ICMIEE18-321

Comparative Numerical Analysis of Heat Transfer between Nonporous and Porous Cylindrical Fins

Farida Ahmed Koly, Abu Raihan Ibna Ali, Moham Ed Abdur Razzaq, and Mostafizur Rahman*
Dept. of Mechanical Engineering, Chittagong University of Engineering & Technology, Chittagong-4349, BANGLADESH

ABSTRACT
Fin is the easiest and cheapest way in enhancing heat transfer of all other methods like increasing fluid velocity, ionizing fluids, using additives, causing vibration etc. It has a lot of applications in the growing number of engineering disciplines. The main purpose of this paper is to enhance heat transfer of cylindrical fin by perforated and axial holes which increases surface area but decreases material cost. Finding out the proper length of the fin is another goal of this paper which also reduces fin size and material cost. Steady state thermal simulation has been done using ANSYS 17. An attempt is made to find out temperature distribution by varying geometry, materials. Investigations show that porous cylindrical fin drops maximum temperature and hence maximum heat transfer occurs because of the increasing ratio of perimeter to cross sectional area. Porous cylindrical fin also has light mass with low cost. And proper length of cylindrical fin increases with the increase in diameter.

Keywords: *Thermal Analysis, Heat Transfer, Porous Fin, Proper Length*

1. Introduction

Growing number of engineering disciplines are concerned with rapid heat transfer rate. In this respect, fins are used to increase the heat transfer rate. Fins are widely used in car radiators, electronic components, heat exchanger, internal combustion engine etc. The study of heat transfer of fin comprises of three factors. One factor is conduction of heat through the fin. The other considers how fin exchanges heat by convection with the surrounding environment. And the third factor is radiation. Heat transfer by conduction can be improved by using high conductivity materials. On the other hand, heat transfer by convection depends on the heat transfer coefficient, surface area, and temperature difference. Heat transfer rate can be increased by increasing heat transfer coefficient by increasing the velocity of the fluid, inserting materials, causing vibration, ionizing the fluid, using additives. But these methods are either costly or have some negative effects on the material. So, the easiest way is to increase the surface area by using light material but low cost.

Fins of different size, shape, and material possess different fin efficiencies. Cylindrical fin has excellent fin efficiency which can be increased by perforated and axial holes. These holes add extra surface area which increase perimeter to cross sectional area and decrease material cost. Perforated holes create a variable cross-sectional area along fin length. It also increases fin effectiveness. S. Kiwan and Al-Nimr [1] suggested altering conventional fin with a porous fin for the improvement of heat transfer. U. V. Awasarmol et al [2] performed an experiment on the perforated rectangular fin. He showed that heat transfer gradually increases with the increase in perforation size. D. H. Lee et al [3] found that heat transfer can be improved with perforated circular holes in the finned tube. D. Bhanja et al [4] noticed an increase in heat transfer by selecting porous medium condition in the T shaped fin. S. Y. Kim et al [5] investigated porous fin in a plate-fin heat exchanger and found that heat transfer is more in porous fins with low permeability and low porosity. Thermal analysis was performed by M.T. Darvishi et al [6] for heat transfer in fully wet porous fins. Their investigations showed that heat flow increases for high permeability of the medium. They also showed that heat flow increases when the buoyancy effect induced in the fluid is strong. M. Liu et al [7] experimentally investigated pressure drop and heat transfer in a copper micro square pin fin heat sink. They observed that pressure drop and Nusselt number of the system increases with the increase in Reynolds number. S. Pashah et al [8] performed a numerical solution for wet hyperbolic annular fins in wet operating conditions. Heat transfer of wavy fins was analyzed by A.A. Khaled [9]. Waqar Ahmed Khan [10] performed numerical simulations for a single circular cylinder and in-line pin fin heat sink and developed average heat transfer coefficient.

Heat transfer can also be enhanced by Nano coating on fin surface which has an excellent effect on the rate of heat transfer. Terry J. Hendricks et al, [11] had made a conclusion that Nano coating of ZnO_2 over aluminum increases heat transfer ten times.

After a certain length, it does not contribute so much in enhancing heat transfer rate rather increases cost and size of fin. So, finding out proper length of the fin is also important. J. D. Forero et al, [12] proved that proper length of rectangular fin increases with the increase in fin thickness of fin. A. Aziz [13] has

* Corresponding author. Tel.: +88-016833941218
E-mail addresses: faridakoly@gmail.com

provided expressions for optimum diameter and fin height for the cylindrical fin. S. Kiwan [14] found that after certain length there is no improvement in fin performance for the increase in fin length.

Analysis of heat transfer in extended surface involves solving second order differential equations. The solution is still easy for the typical simple geometrical fin. When fin involves complex shape with the variable cross-sectional area, analytical solutions become troublesome. In this case, simulation is the best way for analysis.

In the present work it is intend to see the comparative heat transfer rate of new type of cylindrical fin having axial and perforated holes. Also, impact of proper length with the increase in diameter of the cylindrical fin was also investigated. Mass of fins with axial and perforated holes is compared.

Here, five different models of cylindrical fins were modeled by SolidWorks 2016 and steady-state thermal simulation had been performed by ANSYS 17. An investigation was performed to observe temperature distribution and total heat flux contour.

2. Modeling

Four different types of cylindrical pin fins were designed using SolidWorks 2016.

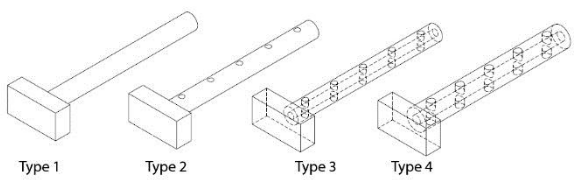

Fig. 1 Cylindrical Fins with and without perforated and axial hole

Type 1, type 2, type 3 fins are used to observe the heat transfer rate by adding perforated holes and axial holes. Type 4 fin is used to observe proper length with the increase in diameter.

Table 1 Specifications of Fins (holes).

Fin	Hole	Number of perforated holes
Type 1	No hole	0
Type 2	• Perforated holes • No axial hole	5
Type 3	• Perforated holes • Axial hole	5
Type 4	• Perforated holes • Axial hole	5

Table 2 Specifications of Fins (length & diameter).

Fin	Length (mm)	Diameter of fin (mm)	Diameter of axial hole (mm)	Diameter of perforated hole (mm)
Type 1	150	15	0	0
Type 2	150	15	0	5
Type 3	150	15	6	5
Type 4	150	20	8	6.67

Specifications of the base:

- Length = 50 mm
- Width = 25 mm
- Thickness = 15 mm

3. Materials

Because of the high thermal conductivity, aluminum and copper were used in simulations. Aluminum has corrosion resistance and is also cheaper than copper.

Table 3: Material Properties (Aluminum)

Property	Symbol	Values (Aluminum)	Values (Copper)
Thermal conductivity ($W\ mm^{-1}\ C^{-1}$)	K	0.2375	0.4
Specific heat ($mJ\ kg^{-1}\ C^{-1}$)	C_p	9.51e+005	3.85e+005
Density ($kg\ mm^{-3}$)	ρ	2.689e-006	8.933e-006

4. Meshing

After selecting the material, mesh has been created for the geometry. Inflation growth rate was 1.2 with maximum 5 layers. Total numbers of nodes were 457180, 537502, 486969, 752633 for type 1, 2, 3, 4 respectively. Total numbers of elements were 108653, 325162, 283135, 473878 for type 1, 2, 3, 4 respectively with element size 0.9 mm.

5. Assumptions

Following assumptions are made during the simulation.

I. Steady state condition
II. Radiation is negligible
III. Uniform heat transfer coefficient ‘h’ over the entire fin surface
IV. No heat generation within the fin itself
V. The thermal conductivity of the material is constant
VI. Homogeneous and isotropic fin material

6. Boundary Conditions

Here, radiation is neglected as its magnitude is low.

Base temperature = 300 °C

Film Coefficient = 1.8e-005 W/mm² °C

Ambient Temperature = 28. °C

7. Numerical Solutions

With the help boundary conditions, simulations have been done in ANSYS 17 for different types of fins with different materials

8. Result and Discussion

8.1. Without Perforated and Axial Holes (Type-1)

This type is a simple cylindrical pin fin without perforated and axial holes.

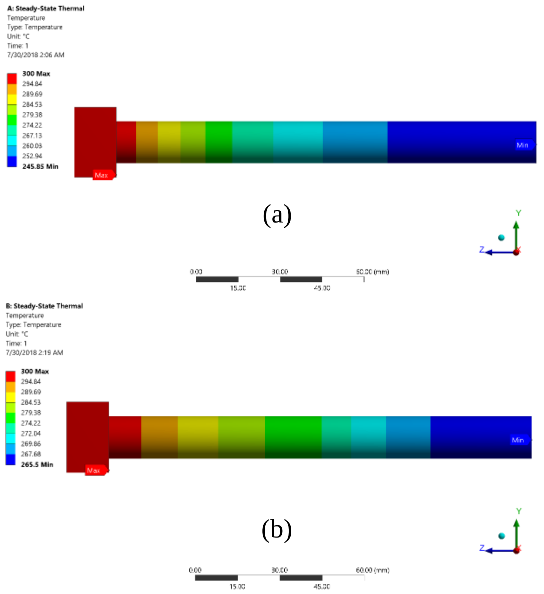

Fig. 2 Temperature distribution contour -Aluminum (a), Copper (b)

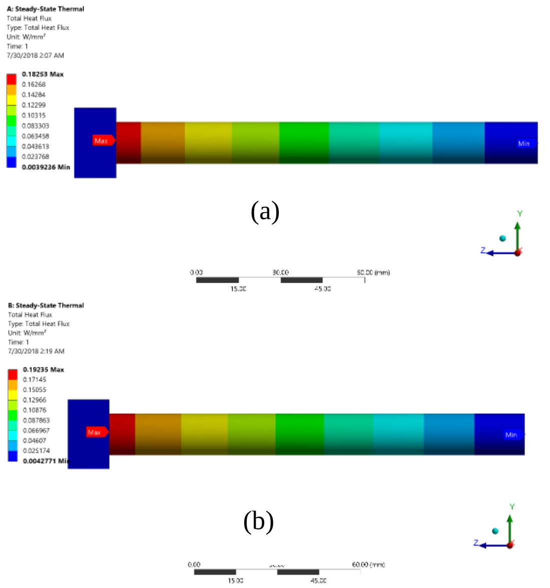

Fig. 3 Total Heat Flux Contour -Aluminum (a), Copper (b)

8.2. With Perforated and No Axial Holes (Type-2)

This type of fin has perforated hole but doesn't have an axial hole and has a higher ratio of perimeter to cross-sectional area than type 1 fin.

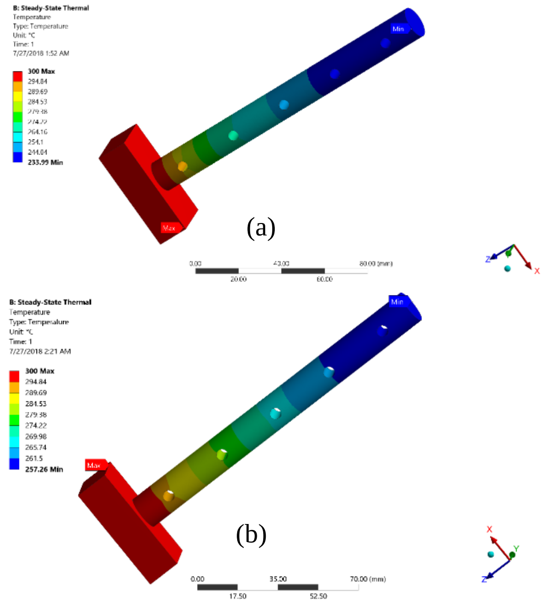

Fig. 4 Temperature distribution contour -Aluminum (a), Copper (b)

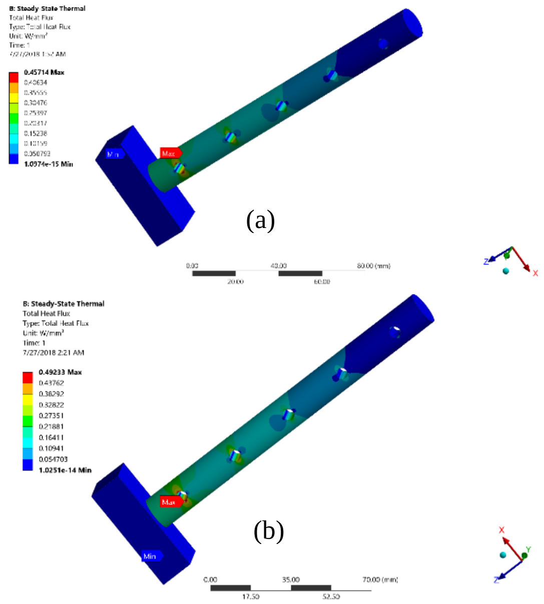

Fig. 5 Total Heat Flux Contour -Aluminum (a), Copper (b)

8.3. With Perforated and Axial Holes (Type-3)

This type of fin has perforated and axial hole with highest temperature drop among first three type of fin. These holes add extra surface area. This type of fin has the highest P/A ratio among the first three types of fins.

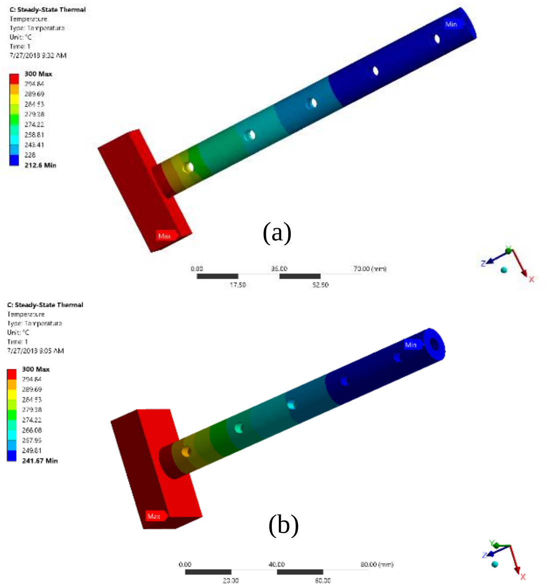

Fig. 6 Temperature distribution contour -Aluminum (a), Copper (b)

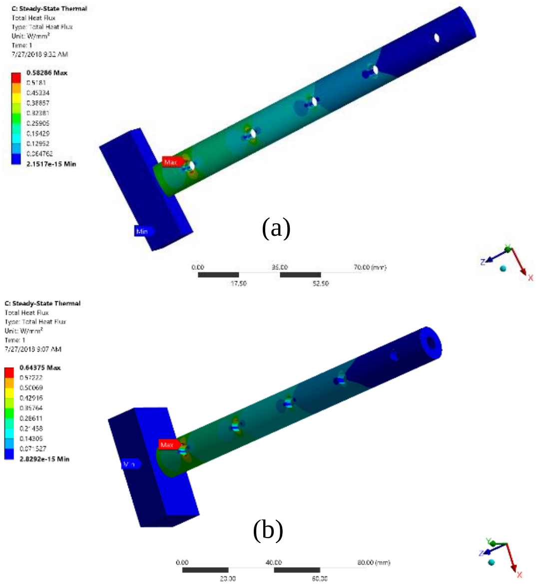

Fig. 7 Total Heat Flux Contour -Aluminum (a), Copper (b)

8.4. Comparative Temperature Profile for Type 1, 2, 3 Fins

Table 4: Maximum & Minimum Temperature, Heat Flux of Aluminum Fins.

Type	Maximum temperature (°C)	Minimum temperature (°C)	Maximum heat flux (W/mm^2)	Minimum heat flux (W/mm^2)
Type 1	300	245.85	0.18253	0.0039236
Type 2	300	233.99	0.45714	1.0974e-15
Type 3	300	212.6	0.58286	2.1517e-15

Table 5: Maximum & Minimum Temperature, Heat Flux of Copper Fins.

Type	Maximum temperature (°C)	Minimum temperature (°C)	Maximum heat flux (W/mm^2)	Minimum heat flux (W/mm^2)
Type 1	300	265.5	0.19235	0.0042771
Type 2	300	257.26	0.49233	1.0251e-15
Type 3	300	241.67	0.64375	2.8292e-15

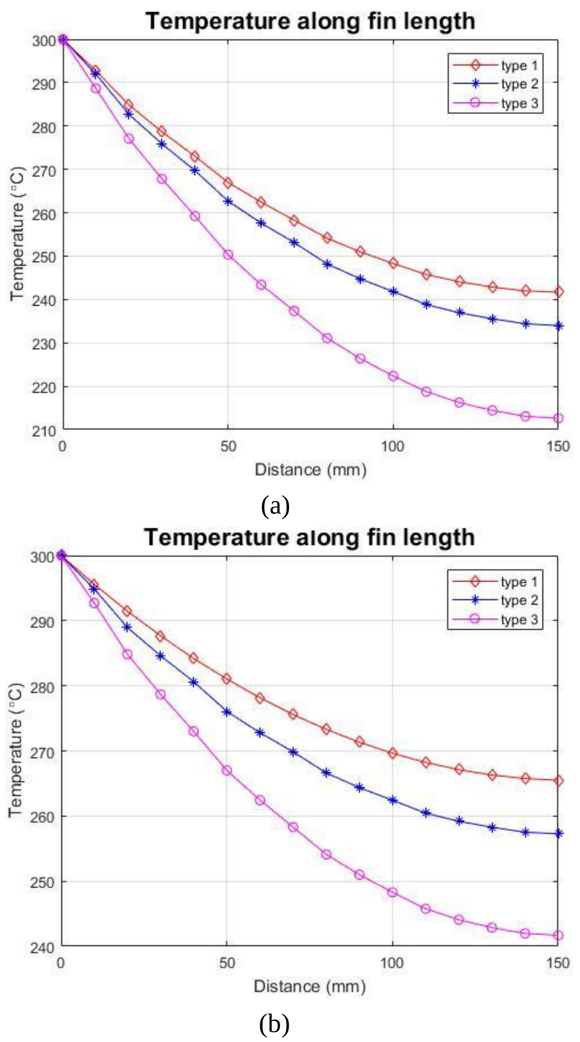

Fig. 8 Comparison of Temperature profile of types 1,2,3 -Aluminum (a), Copper (b)

Figure 8(a) shows temperature along the length for three types of fins with aluminum materials. Temperature decreases exponentially with a downward slope for these three types of fins. Minimum temperatures of the first three types of fins with aluminum materials are 245.85 °C, 233.99 °C, 212.6 °C respectively. Maximum temperature drops in type 3 aluminum fin. The increasing order of maximum temperature drop of the aluminum fin of three type is Type 3 > Type 2 > Type 1.

Maximum temperature drop means maximum heat transfer. Perforated holes and axial hole add extra surface area and increase ratio of perimeter to cross sectional area. When this ratio increases, fin effectiveness also increases. Hence Maximum temperature gradient occurs in type 3 which has most fin effectiveness.

Figure 8(b) shows that temperature decreases exponentially which has a downward slope for these three types of fins. Minimum temperatures of the first three types of fins with copper materials are 265.5 °C, 257.26 °C, 241.67 °C respectively. Maximum temperature drops in type 3 copper fin. The increasing order of maximum temperature drop of the copper fin of three type is Type 3 > Type 2 > Type1.

Copper has comparatively low conduction resistance. That's why at the tip for same geometrical fin with copper material has high temperature than aluminum. But maximum heat flux is higher than aluminum. So, copper fin for same geometry has high fin effectiveness.

Maximum temperature drop means maximum heat transfer. Perforated holes and axial hole add extra surface area and increase ratio of perimeter to cross sectional area. Hence Maximum temperature gradient occurs in type 3 which has most fin effectiveness. Figure 8(a) and 8(b) has mainly two regions. They are high-temperature zone and low-temperature zone. If the fin is very long fin it will reach the environment temperature at some length which doesn't contribute to heat transfer. It does not contribute to heat transfer in figure 8(a) and 8(b) when the slope of the curve will be zero. So, length of fin is preferable in the region where the temperature gradient is not zero. Again, after a certain length, temperature drops little though length increases much. Fins having such length are not economical and feasible. So, our aim is to design fin in such length where the temperature gradient is high. This is called proper length. Figure 8 depicts temperature gradient is low after around two-thirds of the length. Fins having a length between this region will reduce both cost and size. Closely spaced more fins contribute more heat transfer than a single fin.

3.5. Comparative Mass of Fins

Table 6: Mass of Fins

Fins (Aluminum)	Mass (gm)	Volume (mm^3)
Type 1	71.28	26507
Type 2	67.375	25056
Type 3	57.401	21345

Because of the perforated holes on type 2 fin, 4.8% mass decreases. On the other hand, 19.47% mass decreases for type 3 fin. Type 3 fin has the lowest mass with maximum temperature drop. It not only has a high heat transfer rate but also less mass which reduces cost and weight.

8.6. Impact of Proper Length with the Increase in Diameter (Type- 4)

All the holes and diameter are increased in 33.33% of type 3 fin.

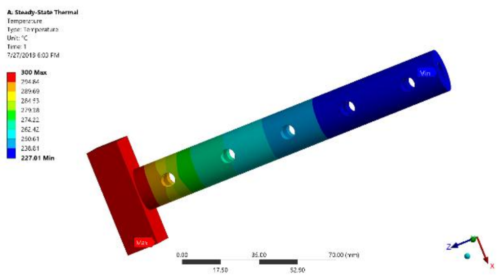

Fig. 9 Temperature distribution contour for type-4 aluminum fin

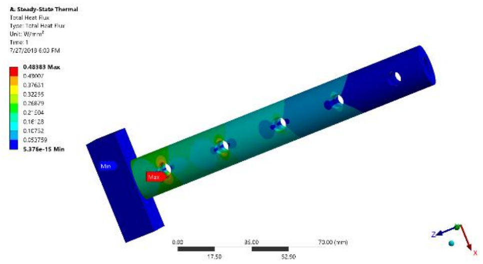

Fig. 10 Total Heat Flux Contour for Type-4 Aluminum Fin

Table 7: Maximum & Minimum Temperature, Heat Flux of Type-4 Aluminum Fin.

Maximum temperature (°C)	Minimum temperature (°C)	Maximum heat flux (W/mm^2)	Minimum heat flux (W/mm^2)
300 °C	227.01	0.48383	5.376e-15

8.7. Comparison of Proper Length

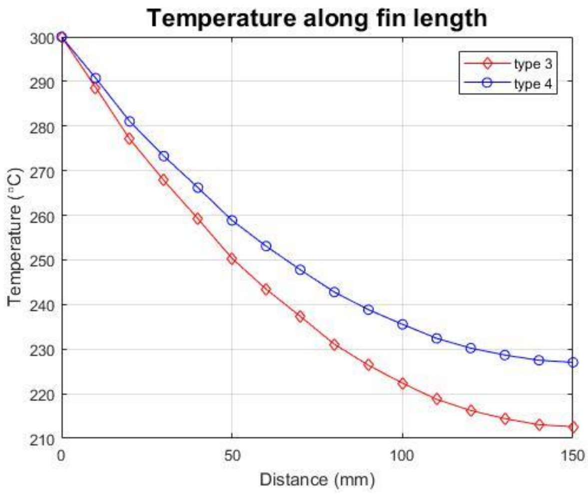

Fig. 11 Temperature profile for aluminum (type 3 and type 4)

Figure 11 shows a comparison of temperature profile between type 3 and type 4 with aluminum material. Tip temperature of type 4 aluminum fin is higher than type 3 aluminum fin. Tip temperature difference for type 3 & type 4 aluminum fin is 14.4 °C. Temperature drop will still occur if we add extra length. So, proper length increases for type 4 fin. Hence, proper length increases with the increase in diameter.

9. Conclutions

The outcomes of the present analysis are as follows.

I. Copper has a high heat transfer rate than aluminum because of higher thermal conductivity. But aluminum is cheaper than copper and also has high corrosion resistance.

II. Temperature drop increases for the perforated and axial hole.

III. Type 3 fin allows maximum heat transfer rate as temperature drop of it is the highest among the first three types of fins. Order of heat transfer rate of the first three types of fins is Type 3 > Type 2 > type 1

IV. Type 3 fin has the highest perimeter to cross-sectional area ratio among first three fins and that's why it has a high heat transfer rate.

V. The proper length of the cylindrical fin increases with the increase in diameter.

VI. Type 3 fin has the lowest weight of the first three types of fins which decrease material waste.

REFERENCES

[1] S. Kiwan and M. A. Al-Nimr, Using Porous Fins for Heat Transfer Enhancement, *Journal of Heat Transfer*, Vol. 123, pp 790–795 (2000).

[2] U. V. Awasarmol and A. T. Pise, An experimental investigation of natural convection heat transfer enhancement from perforated rectangular fins array at different inclinations, *Experimental Thermal and Fluid Science*, Vol. 68, pp 145–154 (2015).

[3] D. H. Lee, J. M. Jung, J. H. Ha, and Y. I. Cho, Improvement of heat transfer with perforated circular holes in finned tubes of air-cooled heat exchanger, *International Communications in Heat Mass Transfer*, Vol. 39, pp 161–166 (2012).

[4] D. Bhanja, and B. Kundu, Thermal analysis of a constructal T-shaped porous fin with radiation effects, *International journal of refrigeration*, Vol. 34, pp 1483-1496 (2011).

[5] S.Y. Kim, J.W. Paek, and B.H. Kang, Flow and heat transfer correlations for porous fin in a plate-fin heat exchanger, *Journal of heat transfer*, Vol. 122, pp 572-578 (2000).

[6] M.T. Darvishi, R.S.R. Gorla, F. Khani, and B.J. Gireesha, Thermal analysis of natural convection and radiation in a fully wet porous fin, *International Journal of Numerical Methods for Heat & Fluid Flow*, Vol. 26, pp.2419-2431 (2016).

[7] M. Liu, D. Liu, S. Xu, and Y. Chen, Experimental study on liquid flow and heat transfer in micro square pin fin heat sink, *International Journal of Heat and Mass Transfer*, Vol .54, pp 5602-5611 (2011).

[8] S. Pashah, A. Moinuddin, and S. M. Zubair, Thermal performance and optimization of hyperbolic annular fins under dehumidifying operating conditions – analytical and numerical solutions, *International Journal of Refrigeration*, Vol. 65, pp 42–54 (2016).

[9] A.A. Khaled, Thermal performance of six different types of wavy-fins, *International Journal of Numerical Methods for Heat & Fluid Flow*, Vol. 2, pp 892-911 (2015).

[10] Waqar Ahmed Khan, Modeling of Fluid Flow and Heat Transfer for Optimization of Pin-Fin Heat Sinks, Ph. D. Thesis, University of Waterloo, Canada (2004).

[11] Terry J. Hendricks, Shankar Krishnan, Changho Choi, Chih-hung Chang and Brian Paul, Enhancement of Pool Boiling Heat Transfer using Nanostructured Surfaces on Aluminum and Copper, *International Journal of Heat and Mass Transfer*, Vol. 53, pp 3357-3365 (2010)

[12] J. D. Forero, G. V. Ochoa, and L. O. Quiñones, Analysis of Proper Lengths of Straight Rectangular Fins for Different Materials, *Contemporary Engineering Sciences*, Vol. 11, pp 1025 – 1031 (2018)

[13] A. Aziz, Optimum Dimensions of Extended Surfaces Operating in a Convective Environment, *Applied Mechanics Reviews*, Vol. 55, pp. 155-173 (1992)

[14] S. Kiwan, Thermal analysis of natural convection porous fins, *Transport in Porous Media*, Vol. 67, pp 17 (2007).