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Experimental Study of Heat Transfer in a Radiator using Nanofluid

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***Abstract* - In this paper the experimental study of the thermal behaviour of the single phase flow through a automobile radiator. The radiator is an important accessory of vehicle engine. Normally, it is used as a cooling system of the engine and generally water is the heat transfer medium. For this liquid-cooled system, the waste heat is removed via the circulating coolant surrounding the devices or entering the cooling channels in devices. Nanofluids have attracted attention as a new generation of heat transfer fluids in building in automotive cooling applications, because of their excellent thermal performance. This study attempts to investigate the heat transfer characteristics of an automobile radiator using water combination based CuO nanofluids as coolants. Thermal performance of an automobile radiator operated with nanofluids is compared with a radiator using conventional coolants.**

***Index term* – Nanofluid, Transducers, Wind tunnel**

I. INTRODUCTION

The automotive industry is continuously involved in a strong competitive career to obtain the best automobile design in multiple aspects like performance, fuel consumption, aesthetics, safety etc. The air-cooled heat exchangers found in a vehicle like radiator, AC condenser and evaporator, charge air cooler, etc. have an important role in its weight and also in the design of its front-end module, which also has a strong impact on the car aerodynamic behavior. Looking at these challenges, an optimization process is mandatory to obtain the best design compromise between performance, size or shape and weight. This optimization objective demands advanced design tools that can indicate not only the better solution but also the fundamental reason of a performance improvement**.** The radiator is an important accessory of vehicle engine. Normally, it is used as a cooling system of the engine and generally water is the heat transfer medium. For this liquid-cooled system, the waste heat is removed via the circulating coolant surrounding the devices or entering the cooling channels in devices. The coolant is propelled by pumps and the heat is carried away mainly by heat exchangers.

Continuous technological development in automotive industries has increased the demand for high efficiency engines. A high efficiency engine is not only based on its performance but also for better fuel economy and less emission. Reducing a vehicle weight by optimizing design and size of a radiator is a necessity for making the world green. Addition of fins is one of the approaches to increase the cooling rate of the radiator. It provides greater heat transfer area and enhances the air convective heat transfer coefficient. However, traditional approach of increasing the cooling rate by using fins and micro-channel has already reached to their limit.

Nanofluids have attracted attention as a new generation of heat transfer fluids in building in automotive cooling applications, because of their excellent thermal performance. Recently, there have been considerable research findings highlighting superior heat transfer performances of nanofluids.

II. EXPERIMENTAL INVESTIGATION

In this paper an experimental investigation is carried out to analyze the heat transfer characteristics of a corrugated louvered fin and flat tube compact heat exchanger used as a radiator in an internal combustion engine. The experiments are conducted by positioning the radiator in an open loop wind tunnel test rig, available with M/s Halgona Radiators Private Limited, Bangalore, India. The details of the radiator test unit, the components of the experimental test rig, layout of the test rig, instrumentation used in the setup and the experimental procedure adopted, are presented here. The tubes are flat in shape and tubes are made of aluminium material. The tubes are kept in such a way that its depth is parallel to the direction of the air flow. The corrugated louvered fin used in the radiator core. The fins are kept in between the tubes, and the louvers made on the surface of the fin are trapezoidal in shape. These fins are also made of aluminium material.

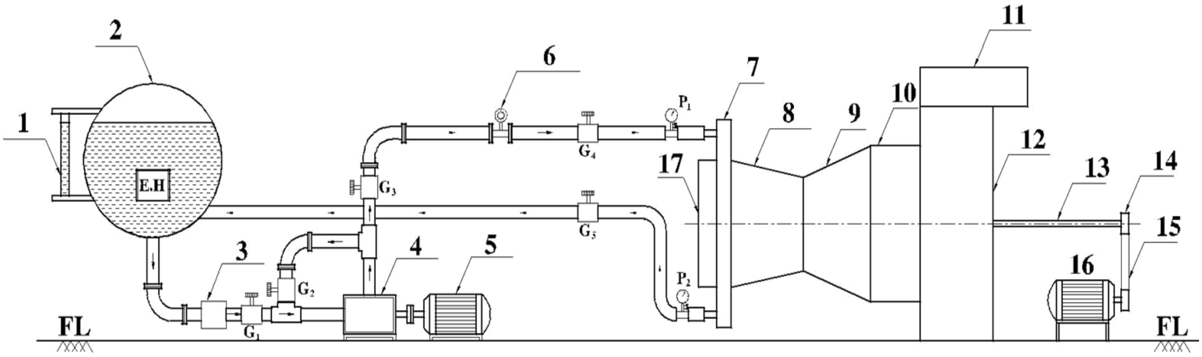

Figure 2.2 Schematic layout of the test rig

1. Water level indicator 2. Boiler 3. Mud box 4. Pump 5. Motor 6. Flow control valve 7. Radiator [test piece] 8. Tunnel 9. Transition piece 10. Circular passage 11. Outlet duct 12. Blower 13. Shaft 14. Pulley 15. Belt 16. Motor 17. Rectangular Duct F.L – Floor level, E.H – Electrical heaters [12 nos], P1, P2 – Pressure transducers, G_1,G_5 - Gate valves

The major components involved in the experimental test rig, are the boiler, centrifugal pump, blower, wind tunnel, flow control valve and the other instruments used for measurements. The details of each component are explained in this section. This air supply line contains a blower, dampers and the necessary instruments. The test rig also has provision for the necessary inlet condition for water, which is supplied through the tube [hot] side of the test unit. Water is supplied through a pipe line that starts from the boiler, followed by a centrifugal pump, flow control valve and converging pipe line to match the entry dimensions of the inlet configuration to be tested. The frontal area of the radiator is connected to the rectangular duct of the cross section equal to the frontal area of the radiator. The rear end of the radiator is fixed to the tunnel. The other end of the tunnel is connected to the damper casing. The damper casing is connected to the blower. The blower is connected to the outlet duct. The hot water from the boiler enters the radiator from the top, and the cold water from the radiator leaves from the bottom. When the blower is switched on, the atmospheric air flows through the radiator core, and becomes hot. This hot air is let out to the atmosphere through the tunnel and the outlet duct. To minimize the heat lost to the surroundings, all the components in the experimental setup are insulated with a 10 mm thick glass wool layer.

III. THERMAL AND PHYSICAL PROPERTIES OF NANOPARTICLES AND BASE FLUIDS

The thermal conductivity measurement of nano fluids was the main focus in the early stages of nano fluid research. Recently studies have been carried out on the heat transfer coefficient of nano fluids in natural and forced flow. Most studies carried out to date are limited to the thermal characterization of nano fluids without phase change. However, nano particles in nano fluids play a vital role in two-phase heat transfer systems and there is a great need to characterize nano fluids in boiling and condensation heat transfer. In any case the heat transfer coefficient depends not only on the thermal conductivity but also on the other properties such as the specific heat, density and dynamic viscosity of a nano fluid.

Table 3.1 Properties of nano particle

Sl. no.	Property	Copper oxide
1	Thermal conductivity W/Mk	400
2	Density [ρ_p] kg/m^3	8933
3	Specific heat [C_P] J/kg K	385

Table 3.2 Properties of base fluids

Sl. no.	Property	Water
1	Thermal conductivityW/mk	0.605
2	Density [ρ_p] kg/m^3	997.1
3	Specific heat [C_f] J/kg-K	4195
4	Dynamic viscosity [μ] Kg/m^3	0.001003

IV. EXPERIMENTAL READINGS AND SIMPLE CALCULATIONS

Table 4.1 Experimental reading of water

Sl. no.	Coolant	Air velocity (m/sec)	Mass flow rate (Kg/s)	Inlet tube temp. (^{0}C)	Outlet tube temp. (^{0}C)	Inlet fin temp. (^{0}C)	Outlet fin temp. (^{0}C)	Heat transfer rate (KW)
1	Water	3	2.5	87.5	79.55	30	80.33	83.37
2			3.34	87.5	81.38	30	81.51	85.74
3			4.17	87.5	82.4	30	82.65	89.21

1	Water	7.2	2.5	87.5	73.93	30	68.16	142.28
2			3.34	87.5	75.85	30	69.08	163.23
3			4.17	87.5	77.86	30	71.30	168.63
1	Water	11.41	2.5	87.5	71.25	30	63.66	170.42
2			3.34	87.5	72.85	30	66.31	205.26
3			4.17	87.5	74.55	30	67.30	226.53

Table 4.2 Experimental reading of water + 10% copper oxide

Sl. no.	**Coolant**	**Air velocity (m/sec)**	**Mass flow rate (Kg/s)**	**Inlet tube temp. (^{0}C)**	**Outlet tube temp. (^{0}C)**	**Inlet Fin temp. (^{0}C)**	**Outlet fin temp. (^{0}C)**	**Heat transfer rate (KW)**
1	Water+ Copper oxide	3	2.5	87.5	74.55	30	84.33	98.345
2			3.34	87.5	76.84	30	85.15	107.63
3			4.17	87.5	78.40	30	86.41	114.82
1	Water+ Copper oxide	7.2	2.5	87.5	67.93	30	73.82	148.02
2			3.34	87.5	70.05	30	74.08	176.36
3			4.17	87.5	73.4	30	75.30	177.91
1	Water+ Copper oxide	11.41	2.5	87.5	63.10	30	67.81	184.58
2			3.34	87.5	66.01	30	70.81	217.19
3			4.17	87.5	69.12	30	72.1	231.92

4.1 Density of Nano Fluids Calculation

For typical nano fluids with nano particles at a value of volume fraction less than 1%, a change of less than 5% in the fluid density is expected. For ten percent nano particles of copper oxide mixes with the base fluid water the sample calculation for density is shown below,

$\rho_{nf} = [1-\Phi S]\ \rho_f + \Phi S\ \rho_p$ ....(1)

Where, ρ_{nf} - Density of nano fluids [kg/m^3], ΦS - nano particles percentage [%], ρ_f - Density of Base fluids[kg/m^3], ρ_p - Density of nano Particles [kg/m]. Here we are using the formula in equation 1 the density is calculated for nano particles percentages from one to thirty.

4.2 Specific Heat of Nanofluids Calculation

For ten percent nanoparticle of copper oxide mixes with the base fluid water the sample calculation for specific heat is shown below,

Specific heat of nano fluids,

$C_{nf} = \frac{[1 - \Phi s]\ \rho f\ Cf\ +\ \Phi s\ \rho p\ Cp}{\rho nf}$ ....(2)

Where, C_{nf} is Specific heat of nano fluids [J/Kg^{0}k], C_f is Specific heat of base fluids [J/Kg^{0}k], and C_p is the Specific heat of nanoparticles [J/Kg^{0}K].

4.3 Experimental Data Analysis

The rate of heat transfer in this radiator from the hot water to the air is determined from an energy balance on water flow,

$Q = [mC_p\,[T_{in} - T_{out}]]_{water}$ ....(3)

The tube-side heat transfer area is the total surface area of the tubes, and is determined from,

$A_i = n\pi D_h L$ ....(4)

Where n is the number of tubes, D_h is the hydraulic diameter of the tube and L is the length of the tube.

$Dh = \frac{4\times[\frac{\pi d^2}{4}+[D-d]\times d}{\pi\times d+2\times[D-d]}$ ....(5)

Knowing the rate of heat transfer and the surface area, the overall heat transfer co efficient can be determined from,

$Q = U_i\, A_i\, F\ \Delta\ T_{lm,CF}$ ....(6)

$Ui = \frac{Q}{Ai\ F\ \Delta\ Tlm,CF}$ ....(7)

Where, f is the correction factor and $\Delta T_{lm,CF}$ is the log mean temperature difference for the counter flow arrangement. These two quantities are found to be,

$\Delta T_1 = T_{h\ in} - T_{c\ out}$

$\Delta T_2 = T_{h\ out} - T_{c\ in}$

$$\Delta T_{lm,\ CF} = \frac{\Delta T1 - \Delta T2}{\ln[\Delta T1/\Delta T2]} \qquad \text{...............(8)}$$

And from heat transfer data hand book,

$$P = \frac{t2 - t1}{T1 - t1}$$

$$R = \frac{T1 - T2}{t2 - t1}$$

Therefore,

$$Ui = \frac{Q}{Ai\ F\ \Delta\ Tlm,CF} \qquad \text{...............(9)}$$

V. EXPERIMENTAL RESULTS AND DISCUSSION

In this experimental work was conduct to investigate the heat transfer rate of automobile radiator of base fluid water and 10% mixture of copper oxide. The results show that, the highest heat transfer rate along the nanofluids and lower heat transfer rate along the water.

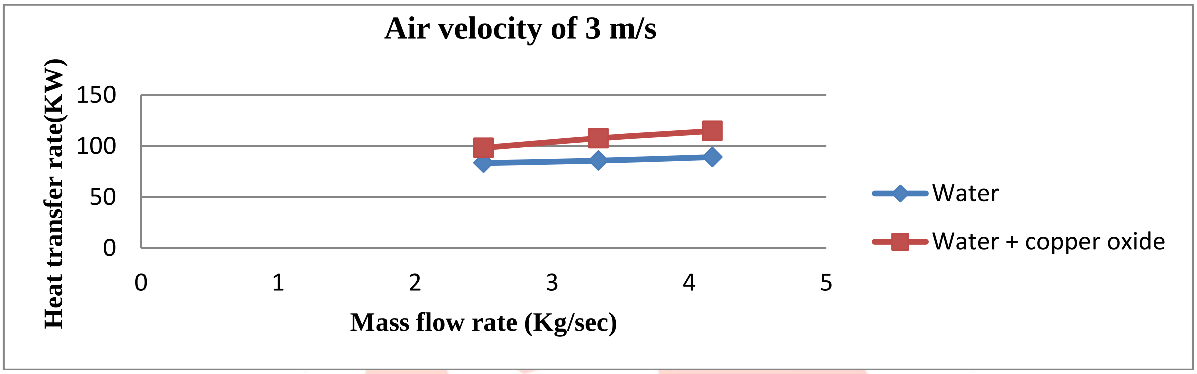

Figure 5.1 Variation of Heat transfer rate along the different mass flow rate at Air velocity of 3 m/sec

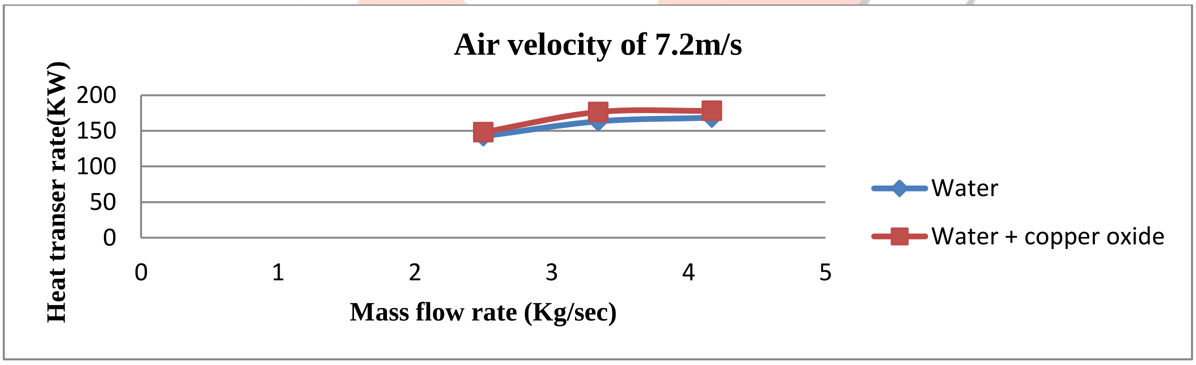

Figure 5.2 Variation of Heat transfer rate along the different mass flow rate at Air velocity of 7.2 m/sec

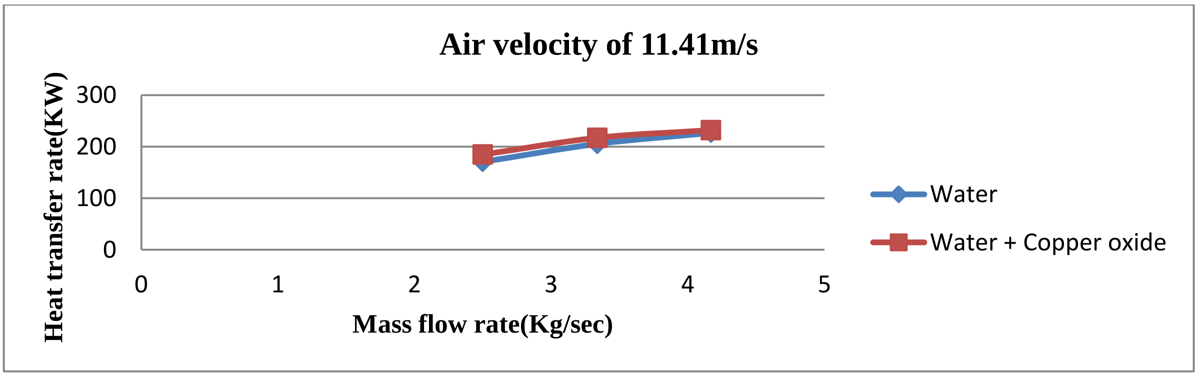

Figure 5.3 Variation of Heat transfer rate along the different mass flow rate at Air velocity of 11.41 m/sec

From the above graphs shows using CuO /water nanofluid as a coolant and 2.5 Kg/s, 3.34Kg/s and 4.17Kg/s mass flow rate of air optimum performance of radiator can be performed. For each mass flow rate of water, experiments are conducted for three different air velocities of 3 m/s, 7.2 m/s, 11.41 m/s. The results show that the nano fluids have large thermal conductivity than the original base fluids under the same mass flow rate and air velocity.

VI. CONCLUSION

This paper presented a experimental investigation of the use of CuO-water nanofluid as a coolant in a radiator of army tanker diesel engine. The heat transfer rate for CuO-water nanofluid at volume fraction 10% was studied. The results indicate that the overall heat transfer coefficient of nanofluid is greater than that of water alone and therefore the total heat transfer area of the radiator can be reduced. However, the considerable increase in associated pumping power may impose some limitations on the efficient use of this type of nanofluid in automotive diesel engine radiators.

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