Study of Thermal Performance of Longitudinal Fin of Rectangular Profile for Different Materials

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Abstract— One-dimensional heat conduction in a longitudinal rectangular fin for different fin materials (AISI 316, Aluminium, Copper) have been numerically investigated. In the present study laminar, one-dimensional, steady state thermal conduction, convection is considered for the analysis. The heat energy balance equation for the concerned longitudinal rectangular fin is formulated and further solved in MATLAB R2014a for evaluating total heat transfer rate, fin efficiency and fin effectiveness. The same longitudinal rectangular fin is modelled and simulated in FLUENT solver of ANSYS R16. Obtained simulated results are validated with exact solutions found from MATLAB R2014a and these results show a good agreement between with both of results with some error. It is observed from the result that the thermal conductivity widely affects the heat transfer rate, fin efficiency and fin effectiveness. The result shows that heat transfer rate increases with the increase in thermal conductivity of material. This work could explore further with some more common industrial fin materials to finding their thermal behaviour with different fin parameters.

Key words: Longitudinal Rectangular Fin, Thermal Conductivity, Fin Efficiency, Fin Effectiveness

I. INTRODUCTION

Fins are extended surface, which provides better heat transfer rate from the primary surface via conduction, radiation and mainly convection, because of increase in heat transfer area for heat flow. These have wide applications in various devices such as electronic components, compressors, transformers, refrigerators, boiler superheater tubes, condenser coils, air cooled engines, etc. There is not enough capacity in a normal surface to maintain the surface at an optimum temperature by losing heat to the environments. So this optimum temperature is obtained by extending the surface by attaching fins which enhances heat transfer by convection between a surface and the fluid surroundings. Agarwal et.al [1] presented the modern mathematical techniques for the temperature distribution in straight profile fin. Aziz and Bouaziz [2] using the least square method for a longitudinal fin with temperature dependent and conclude that the double linearization method gives better method as compared to the other alternative method. The heat distribution in rectangular fin using a Finite Element Method and Differential Quadrature Methods is investigated by Basri et.al. [3]. Straight fins efficiency with temperature-dependent thermal conductivity is studied by using Variation Iteration Method(VIM) and compared with A domain Decomposition Method(ADM) get a goodness of VIM over ADM. Joneidi et.al. [5] Determine an analytical expression for fin efficiency of the temperature dependent straight fin with DTM method. Kundu [6] analyse the performance of wet fins between humidity ratio and temperature. Torabi and Zhang [7] evaluate the efficiency and thermal performance of straight fins with various fin geometry. Harley and Moitsheki [8] consider a longitudinal fin with a rectangular fin for numerical investigation of the temperature profile.

In this paper, we analysed two methods for the analysis of longitudinal rectangular fin for different material. First one is numerical method, studied by a simple MATLAB code and second one is simulation method, performed on ANSYS FLUENT solver and then converts its results in numerical form.

II. PROBLEM FORMULATION

Consider a longitudinal rectangular fin of the length L, perimeter P, with a constant cross-section area A_c and surface area A_s. Fin surface is exposed to a convective surrounding at temperature T_∞. The convective heat transfer coefficient h along the fin surface is constant, and the constant thermal conductivities of different materials are taken as k_{Cu} (Copper), k_{Al} (Aluminium) and $k_{AISI316}$ (Stainless Steel).

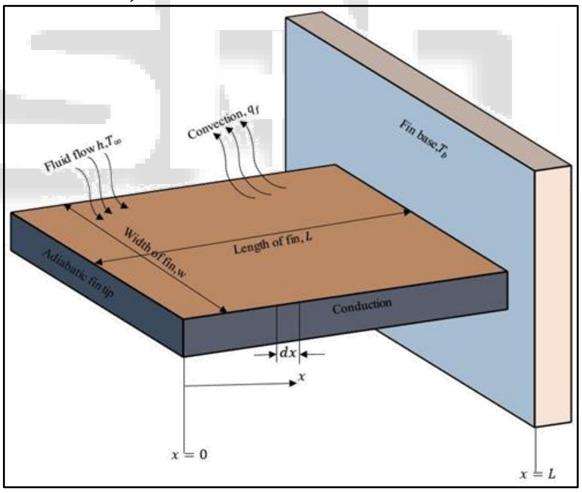

Fig. 1: Geometry of longitudinal rectangular fin

One dimensional steady state differential energy balance for longitudinal rectangular fin can be expresses as,

$$\frac{d}{dx}\left[kA_c\frac{dT}{dx}\right] - h\frac{dA_s}{dx}(T - T_\infty) = 0 \quad (1.1)$$

$$\text{Or, } \frac{d^2T}{dx^2} - \frac{hP}{kA_c}(T - T_\infty) = 0 \quad (1.2)$$

On solving (1.2) a second order differential equation we get the temperature profile along fin length in x direction of longitudinal rectangular fin as:

$$\frac{T(x)-T_\infty}{T_b-T_\infty} = \frac{\left(\sin hm(L-x)+\frac{h}{mk}\cos hm(L-x)\right)}{\left(\cos hmL+\frac{h}{mk}\sin hmL\right)} \quad (1.3)$$

$$\text{Where } m^2 = (h.P)/(k.A_c) \quad (1.4)$$

'm' is called a fin parameter.

Total heat transfer rate of longitudinal rectangular fin can be expressed as:

$$\text{Total heat transfer rate, } q_f = -kA_c\left.\frac{dT}{dx}\right|_{x=0} \quad (1.5)$$

$$q_f = \frac{M[\sin hmL + \frac{h}{mk}\cos hmL]}{\cos hmL + \frac{h}{mk}\sin hmL} \quad (1.6)$$

Where $M = \theta_b\sqrt{kA_chP}$ (1.7)

since $KA_ch = KA_c\sqrt{\frac{hP}{KA_c}} = \sqrt{KA_chP}$ (1.8)

Fin effectiveness (ϵ) is calculated as;

$$\epsilon = \frac{\text{Energy transfer with fin}}{\text{Energy transfer without fin}} = \frac{q_f}{hA_c\theta_b} \quad (1.9)$$

Fin efficiency (η) is calculated as;

$$\eta_f = \frac{\text{Energy transfer with fin}}{\text{Max the energy that could be transferred with fin}} = \frac{q_f}{q_{max}} = \frac{q_f}{hA_s\theta_b} \quad (1.10)$$

Parameters	Values
L (m)	0.1
w (m)	0.05
t (m)	0.002
h (W/m^2-k)	100
T_b (K)	373
T_∞ (K)	298
k_{Al} (W/m-k)	180
$k_{AISI316}$ (W/m-k)	14
k_{Cu} (W/m-k)	398

Table 1: Geometrical and Thermal Properties Parameters of Fin

III. SIMULATION OF PROBLEM IN ANSYS

The same fin problem is modelled in ANSYS R16 and solved in FLUENT solver for its thermal performance analysis.

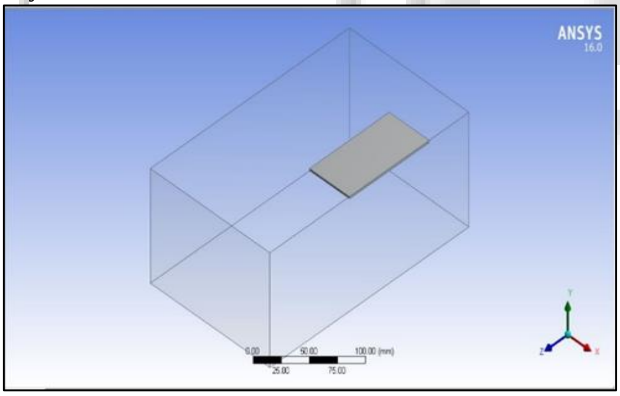

Fig. 2: Isometric view of mesh generation

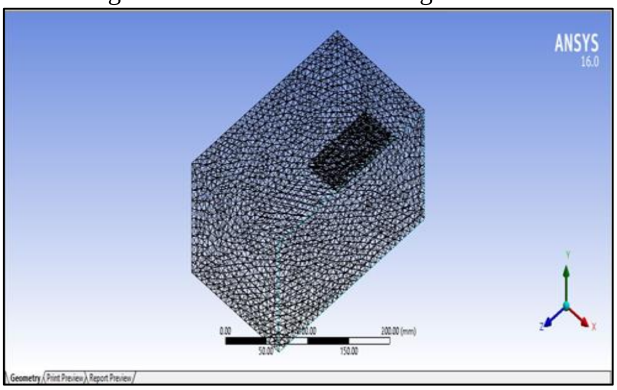

Fig. 3: Isometric view of mesh generation

Properties at 335.5 K	AISI316 (Stainless Steel)	Al	Cu
Density(ρ) (in kg/m3)	8238	2707	8954
Specific Heat capacity(Cp) (in J/Kg-K)	468	896	383
Thermal Conductivity (in W/m-K)	14	180	398

Table 2: Thermo-Physical Properties of Fin Material

The physical properties involved in these calculations such as density, thermal conductivity, specific heat were taken for different materials at mean temperature, where mean temperature is taken as,

$$T_m = \frac{373+298}{2} = 335.5 \text{ K}$$

Fluid media = Incompressible ideal gas
Inlet temperature = 298 K
Fin base temperature = 373 K
Inlet velocity = 2.00 m/s
The outlet of the duct kept open to the atmosphere
The physical and geometrical assumptions are following:

1) The flow is laminar and steady.
2) The fluids are incompressible, Newtonian with constant properties.
3) Flow and heat transfer is three dimensional.
4) The pressure gradient is in axial direction only.
5) The energy dissipation is negligible.

IV. RESULTS AND DISCUSSION

In this paper steady-state heat transfer in a longitudinal regular fin was studied. By solving the governing equations using FLUENT solver the heat flux and temperature distribution are determined in the solid domains of rectangular fin. Fig. 4, Fig. 5 and Fig. 6 shows the temperature variation along the fin length for different thermal conductivity material taken in this study.

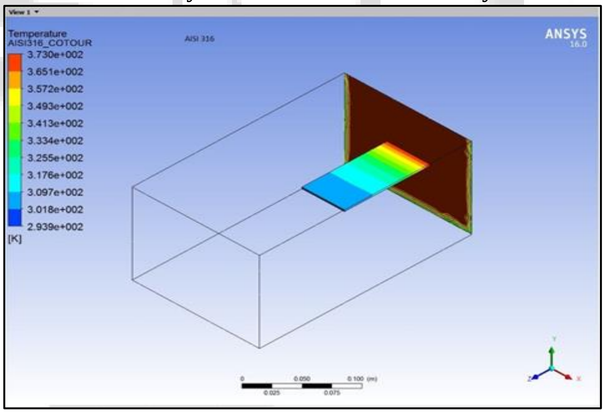

Fig. 4: Temperature variation for AISI 316 Stainless steel longitudinal rectangular fin material

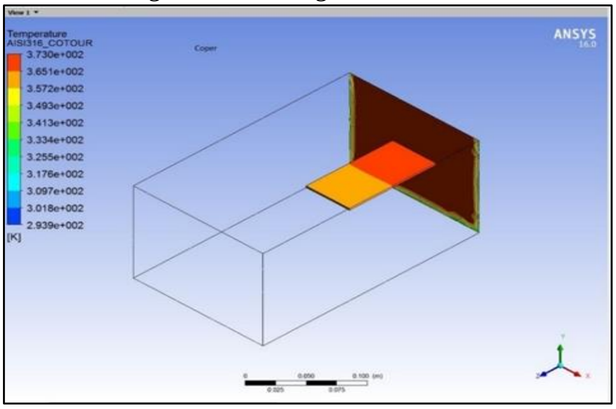

Fig. 5: Temperature variation for Copper longitudinal rectangular fin material

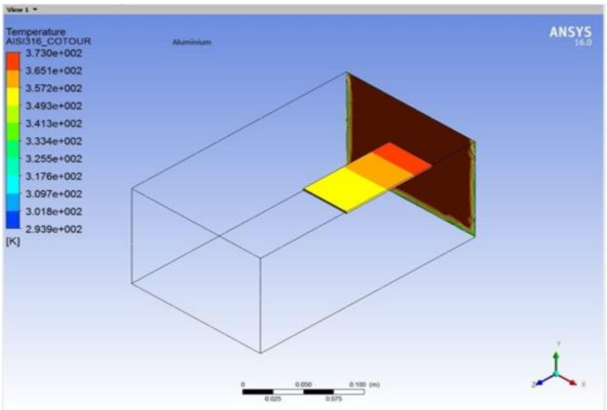

Fig. 6: Temperature variation for Aluminium longitudinal rectangular fin material

Further simulated results are extracted and calculated numerically and find net heat transfer rate q_f, Fin Efficiency η_f and Fin effectiveness ϵ_f as shown in TABLE III.

Fin Materials	**Heat Transfer Rate q_f, (in W)**	**Fin Efficiency η_f (in %)**	**Fin effectiveness ϵ_f(Dimensionless)**
Cu	761.57	88.5	10.14
Al	685.34	79.64	9.12
AISI316 (Stainless Steel)	278.14	32.32	3.7

Table 3: Results from Simulation of Present Problem

Now the similar study is carried out in MATLAB and (1.3), (1.6), (1.9) and (1.10) are solved and obtained results as tabulated in Table 4.

Fin Materials	**Heat Transfer Rate q_f, (in W)**	**Fin Efficiency η_f (in %)**	**Fin effectiveness ϵ_f (Dimensionless)**
Cu	775.53	91	10.34
Al	700.11	82	9.33
AISI316 (Stainless Steel)	284.75	33	3.8

Table 4: Analytical Solutions of Present Problem In Matlab

Fin Material	**Error in Heat Transfer Rate q_f (in %)**	**Error in Fin Efficiency η_f (in %)**	**Error in Fin effectiveness ϵ_f ((in %)**
Cu	1.8	2.75	1.98
Al	2.11	2.88	2.24
AISI316 (Stainles s Steel)	2.32	2.05	2.59

Table 5: Errors in Percentage between Results Of Matlab And Ansys

When we compare results of both approach, we find a good agreement between simulated results and MATLAB results with some error as shown in TABLE V.

Temperature distribution depicted in Fig. 7 provide a clear difference between lower to higher thermal conductivity material for the better suitability of fin according to their application in industrial or engineering disciplines. In Fig. 8 a comparative preview is depicted among heat transfer rate, fin efficiency and fin effectiveness for results obtained by simulation study in ANSYS and numerical study of MATLAB. As expected maximum heat transfer rate occurs at longitudinal rectangular fin of copper material.

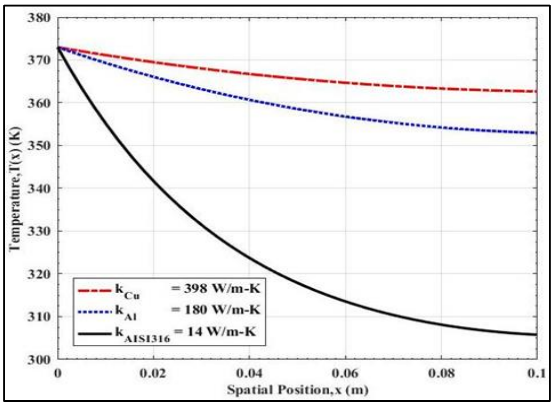

Fig. 7: Temperature profiles of fin for different materials

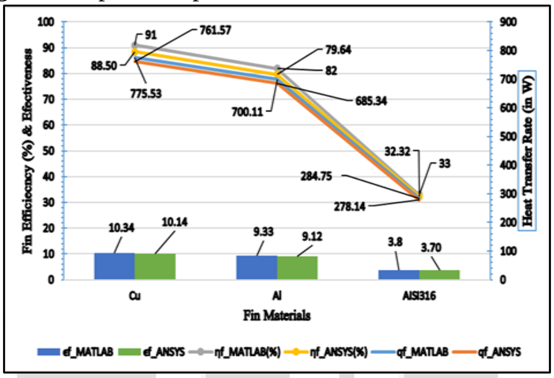

Fig. 8: Comparison chart of the heat transfer rate, efficiency and effectiveness for different materials of rectangular fin

V. CONCLUSIONS

The effect of different thermal conductivity materials on longitudinal rectangular fin heat transfer is analysed numerically and with simulation method on software and to find best fin for different material selection criteria is reported in this study. The static temperature of longitudinal rectangular fin with the no-slip velocity boundary conditions at the walls have been investigated numerically. The analysis uses the continuum model, which includes the conventional Navier-Stokes equations and the conventional energy equation. From the present work following points are concluded.

1) The heat transfer rate, efficiency and effectiveness is increases with increase in thermal conductivity of fin material.
2) The fin efficiency is maximum for Copper followed by Al and then AISI316.
3) The fin effectiveness is maximum for Copper followed by Al and then AISI316.
4) Best fin material is Copper among three of them taken in this study.

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