surfaces [1]. Fins are generally made of materials with high thermal conductivity. Olayiwola and Walzel [2] experimentally assessed the flow pulsation effects on the convective heat transfer coefficient. Pulsation amplitude varied between 0.28 and 0.53 mm where the pulsation frequency ranges was set at 16- 54 Hz. They found that the maximum heat transfer became 2.5 times at a relative fin height of 29 mm. It was also observed that the variation of flow rates had a little effect on the heat transfer. Kelkar and Patankar [3] constructed a passage by using two parallel plates. They attached the fins to the parallel plate channel and numerically predicted the fluid flow and heat transfer. Keeping the temperature of both of the plates constant, the authors changed the cross section in such a way that the temperature as well as the flow fields was periodically reproduced after regular length intervals. The authors reported that the fins enhanced the heat transfer but this heat transfer was reportedly dominated by the pressure drop associated with the process. Suga and Aoki [4] studied the behavior of multi louvered fins and determined the optimum combination of various geometrical parameters by using a two dimensional finite difference code. The authors proposed an empirical relationship between different fin parameters and suggested that the heat exchangers with smaller louver angle exhibited superior performance. Romero et al. [5] considered a single row fin tube heat exchanger. They numerically investigated the effect of fin spacing on the over-tube side of the heat exchanger. The authors used the fin spacing to characterize the flow; the flow was Hele-Shaw for smaller values of fin spacing and a horseshoe vortex was observed as the fin spacing was increased. The Nusselet number became maximum at the horseshoe vortex.

Romero et al [1] developed a model to evaluate the conduction process through fins. The authors assessed the influence of different parameters on the performance of a single-row plate-fin and tube heat exchanger. In case of tube-to-tube conduction of the heat exchanger, a performance drop was observed. Luviano Ortiz et al [6] conducted a study to investigate the heat transfer coefficient for a horizontal channel with and without deflectors. The study employed parallel plates to construct a channel in which heated blocks have been periodically inserted. The curved deflectors were used to guide the fluid flow to the space present between the heated blocks. It was found that the value of heat transfer coefficient became higher when deflectors were used than that when no deflectors were used. This increase of the coefficient of heat transfer was attributed to the motion of the fluid between the heated blocks due to the stirring effect caused by the deflectors.

Wei and Honda [7] studied the relationship between the boiling heat transfer and the fin height by utilizing square micro-pin-fin made of silicon. Six types of micro-pin-fins were used and their pitch was chosen to be twice their thickness. Results of the heat transfer with these micro-pin-

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fins in placed were compared to cases when there were no micro-pin-fins installed and the authors reported significant increase in heat transfer when these micro-pin-fins were use. Zhang et al [8] conducted a two dimensional analysis of a wavy plate fin channel. The authors investigated several parameters such as the isothermal fanning friction factor, the temperature and velocity fields, and the Colburn factor for fluid flow rates having Re in the range of 10 to 1000. The authors observed periodic disruption and boundary layer thinning as result of the surface waviness and reported high local heat fluxes as an ultimate consequence. This article studies the effect of fin geometry and material on the fin efficiency and the amount of heat transferred. Rectangular and triangular fin geometries are taken and two fin materials, i.e., aluminum and carbon steel have been used. The numerical study has been conducted using ABAQUS.

2. Materials and Method

Solid modeling has been done on PTC-Creo Parametric. The tube pass ratio is 2:1:1, which means that in the first two rows, hot fluid enters and then the fluid from these two rows combine and starts cooling down as it enters into the next individual tube passes. The required data such as the material properties of the fin, type of the elements to be used and the boundary conditions to initialize the finite element model (FEM) was resourced from the DESCON Limited. For modeling, a general purpose FEM package known as ABAQUS was used. A core i3 Laptop equipped with ABAQUS 6.13-1 was used for modeling the fin.

3. Results and Discussion

3.1 Assumptions

Following assumptions were made to run the simulations.

- The heat flow and temperature remain constant in the fin.
- Homogeneous fin material and constant thermal conductivity in all directions.
- The convective heat transfer coefficient do not change on the fin faces.
- The fin peripheral temperature remains constant.
- The thickness of the fin has been assumed to be small as compared to its height and length, leading tonegligible temperature gradient across the fin thickness.
- The base temperature of the fin is constant.
- The heat generation inside the fin is zero.
- The heat transfer thorough the lateral fin surface is much higher than the heat transfer through its tip.

Table 1 presents the simulation parameters selected for the simulation whereas the material properties and configuration of the tube and fin are given in Table 2.

Table 1: Simulation parameters used

Parameter	Tube Inlet	Tube Outlet	Air Entry	Air Exit
Flow Rate(kg/s)	62.48	62.48	497.66	497.66
Temperature (^{o}C)	105.56	57.22	42	63.88
Absolute Pressure (bar)	4.667	4.330	101326	101326
Velocity (m/s)	0.58	1.1	6.8	7.28
Density (kg/m^3)	956.3	996.5	1.12	1.05
Viscosity (m.Pa.s)	0.319	0.701	0.0192	0.0291
Thermal Conductivity(W/mK)	0.4015	0.4015	0.0274	0.0291
Reynolds Number	34496.36	31054.47	10102.6	9610.55

Table 2: Material properties and configuration of the tube and fin

Parameter	Value
Fin ID (mm)	19.86
Fin OD (mm)	25.4
Fin Type	L - Shaped
Fin Material	Al -1060
Fin tip diameter (mm)	57.15
Fin thickness (mm)	0.28
Fin density (/m)	433
Thermal Conductivity of Fin (W/m K)	234
Tube Material	Carbon Steel
Thermal Conductivity of Tube (W/m K)	54

3.2 Effect of fin material and geometry on the fin tip temperature

Fig. 1a and 1b shows the rectangular and triangular mesh used in the study for the heat transfer analysis, respectively. Figs. 2a, 2b and 2c present pressure, temperature and vorticity contours of the fluid obtained from the simulation. It is evident from the temperature contours that the temperature remains constant along the wall of the tube. This can be attributed to the relatively small tube length (0.1 m) when compared to the velocity of the fluid set for this case (0.58 m/s). Due to this relatively higher velocity, there was not enough time to exchange the heat with the tube wall. The contour plot reflects significant variation of temperature along the radial direction. As shown by the vorticity contours, the vorticity is higher at the boundaries of the fluid when compared to the center of the flow and this can explain the transfer of heat from the wall first where the flow is more turbulent. Fluid is pumped under pressure to drive the flow which is kept in accordance with material properties. In this case the fluid enters the tube at 3.67 bars which remains almost constant

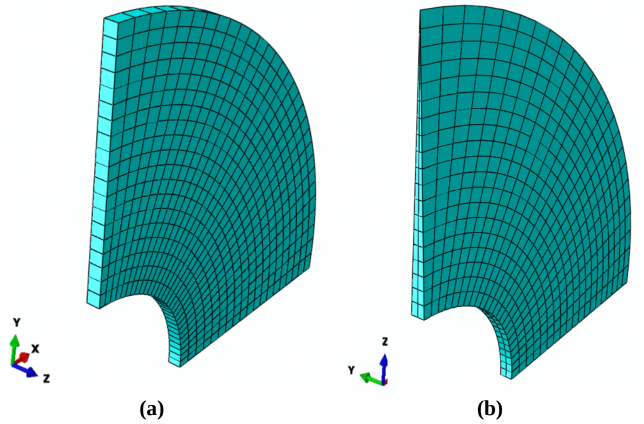


Fig 1: Rectangular (a) and triangular (b) mesh used in the study to conduct the analysis

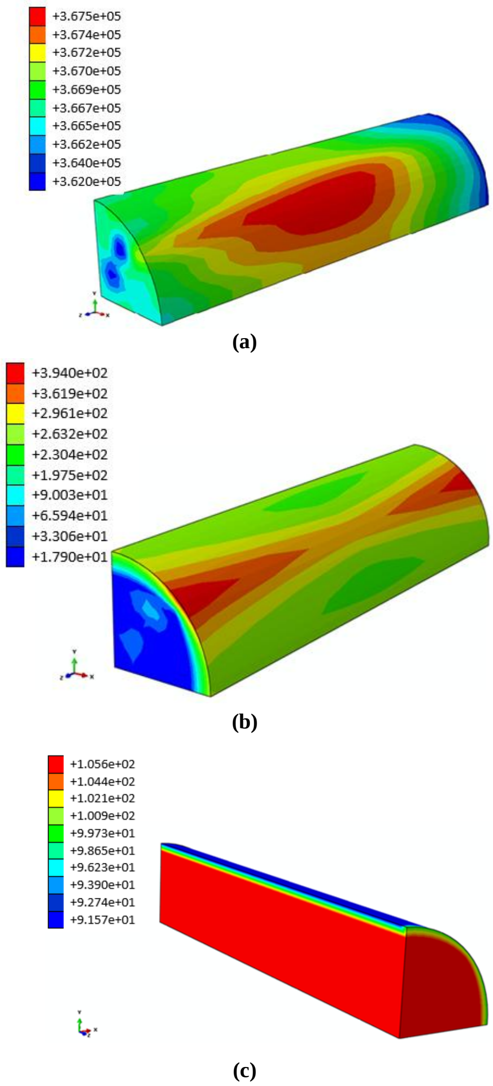


Fig 2: Pressure (a), temperature (b) and vorticity (c) contours of the fluid obtained from ABAQUS

at the center but little variation occurs in radial direction. This section presents the effect of the fin geometry and thickness on the tip temperature of the fin for a range of base fin thickness. Fig. 3a and 3b reflect the effect of rectangular and triangular aluminum geometries on the fin tip temperature.

Comparison of these figures reveals that the range of fin tip temperature is smaller for the rectangular fin geometry as compared to the triangular geometry for a particular value of the convective heat transfer coefficient. These figures also reflect that the heat transfer in triangular cross section is higher when compared to that of the rectangular cross section. The temperature for the aluminum rectangular section drops from 94.62 ^{o}C to 84.67 ^{o}C whereas it ranges from 94.62 ^{o}C to 79.36 ^{o}C for triangular section. When a comparison is made between the fin tip temperatures of the rectangular fins of aluminum (Fig. 3a).

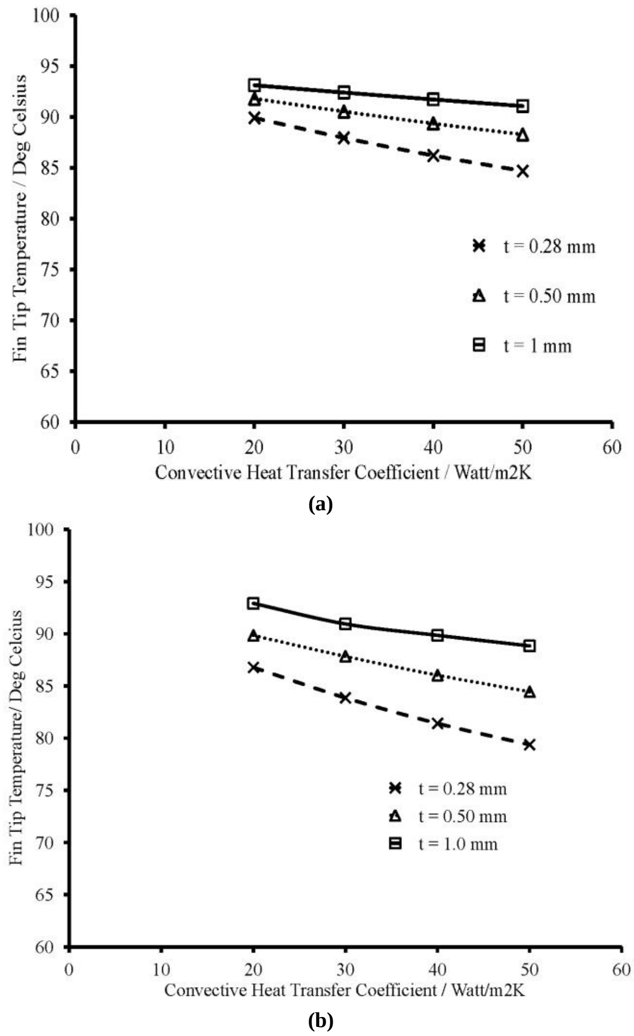
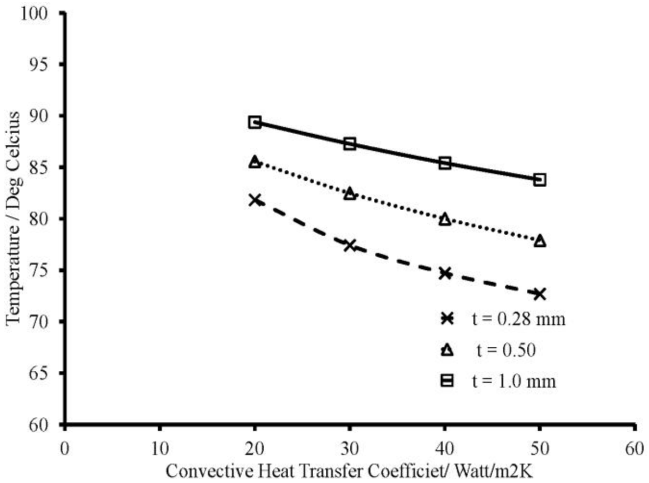
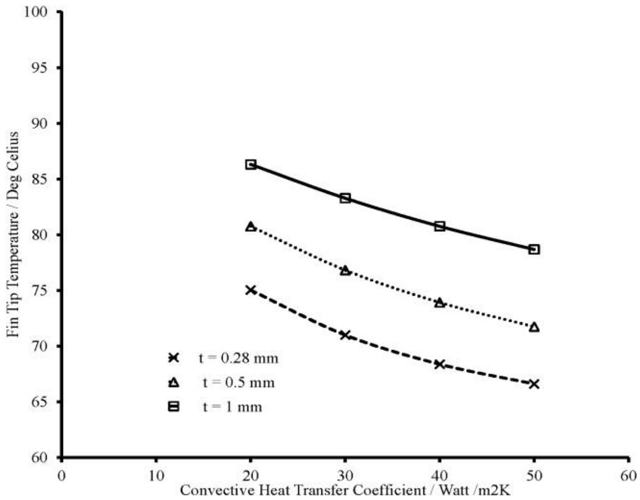


Fig. 3: Effect of fin geometry on the fin tip temperature for rectangular (a) and triangular (b) aluminum fins for a range of convective heat transfer coefficient



(a)



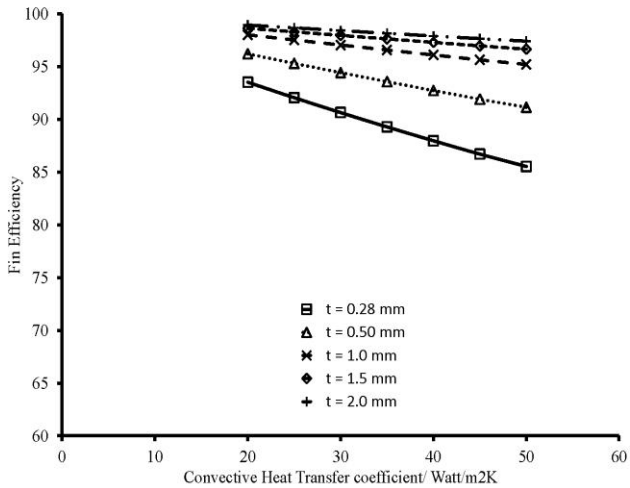
(b)

Fig. 4: Effect of fin geometry on the fin tip temperature for rectangular (a) and triangular (b) carbon steel fins for a range of convective heat transfer coefficient

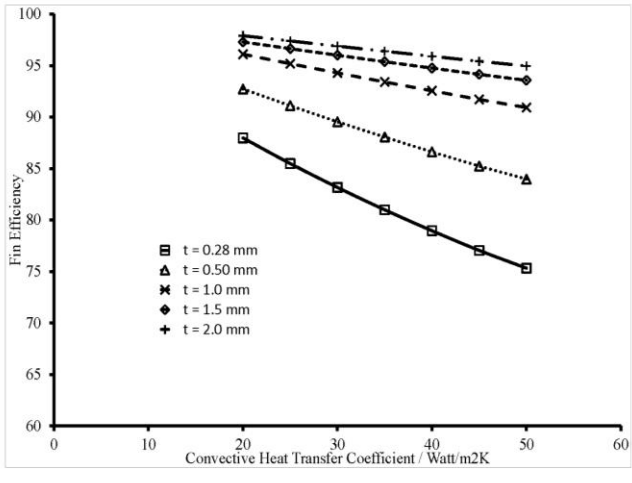
and carbon steel (Fig. 4a), unlike aluminum rectangular fin, the carbon steel fin has shown considerable range of fin tip temperatures across the range of convective heat transfer coefficient. For triangular section at a thickness of 0.5mm, the temperature drops from 94.62 ^{o}C to 84.44 ^{o}C. If we compare it cross section-wise, the triangular geometry comes with less tip temperature mainly due to lower resistance as compared to the rectangular section but on the other hand, comparing the same cross section at a different base thickness (t = 0.28mm) it results in higher tip temperature due to increased thermal inertia. Lower thermal conductivity of carbon steel when compared to aluminum can also explain the differences between the fin tip temperatures of the two materials. As the base-thickness of the fin increases, the slope of the graph starts decreasing indicating that at higher thicknesses the tip temperatures are not varying significantly with any changes in ‘h’. This can be due to higher thermal inertia of the fin due to its larger mass.

3.3 Effect of fin geometry and material on fin efficiency

Figures 5a, 5b, 6a and 6b reflect the effect fin geometry and material on the fin efficiency. Heat transfer from the fins to the surroundings is done through convection process. The heat transfer process depends upon the difference of the surface and surrounding temperatures. Owing to the material’s finite thermal conductivity, the temperature drops along the fin length, making the heat transfer process less effective towards the end of the fin. Ideally the heat transfer will be maximum when the temperature along the fin length remains the same as the fin-base temperature but this does not happen in practice. The possible heat transfer



(a)



(b)

Fig. 5: Effect of fin geometry on the fin efficiency for rectangular (a) and triangular (b) aluminum fins for a range of convective heat transfer coefficient

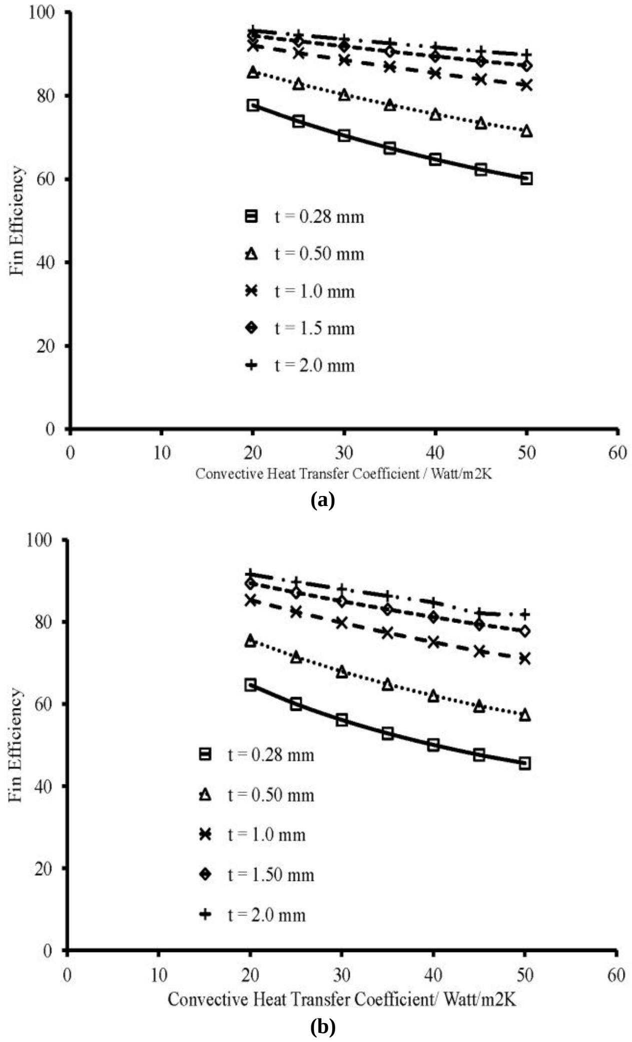


Fig. 6: Effect of fin geometry on the fin efficiency for rectangular (a) and triangular (b) aluminum fins for a range of convective heat transfer coefficient

in the ideal and the real cases is used to define the fin efficiency.

$$\eta_f = \frac{q_f}{q_{max}}$$

where q_{max} represents an ideal situation where the fin is made of a material with infinite thermal conductivity, whereas q_f represents the actual heat transfer. For all cases, the fin efficiency has decreased when the convective heat transfer coefficient is increased. This has shown to be a function of fin geometry, material and fin base-thickness. As the fin thickness is increased, the fin efficiency becomes less sensitive to any change in the convective heat transfer coefficient. This reduction in the efficiency with the increase in convective heat transfer coefficient can also be physically interpreted.

4. Conclusions

The results of the study can be summarized as below;

- Higher heat transfer or heat dissipation is noted in case of triangular section when compared to the rectangular section.
- Uniform heat dissipation and hence lower tip temperature are recorded in case of triangular section when comparedto the rectangular section. This lower tip temperature can be attributed to the lower resistance offeredby the triangular geometry when compared to the rectangular section but on other hand comparing with same section (t=0.28mm) it results in higher tip temperature due to increased thermal inertia.
- The transfer of heat within a material, i.e., the heat flux, decreases with the increase in material thickness.
- The thermal inertia of fin increases with the increase offin thickness even if the heat flux through the fin decreases. Due to increased thermal inertia the ability of fin to loose temperature decreases and the increased heattransfer is not just enough to reduce the tip temperature.
- Large amount of heat is transferred in case of aluminum when compared to the corresponding thickness of the carbon steel material. This can be attributed to the higher thermal conductivity of aluminum as compared to carbon steel.

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