Comparative Thermal Analysis of Fins

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Abstract. In many engineering applications, heat dissipation is an important factor which if not taken care of may lead to high thermal stresses and mechanical failures. The amount of heat dissipated depends on heat transfer coefficient and surface area which can be enhanced by use of extended surfaces i.e. fins. Thermal Analysis of three fins namely Rectangular, Inclined Non-Uniform Perforated, Twin Extension was performed. The models were designed on Creo Parametric 4.0 and the analysis was carried out using ANSYS Workbench 15.0. The fins were analyzed for forced convection. The fins were compared on the basis of non-dimensional Nusselt number and Reynolds number which proved that Twin Extension fin was the most effective among all the three. It was followed by Inclined Non-Uniform Perforated fin.

Keywords: Twin Extension fin, Rectangular fin, Inclined Non-Uniform Perforated fin, Heat transfer coefficient.

1 INTRODUCTION

The enhancement of heat transfer is an important subject of thermal engineering. The removal of excessive heat from system is essential to avoid overheating. The heat transfer from surface may be enhanced by increasing the heat transfer coefficient between surface and surrounding or by increasing the heat transfer area surface, or by both. Extended surfaces also referred as fins are commonly used for increasing the surface area and enhancing heat transfer coefficient in many industries[1]. The heat conducted through solids, walls or boundaries has to be continuously dissipated to the surrounding or environment to maintain the system in a steady state condition. In many engineering applications large quantities of heat have to be dissipated from small areas. Heat transfer by convection between a surface and fluid surrounding it can be increased by attaching to the surface thin strips of melts called “fins”[2].

Fins are manufactured in different geometries depending upon practical applications. A fin is a solid within which heat transfer by conduction is assumed to be one directional while heat is also transfer by convection from the surface in a direction transverse to that of conduction. The fin surface sticks out from the primary heat transfer surface. The temperature difference diminishes as one moves out along the fin. Fins are classified according to the following criteria: Geometrical design, Arrangement, Number of fluid reservoirs in contact, Location and Composition. Fins are often found in industry especially in heat exchanger industries as in finned tubes of double pipe shell and tube and compact heat exchangers. Moreover fins are also utilized in cooling of large heat flux electronic devices as well as in cooling of gas turbine blades.

The heat transfer and heat transfer coefficient depends on the geometry and material of fins. The geometry and cross-sectional area plays a vital role in determining the effectiveness and efficiency of fin [3]. The heat transfer coefficient increases with increase in turbulence effect which can be increased by notching the surface of fin [4]. Creation of holes i.e. perforation also increases turbulence effect thus increasing heat transfer coefficient [5]. Making grooves also increase the turbulence effect which in turn increases the heat transfer coefficient [6].

Changing materials also may increase or decrease heat transfer. Alloy steel gives more heat dissipation than aluminium steel [7]. The heat transfer can also be increased by use of composite materials. More heat transfer can be achieved in non-metallic radial fins than metallic fin. Non-metallic fins are also easy to manufacture [8]. Thermal flux for Beryllium material was more than other materials like aluminium alloy and magnesium alloy and also thickness plays an important role in heat dissipation [9].

Nusselt number (Nu) is the ratio of convective to conductive heat transfer across (normal to) the boundary [17].

$$\mathrm{Nu} = \frac{\text{Convective Heat Transfer}}{\text{Conductive Heat Transfer}} = \frac{hD}{k} \qquad (1)$$

h = heat transfer coefficient ($W/m^2.k$)
D = Hydraulic Diameter (m)
k = thermal conductivity (W/m.k)

The Reynolds number is the ratio of inertial forces to viscous forces and is a convenient parameter for predicting if a flow condition will be laminar or turbulent [18].

$$\mathrm{Re} = \frac{\text{Inertia Forces}}{\text{Viscous Forces}} = \frac{\rho.V.D}{\mu} (2)$$

ρ = Density (kg/m^3)
V= Velocity of air (m/s)
D = Hydraulic Diameter (m)
μ = Absolute viscosity (Pa.s)

The most important parameter affecting the heat transfer was Reynolds number and secondly geometry of perforation. Utilization of perforated fins increases heat dissipation rate, simultaneously reducing the fin's weight, low weight means saving material of fin [1]. The heat dissipation rate increases with the size of the perforation because of more free convection due to the perforation [10]. Increasing the size of perforation increases the Heat transfer upto a certain limit and then decreases [3]. Increasing the eccentricity of perforation decreases the value of heat transfer coefficient thus the eccentricity of perforation should be as low as possible. At higher value of Reynolds number, heat transfer coefficient becomes almost constant for all the shapes of perforation [11]. The heat transfer rate was more in fins with two perforations in both natural as well as in forced convection compared to solid fins and fins with one perforation. Staggered perforations showed more heat transfer than inline perforation [12].

Fin with extensions provided near about 5 % to 13% more enhancement of heat transfer as compared to fin without extensions. Heat transfer through fin with rectangular extension was higher than that of fin with other types of extensions [13]. It was found that Heat Transfer rate was higher for the copper trapezoidal rod than that of Circular copper rod and rectangular copper rod [14]. The efficiency of fin varied with change in shape even if the fins had same surface area. Parabolic fin was found to be more effective over conical and cylindrical fins [2].The wavy surface increases the length of air flow and also mixes the air flow which leads to increase in heat transfer [15].The percent of relative humidity in air has negligible effect on heat transfer coefficient [16]

2 MODELLING OF FINS

The 3 D modeling of Rectangular, Inclined Non uniform perforated and Twin-extension fins were done using Creo Parametric 4.0 as shown in Fig. 1, 2 & 3. The dimension of base plate was 200m x 55mm x 3mm. The size of fin was 25.4mm x 200mm x 3mm and the fin spacing was 5mm. The size of perforation was 8mm in diameter and the length of extension was 2mm and 1mm at a length of 20mm and 16mm from tip of fin respectively. The thickness of extensions was 3mm.

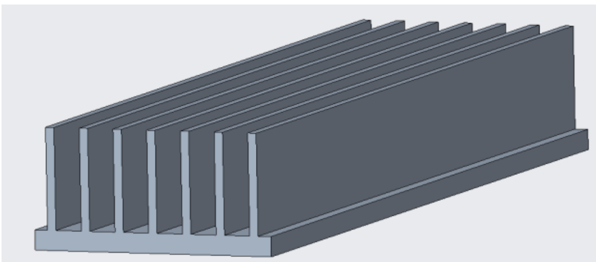

Fig. 1: Rectangular fin

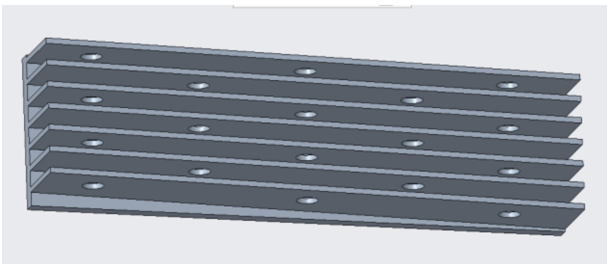

Fig. 2: Inclined Non-Uniform Perforated fin

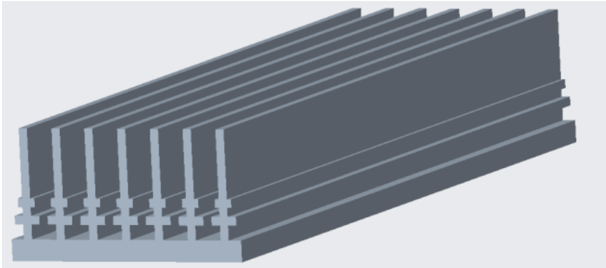

Fig. 3: Twin Extension fin

3 THERMAL ANALYSIS OF FINS

ANSYS Workbench 15.0 was selected as the software for analysis. Fluid Flow (Fluent) was selected as the analysis consisted of a solid surface surrounded by a fluid medium.

Thermal analysis of fin was done in three steps:

Step 1: Design of duct.

An enclosure was created around the fin of dimension 600mm x 80mm x 50mm as shown in Fig. 4. This enclosure will act as duct. The fin model will be placed in the enclosure and air will be flown over it. The hydraulic diameter of the enclosure was 62.53mm. The enclosure created was of same dimension for all three fins.

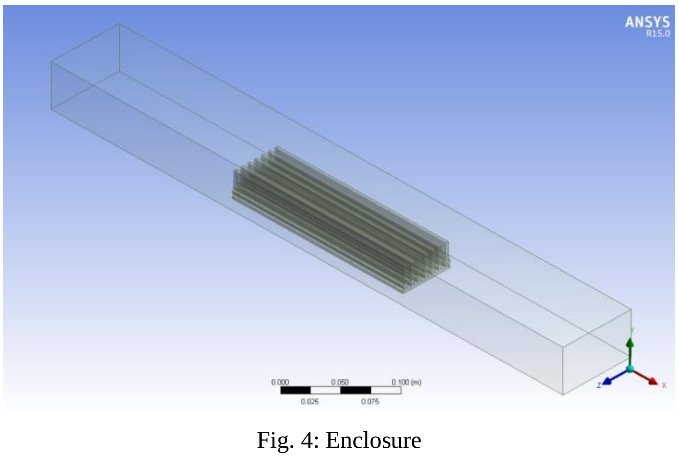

Fig. 4: Enclosure

Step 2: Mesh generation.

Fine meshing was done to get accurate and precise results. The mesh element was tetrahedral because it covers the entire volume of specimen and leaves behind minimal voids as shown in Fig. 5. The mesh was generated and the number of nodes and elements for all fins are shown in Table 1. The specific sections required for boundary conditions such as inlet, outlet, fin surface, heat flux were defined.

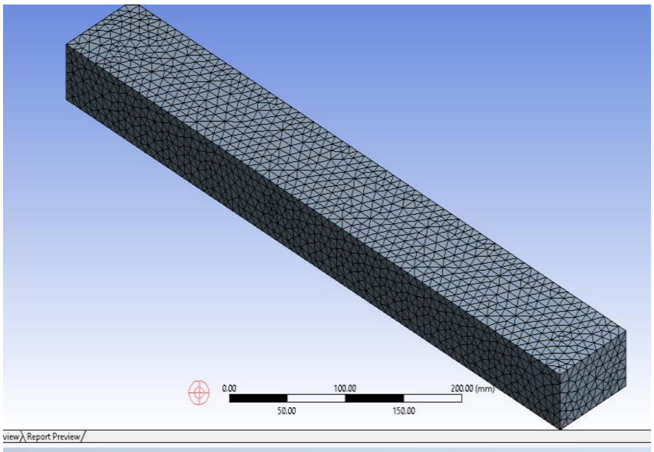

Fig. 5: Mesh generation.

Table 1: Number of nodes and elements

Fin	Number of nodes	Number of elements
Rectangular Fin	8048	27299
Inclined Non-uniform perforated Fin	53348	236255
Twin-Extension Fin	14066	38744

Step 3: Applying input parameters

The prominent input parameters required for analysis of all the three types of fins were Inlet air velocity, Temperature of base plate, Temperature of inlet air and Heat flux. The analysis was carried out selecting Energy model and K-Epsilon model in totake into consideration the turbulence effect. The Table no. 2shows the input parameters which are applicable for all the three fins.

Table 2: Boundary Conditions

Case No.	Inlet Air Velocity(m/s)	Temperature of Inlet Air (K)	Temperature of Base Plate (K)	Heat Flux (W/m^2)
1	1	300	450	5000
2	2			
3	3			
4	4			
5	5			
6	6			
7	7			
8	8			

The equations of Turbulent Dissipation rate, Momentum and Turbulent kinetic energy were selected to be of second order because the basic equation of fin is of second order. The material of fin was chosen to be Aluminium and the fluid flowing through the duct is air. The properties of Aluminium and Air are given below in Table no. 3.

Table 3: Properties

Property	Aluminium	Air
Density(kg/m^3)	2719	1.225
Specific Heat(J/kg.k)	871	1006.43
Thermal Conductivity(W/mk)	202.4	0.0242
Viscosity(kg/m.s)	-	1.7849×10^{-5}

The solution was using Hybrid Initialization as there was no phase change taking place in air from inlet to outlet of duct.

4 RESULTS AND DISCUSSION

After carrying out thermal analysis of the selected three types of fins on ANSYS Workbench 15.0,the following results of heat transfer coefficient were obtained as shown in Fig. 6, 8 & 10 and Table 4, 5 & 6. Moreover from the obtained results, the values of Nu and Re were calculated as shown in Table 4, 5 & 6 and the graphs were plotted as shown in Fig. 7, 9 & 11.

Case 1: Rectangular Fin

Table 4: Rectangular Fin

Sr. No.	Velocity(V)	Heat transfer coefficient(h)	Nusselt No.(Nu)	Reynolds No.(Re)
1	1	18	46.728	5681.7
2	2	28	72.688	11363.4
3	3	40	103.84	17045.1
4	4	51	132.396	22726.8
5	5	59	153.164	28408.5
6	6	65	168.74	34090.2
7	7	76	197.296	39771.9
8	8	81	210.276	45453.6

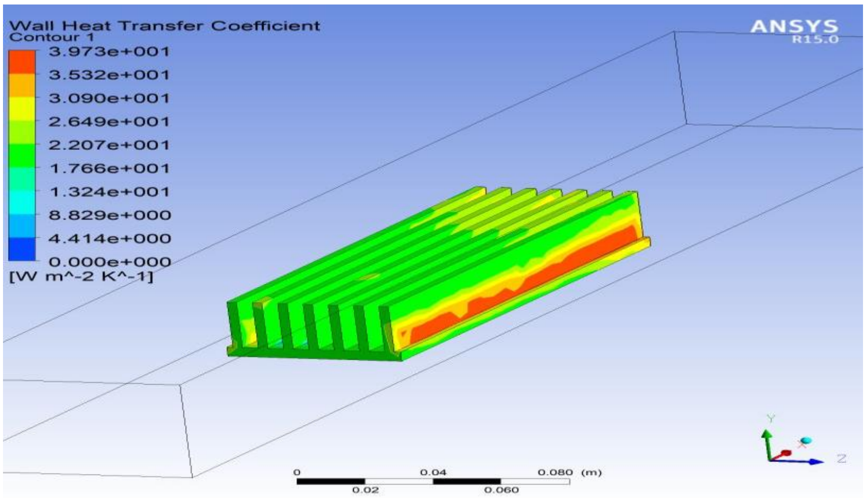

Fig. 6: Contour of Heat Transfer Coefficient for Rectangular fin

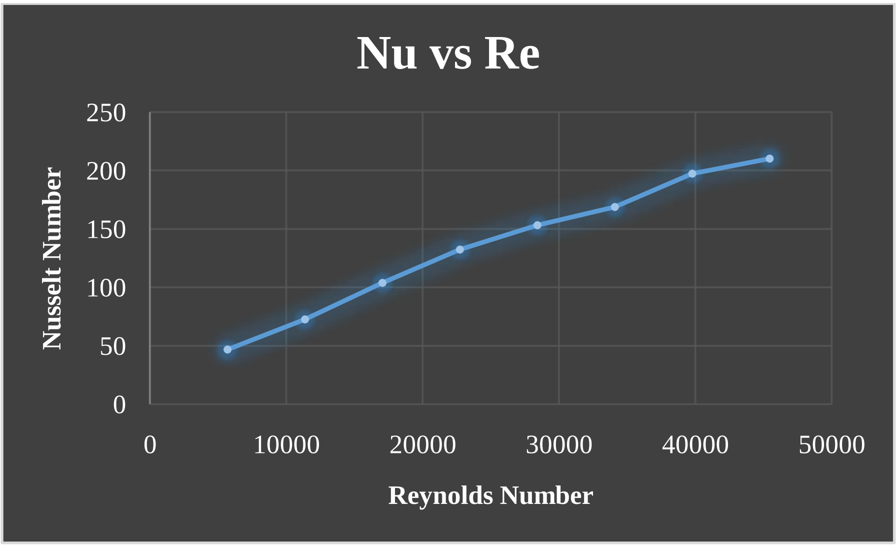

Fig. 7: Graph of Nusselt number V/S Reynolds number for Rectangular fin

Case 2: Inclined Non-uniform perforated Fin

Table 5: Inclined Non-Uniform Perforated fin

Sr. no.	Velocity(V)	Heat transfer coefficient(h)	Nusselt no.(Nu)	Reynolds no.(Re)
1	1	41	106.436	5681.7
2	2	44	114.224	11363.4
3	3	50	129.800	17045.1
4	4	58	150.568	22726.8
5	5	64	166.144	28408.5
6	6	70	181.72	34090.2
7	7	80	207.68	39771.9
8	8	91	236.36	45453.6

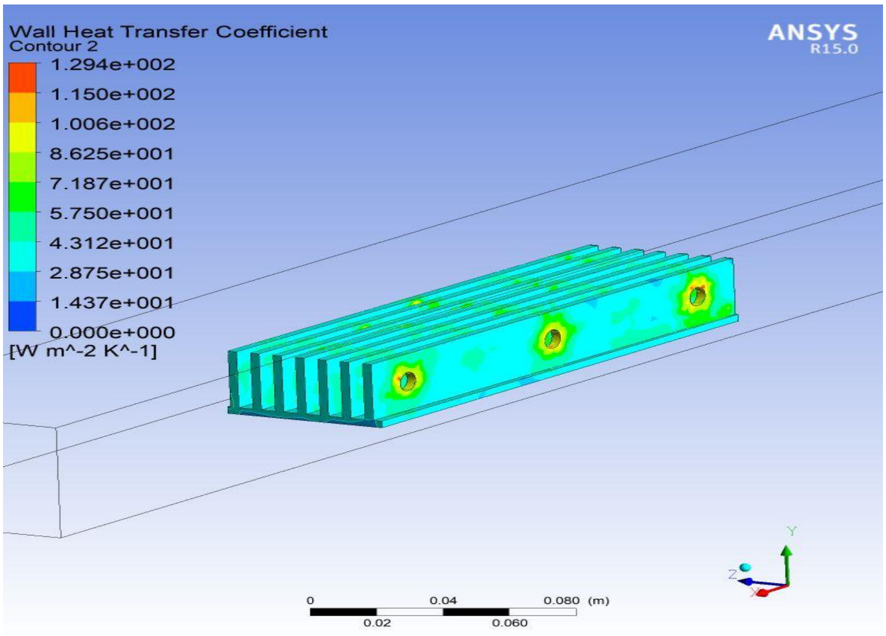

Fig. 8: Contour of Heat Transfer Coefficient for Inclined Non-Uniform Perforated fin

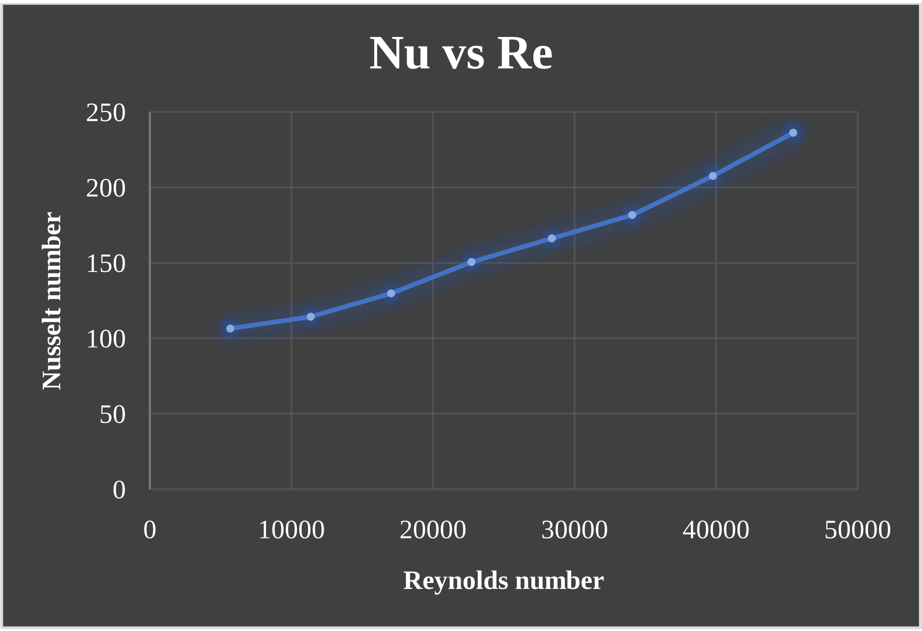

Fig. 9: Graph of Nusselt number V/S Reynolds number for Inclined Non-Uniform Perforated fin

Case 3: Twin Extension Fin

Table 6: Twin Extension fin

Sr. No.	Velocity(V)	Heat transfer coefficient(h)	Nusselt no.(Nu)	Reynolds no.(Re)
1	1	37	96.052	5681.7
2	2	41	106.436	11363.4
3	3	52	134.992	17045.1
4	4	62	160.952	22726.8
5	5	75	194.700	28408.5
6	6	86	223.256	34090.2
7	7	100	259.600	39771.9
8	8	37	96.052	45453.6

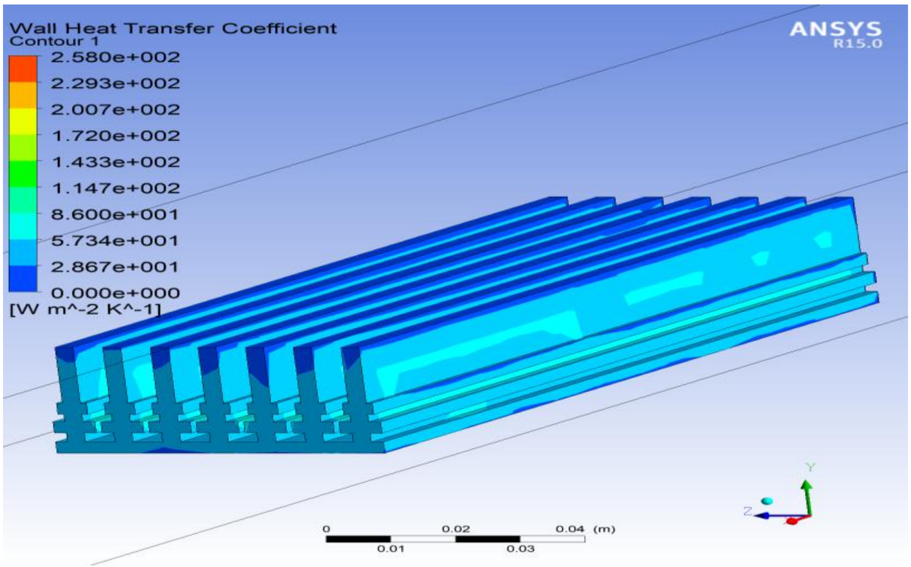

Fig. 10: Contour of Heat Transfer Coefficient for Twin Extension fin

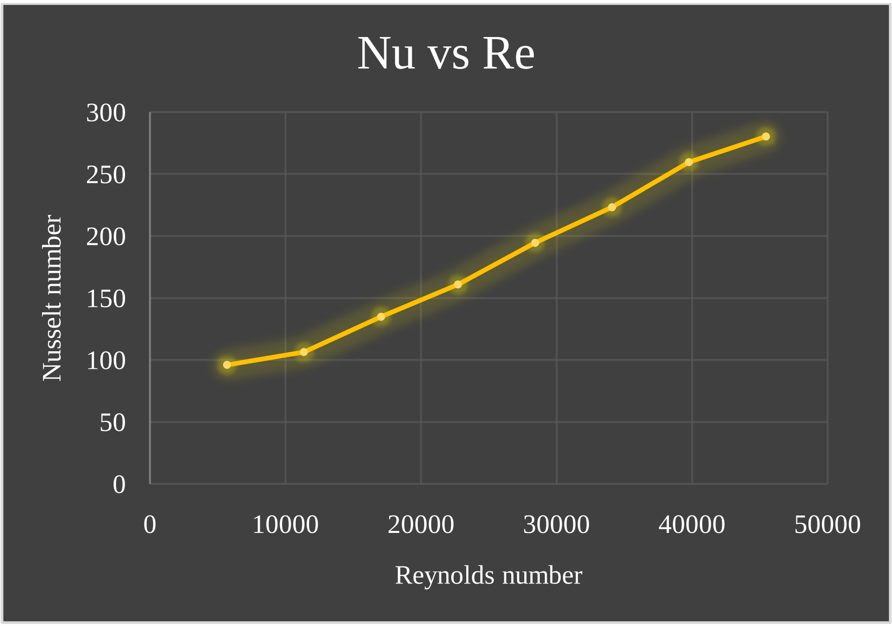

Fig. 11: Graph of Nusselt number V/S Reynolds number for Twin Extension fin

After studying heat transfer coefficient plots of all the three types of fins,the graph of Nu vs. Re depicting the combination of all the three fins was made as shown in Fig. 12

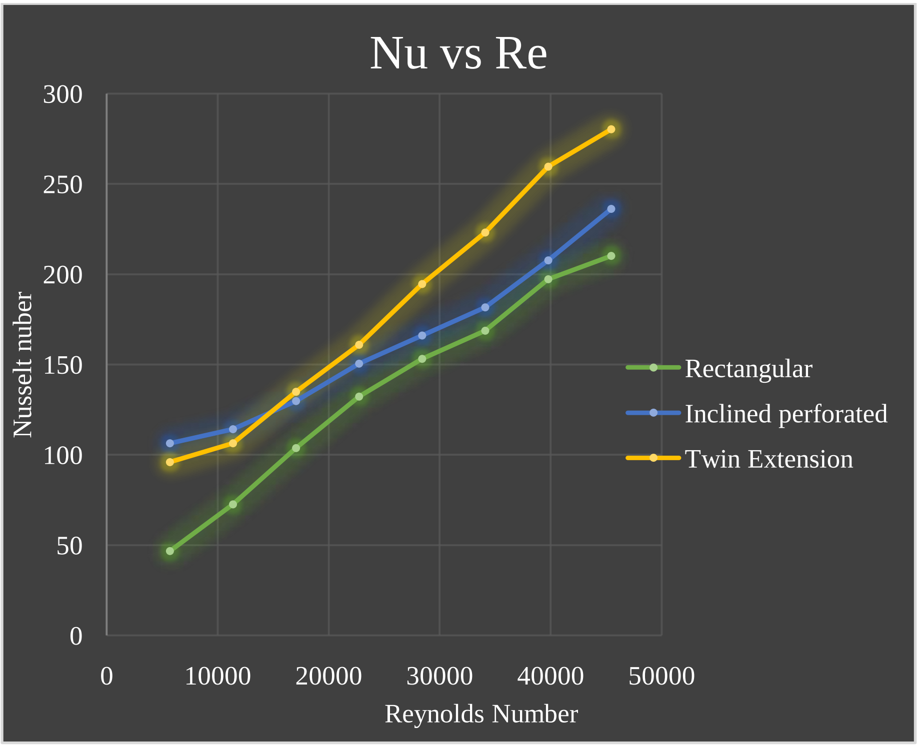

Fig. 12 Graph of Nusselt number V/S Reynolds number for all the fins

5 CONCLUSION

From the combined graph of Nu vs. Re for all the three types of fins, it is evident that:

- Both the Inclined Non- uniform perforated fins and Twin Extension fins are more effective than Normal Rectangular fins.
- For lower velocities i.e. upto 2m/s, Inclined Non-uniform perforated fins are superior to Twin Extension fins.
- For higher velocities, Twin Extension fins are more preferable.

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