Evaluation of Heat Transfer and Friction Factor on Wavy Fin Automotive Radiator

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Abstract— Forced convection heat transfer plays a vital role in many of the automobile applications. One such application is in a radiator of an automobile engine. The radiator is fixed in front of the automobile to cool the engine cylinder. The fluids used are water in early days but now they are being replaced by ethylene glycol combined with water. Now attempts are being made to use nano fluids with water in place of ethylene glycol-water as a coolant. In this paper, an automotive radiator with coolant circulating in vertical tubes are taken and the air is taken as a medium through wavy arch perpendicular to the coolant flow. This takes away the heat absorbed by this coolant from engine cylinders. The heat absorption is considered by varying velocities of automobile from 30 to 70 km/hr., keeping coolant mass flow rate constant. Input parameters such as mass flow rates of air from 4.3 kg/s to 8 kg/s, inlet temperatures of air as 30^oC, inlet fluid temperature as 90^oC maintaining fluid flow rate of 1.3 kg/s are taken and output parameters such as friction factor of air, heat transfer coefficient of air and fluid, overall heat transfer coefficient are determined. Furthermore, the enhancement of heat transfer coefficient using nano fluid is determined for different volume fractions varying from 0.5% to 2.5% with base fluid (ethylene glycol-water).

Key words: Radiator, Wavy Fin, Friction Factor, Heat Transfer Coefficient

I. INTRODUCTION

Radiator is a component used to cool the coolant coming from the engine cylinder. There are so many applications of these radiators. Radiator using wavy fin is giving importance for the removal of heat. The heat transfer is basically by means of convection. Dwivedi and Rai [1] has taken an automobile radiator (Wavy fin type) model and modeled on CATIA V5. Performance evaluation is done on pre-processing software ANSYS 14.0. Junqi et al. [2] investigated eleven cross-flow heat exchangers having wavy fin and flat tube experimentally, and proposed correlations such as j factor and friction factor. Leong et al.[3] investigated performance of an automotive car radiator operated with copper nano fluid as a coolant. Thermal performance of automobile radiator is done using 2% volume concentration of copper particles with base fluid ethylene glycol. Gong et al.[4] in their paper discussed numerically the air-side heat transfer and fluid flow characteristics of wavy fin-and-tube heat exchanger punched with combined rectangular winglet pairs. It was found that the suction side of the wavy fin punched with Rectangular Winglet Pairs(RWPs) can increase Nusselt number by 1.2%–4.1%, and decrease friction factor by 2.7%–9.6%. Bhogare and Kothawale[5] investigated the effect of Al_2O_3 nano particles in the mixture of base fluid(EG-water), and they showsed about 40% heat transfer enhancement was achieved with addition of 1% Al_2O_3 particles at 84391 air Reynolds number and at constant mass flow rate 0.05 kg/s. Hussein et al. [6] in their article presented the, heat transfer enhancement using TiO_2 and SiO_2 nano powder suspended in pure water is presented. The test setup includes a car radiator, and the effects on heat transfer enhancement under the operating conditions are analyzed under laminar flow conditions.The volume flow rate, inlet temperature and nano fluid volume concentrations are in the range of 2–8 LPM, 60–80 °C and 1–2% respectively. The results showed that the Nusselt number enhancements of up to 11% and 22.5% were obtained for TiO_2 and SiO_2 nanoparticles, respectively in water. Compared SiO_2 nano fluid produces a higher heat transfer enhancement than the TiO_2 and TiO_2 Nano fluid produces higher heat transfer more than pure Al_2O_3 nanoparticles varied in the range of 13 to 30 nm and they observed enhancement in the thermal conductivity of 2% to 36%. Tarodiya et al.[7] conducted theoretical performance analyses of the flat fin tube automotive radiator using nano fluids as coolant. The results shows that cooling capacity and effectiveness increase with increase in mass flow rate of air and coolant, and cooling capacity of radiator using nano fluid is greater than radiator using base fluid alone. Requirement of pumping power is reduced with the use of nano fluid in radiator, and pumping power requirement decreases with the increase in volume fraction of nanoparticles upto 2%. Patel and Mavani [8] in their paper conducted CFD simulation by taking mass flow rate of air passing around the tubes and mass flow rate of coolant (CuO/ water nano fluid). They estimated total heat transfer rate of a radiator. The air flow and coolant simulation is conducted using commercial software STAR CCM+. The CFD process here starts with defining the water type geometric clean up and meshing using the hyper mesh V11.0 software. The flow characteristics are analyzed compared and verified according to known physical situation and existing experimental data and finally they showed lower coolant outlet temperature and higher heat transfer occuring for CuO/ water Nano fluid at 4 kg/s mass flow rate of air. Kuppan [9] in his book as given the equations for calculate free flow area, core frontal cross sectional area.

II. DESCRIPTION AND WORKING OF AUTOMOTIVE RADIATOR

The radiator core consists mainly of many tubes and fins, the main parts of radiator are

– Tube
– Wavy fin
– Upper cover
– Lower cover

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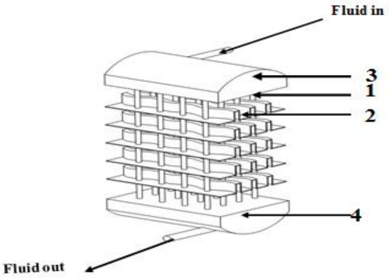

Fig. 1: Radiator Core Geometry

1) Tube

Radiator consists of circular tubes whose diameter is 0.59 cm (air side) and 0.56 cm (coolant side), number of tubes are arranged in parallel as shown in Fig.1. The fluid circulates through the tubes which take out the heat from the engine cylinder.

2) Wavy Fin

Continuous fins of thickness, made of aluminum is taken

3) Upper and Lower Cover

The upper and lower radiator covers are surrounded on top and bottom of radiator.

A. Working of Automotive Radiator

The automotive radiator consist of number of circular tubes which are arranged in parallel. To cool down the engine the coolant is passed through engine block, where it absorbs heat from the engine, once the temperature reaches 93^o c, the cooling system has to kick in and helps to cool the engine.

The cooling system works near the front of the engine with a thermostat. As the engine heats up and reaches a certain temperature, the thermostat opens to allow the flow of coolant. The hot coolant is fed into the radiator upper cover which distributes through the tubes and transfers the heat to the fins. The fins release the heat to the ambient air, which passes across the tubes. Fins are used to greatly increase contact surface of the tubes to the air. Once the coolant has made the trip through the radiator it is ready to go back to the engine and pick up more heat and the process is repeated.

III. ANALYSIS OF THE PROBLEM

A. Air Side Calculations

Fin frontal cross sectional area is given by (A_{cf})

$$A_{cf} = [(2F_h + F_w)t_f \times N_{fl} + ((P_t - d_o) - F_w)t_f \times N_{fl}]N_l \quad (1)$$

where

F_h=fin height, m F_w=fin width, m

t_f=fin thickness, m N_{fl}=number of fins per layer

N_l=number of layers P_t=transverse pitch,

d_o= tube outer diameter, m

Tube frontal cross sectional area (A_{ct})

$$A_{ct} = d_o(L_t - t_f N_f)N_{tr} \quad (2)$$

L_t=length of tube per unit length, m

N_{tr}=number of tubes per row

Free flow area of air is calculated by (A_{ff})

$$A_{ff} = A_{fr} - (A_{cf} + A_{ct}) \quad (3)$$

Frontal area of radiator core is calculated as (A_{fr})

$$A_{fr} = H \times W \quad (4)$$

Mass flow rate of air (m_a)

$$m_a = \rho A_{fr} V \quad (5)$$

Mass velocity of air (G_a) can be calculated as

$$G_a = \frac{m_a}{A_{ff}} \quad (6)$$

Reynolds number of air (Re_a) is determined by

$$Re_a = \frac{G_a D_h}{\mu_a} \quad (7)$$

Hydraulic diameter is given by

$$D_h = \frac{4 \times A}{P} \quad (8)$$

Colburn j factor said by Dong Junqi [2] calculated as

$$j = 0.0836 Re_a^{-0.2309} \left(\frac{F_p}{F_h}\right)^{0.1284} \left(\frac{F_p}{2A}\right)^{-0.153} \left(\frac{L_d}{L}\right)^{-0.326} \quad (9)$$

Heat transfer coefficient is given by

$$h_a = \frac{j_a G_a C_{p,a}}{Pr_a^{\frac{2}{3}}} \quad (10)$$

The frictional performance by Dong Junqi [2] of the wavy fin is expressed as

$$f = 1.16 Re_a^{-0.309} \left(\frac{F_p}{F_h}\right)^{0.3703} \left(\frac{F_p}{2A}\right)^{-0.25} \left(\frac{L_d}{L}\right)^{-0.1152} \quad (11)$$

B. Heat Transfer Calculations on Base Fluid Side

Reynolds Number of base fluid (Re_{bf}) is

$$Re_{bf} = \frac{\rho_{bf} V d_i}{\mu_{bf}} \quad (12)$$

Nusselt Number of base fluid is given (Nu) as

$$Nu = 0.023(Re_{bf})^{0.8} Pr_{bf}^{0.3} \quad (13)$$

Heat transfer coefficient of base fluid is calculated as

$$h_{bf} = \frac{Nu k_{bf}}{d_i} \quad (14)$$

Overall heat Transfer Coefficient (U) is expressed by neglecting wall resistance and fouling factors

$$\frac{1}{U} = \frac{1}{h_a} + \frac{1}{h_{bf}} \quad (15)$$

C. Correlations for Calculating Heat Transfer coefficient Properties for Nano Fluid Side

Pak and Cho [4] gave density equation as

$$\rho_{nf} = (1 - \phi)\rho_f + \phi\rho_p \quad (16)$$

Specific heat for nano fluid (C_{pnf}) is proposed by Xuan and Roetzel [4]

$$C_{pnf} = \frac{(1-\phi)\rho_{bf} C_{p,bf} + \phi\rho_p C_{p,p}}{\rho_{nf}} \quad (17)$$

Thermal conductivity of nano fluid by M.Eftekhar [9]

$$\frac{k_{nf}}{k_{bf}} = \frac{k_p + (SH-1)k_{bf} - (SH-1)(k_{bf} - k_p)\phi}{k_p + (SH-1)k_{bf} + (SH-1)(k_{bf} - k_p)\phi} \quad (18)$$

For spherical shape of the nano particle, SH=3

Viscosity of nano fluid proposed by Nguyen et al [4]

$$\frac{\mu_{nf}}{\mu_{bf}} = \frac{1}{(1-\phi)^{2.5}} \quad (19)$$

Prandtl number can be calculated as

$$Pr_{nf} = \frac{\mu_{nf} C p_{nf}}{k_{nf}} \quad (20)$$

IV. RESULTS AND DISCUSSION

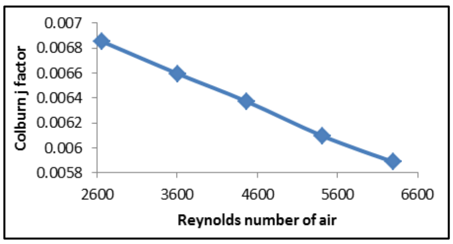

Fig. 2: Colburn j factor with Reynolds number of air

The above Fig 2 shows the variation of Colburn j factor with air Reynolds number. The results show that the Colburn j factor decreased with increasing air Reynolds number of radiator using wavy fin. Because of the waviness the air side flow is mixed better at increase Reynolds number. Hence there is a decrease in Colburn j-factor.

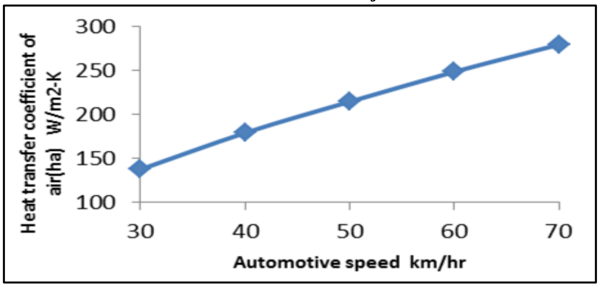

Fig. 3: Heat transfer coefficient with automotive Speed

The Fig 3 shows the effect of different automotive speeds on heat transfer coefficient of air h_a. Results show that the heat transfer coefficient is enhanced by increasing automotive speed. The coolant mass flow rate is kept constant.

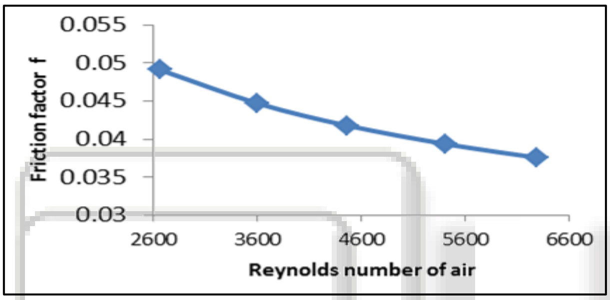

Fig. 4: Friction factor with Reynolds number of air

This Fig 4 gives a variation between friction factor and Reynolds number of air. The results show that friction factor decreased with increased in air Reynolds number. However, as Reynolds number increased, friction factor decreases.

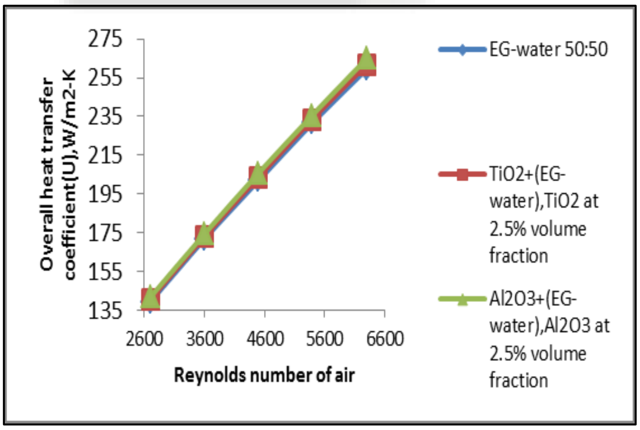

Fig. 5: Variation of Overall Heat Transfer Coefficient with Reynolds number of air

Fig 5 shows the variation between Reynolds number and overall heat transfer coefficient using ethylene glycol(EG)-water(50:50),Al_2O_3+(EG-water) and TiO_2+(EG-water) nano fluid with 2.5% volume concentration. It was found that as mass flow rate of air gets increased with respect to the vehicle speed, the overall heat transfer coefficient increased. However, it is seen that using nano fluid as a coolant increased overall heat transfer coefficient

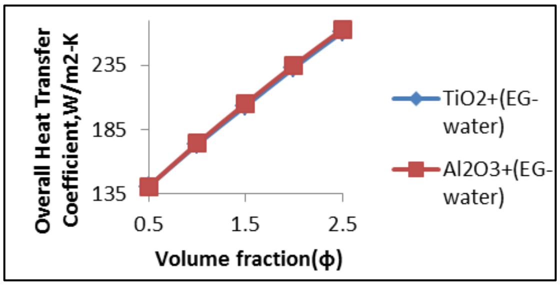

Fig. 6: Overall heat transfer coefficient with particle volume fraction

The above graph Fig 6 shows the effect of nanoparticle concentration on overall heat transfer coefficient. The results show that nano fluid enhances the overall heat transfer coefficient in the automotive radiator. It is also noted that at higher speeds and high volume fractions overall heat transfer coefficient on air side increases, the increase in overall heat transfer coefficient is more in Al_2O_3+(EG-water) compared to TiO_2+(EG-water) nano fluid.

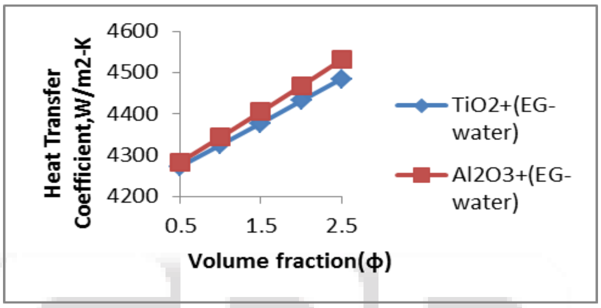

Fig. 7: Heat transfer coefficient Vs. Volume fraction

The Fig 7 shows the effect of nanoparticle concentration on the heat transfer coefficient of nano fluid. Results show that the heat transfer coefficient can be enhanced by adding nano particles to the base fluid. Enhancement of heat transfer by the nano fluid is resulted from the following aspect that incremented particle increases the thermal conductivity of the mixture. However, it is also noted that increasing the particle concentration raises the fluid viscosity and decreases the Reynolds number and consequently increases the heat transfer coefficient.

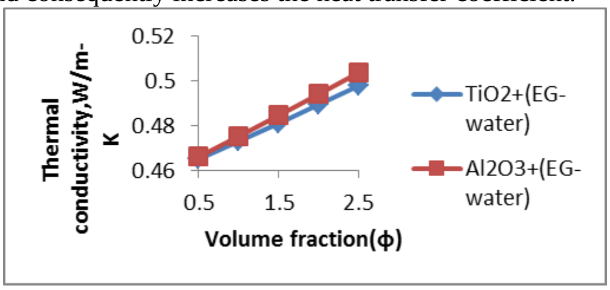

Fig. 8: Volume Fractions Vs. Thermal Conductivity

The above fig 8 shows the effect of volume fraction on thermal conductivity of nano fluids. This figure reveals that as the volume concentration is increased, thermal conductivity increases.

V. CONCLUSIONS

The surfaces with wavy patterns are one of the popular surfaces in Plate-fin heat exchanger. However, due to sinusoidal curve of this surface calculating heat transfer area is difficult. In this work, numerical investigation is presented using of EG-water 50:50, Al_2O_3+(EG-water),

TiO_2+(EG-water) as a coolant in an automotive radiator with wavy fin. The local convective and overall heat transfer coefficients of Al_2O_3+(EG-water) and TiO_2+(EG-water) nano fluid at different volume fractions (0.5% – 2.5%) were studied under turbulent flow conditions. Also, the effects of the coolant and the automotive speed on the radiator performance are presented in this work.

Based on the above, the following conclusions are discussed.

1) For an increase of mass flow rate from (3.4 - 8 kg/s) Colburn j-factor on air side decreased by 17.74%.
2) Increasing the speed of the vehicle by 1.33%, heat transfer coefficient of air enhanced by 91.63%.
3) Friction factor has an effect on mass flow rate of air. Hence with an increase in Reynolds number on air side from 2695.63 to 6293.19 friction factor decreased by 22.95%.
4) Overall heat transfer coefficient on Reynolds number of air for Al_2O_3+(EG-water) and TiO_2+(EG-water) nano fluid gives an almost equal enhancement 2.69% at 2.5% volume fraction when compared to base fluid (EG-water).
5) As volume fraction of nano fluid increased from (0.005-0.025), overall heat transfer coefficient of Al_2O_3+(EG-water) increased by 1.08% compared to TiO_2 +(EG-water).
6) The heat transfer coefficients as an effect on volume fraction. As volume fraction increases from (0.5%-2.5%) heat transfer coefficient of Al_2O_3+(EG-water) of 0.26% to 1.03% compared TiO_2 +(EG-water).

Nomenclature

A	area, m²
C_p	Specific heat, J/kg-K
d	diameter, m
f	Friction factor
F_h	Fin height, m
G	mass velocity, kg/s- m²
h	heat transfer coefficient, W/ m²-K
H	core height, m
j	Colburn factor
k	thermal conductivity, W/m-K
M	mass flow rate, kg/s
N	number of tubes
Nu	Nusselt number
Pr	Prandtl number
P_t	transverse pitch, m
Re	Reynolds number
t	thickness, m
U	overall heat transfer coefficient, W/m^2-k
V	velocity, m/s
W	core width, m

Greek Symbols

μ	Dynamic viscosity, kg/m-s
ϕ	volume fraction
ρ	density, kg/m^3

Subscript

bf	base fluid
f	fin
ff	free flow
fl	fins per layer
fr	frontal
i	inlet
l	layer
nf	nano fluid
o	outlet
p	particle
tr	tubes per row
w	width

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