Analytical Investigation of Exergetic Analysis of Louvered fin Automobile Radiator using Nano Fluids as Coolants

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Abstract:- *It is said that the traditional methods for analysis and design of heat exchanger using first law of thermodynamics emphasized that the energy is conserved quantity wise and disregards the quality of energy. It means it takes no account of wastage of useful energy (available energy) during the heat transfer process. Conventional approach recognizes only the total amount of energy supplied to the system and as a result, this yields the substantive design rather than the thermodynamically efficient one. In the second law analysis all loses are treated as the source of entropy production. It is thus possible to compare and sum them. Second law of thermodynamics is believed to be the supreme law of nature.*

. Energy waste, appearing in whatever forms, results in reducing the available work from the assigned energy resources. Second law or exergetic viewpoint accounts for this destruction of useful potential work and results in thermodynamically efficient analysis rather than substantive viewpoint of first law. Today, heat exchangers are widely used in automotive industries. The design of a heat exchanger involves consideration of both the heat transfer rates between the fluids and the mechanical power expended to overcome fluid friction and to move the fluids through the heat exchanger. The second law analysis allows the heat exchanger designer to consider both the factors simultaneously as the same is not possible with first law analysis. Therefore, there is a need for systematic design of heat exchangers using a second law based procedure

The present research work investigates the exergetic analysis of an automotive radiator having louvered fin-geometry that uses nano-fluids as coolant. The four types of nano-particles (Al2O3, CuO, MgO and ZnO) are mixed in water by volume. A computer code in C++ language was developed to calculate the second law efficiency with the variation in mass flow rate of air, and coolant, inlet temperature of air and coolant and volume concentration of nano-particles.

It is seen that nano-fluids have higher second law efficiency as compared to base fluids water only. About 5% to 7% increment achieved in the second law efficiency with the use of nano-particles (Al2O3, CuO, MgO and ZnO) in water base fluid as compared to base fluid water only. MgO based nano fluid has highest second law efficiency as compared to other nano fluids. However, CuO and ZnO based nano fluids showed almost same second law efficiency. Irreversibility decreased by 4% to 7% by using nano fluids as compared to water coolant only.

Keywords:-*Nanofluid, effective thermal conductivity, mathematical modelling, exergetic analysis.*

I. INTRODUCTION

1.1:- Second law analysis

It is said that the traditional methods for analysis and design of heat exchanger using first law of thermodynamics emphasized that the energy is conserved quantity wise and disregards the quality of energy. It means it takes no account of wastage of useful energy (available energy) during the heat transfer process. Conventional approach recognizes only the total amount of energy supplied to the system and as a result, this yields the substantive design rather than the thermodynamically efficient one. In the second law analysis all loses are treated as the source of entropy production. It is thus possible to compare and sum them.

Second law of thermodynamics is believed to be the supreme law of nature and any new proposition in thermal science is needed to be examined under the microscope of the second law to prove its consistency. In-spite of having such importance, this law does not find any application in the performance evaluation of most of the components of a power or process cycle till today due to the existing concept that its applications exist only in reversible systems. This leads to first law of thermodynamics approach, further leading to a substantive view of energy aspect without caring for its quality aspect.

Second law or exergetic viewpoint accounts for this destruction of useful potential work and results in thermodynamically efficient analysis rather than substantive viewpoint of first law. Therefore, there is a need for systematic design of heat exchangers using a second law based procedure.

This project work presents the second law analysis of a cross flow heat exchanger by using nano fluids as coolants. Cross flow heat exchangers have been particularly considered due to their wide applications in air/gas heating and cooling applications including the automotive and refrigeration industry.

Therefore, second law of thermodynamics makes possible to design a heat exchanger, which operates in most efficient way thermodynamically and wasting the least amount of energy. The irreversibility's in any heat exchanger may be listed as follows:

(1) Internal irreversibility
(2) External irreversibility

In all traditional approaches, heat exchanger is considered perfectly insulated from ambient. But in actual practice it is not worthwhile, especially in high efficient compact heat exchangers, to disregard the heat-in-leak from surrounding that causes some amount of destruction of useful energy. The other sources of the irreversibility in compact heat exchangers are the cold end and hot end of heat exchanger. The cold end of heat exchanger where hot stream, which is cooled within the heat exchanger, leaves for the process application and exergy associated with it is a 'useful energy' and not wastage. Hence, the cold end may provide the room for moving the irreversibility via conduction through connecting tubes where it has to be used. At the hot end of heat exchanger, the cold stream, after cooling the hot stream, does not approach the hot stream inlet temperature due to the internal irreversibility. Hence the exergy left with the cold gas, which the exchanger has failed to transfer to hot fluid, having gone waste to the surroundings since anything external to it forms part of surroundings. The exergy loss associated to the hot end may be termed as the 'leaving exergy losses' of heat exchangers. The irreversibility's listed in this paragraph are called the external irreversibility. However, it is more convincing to describe these irreversibility's as the external thermal irreversibility's. Therefore, it makes good engineering sense to focus on external irreversibility's in addition to internal thermal irreversibility's for the effective operation of heat exchanger.

The irreversibility associated with any process, which is the quantitative measure of exergy loss in the process, is related to the entropy production within the system. This can be presented by Gouy–Stodola theorem as follows:

$$I=T_0\, S_{gen}$$

As has been said that entropy generated within the heat ex-changer can be split as follows:

$$S_{gen}=S_{gen,internal}\; S_{gen,external}\; S_{gen,\Delta p.}$$

1.2:- Nano Fluids

Nanofluids are a relatively new class of fluids which consist of a base fluid with nano-sized particles (1–100 nm) suspended within them. These particles, generally a metal or metal oxide, increase conduction and convection coefficients, allowing for more heat transfer out of the coolant. Figure 1 provided excellent examples of nanometer in comparison with millimeter and micrometer to understand clearly as can be seen in Fig. 1.

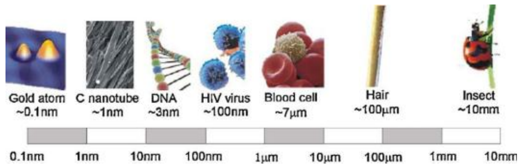


Fig. 1: Length scale and some examples related

In the past few decades, rapid advances in nanotechnology have lead to emerging of new generation of coolants called "nanofluids". Nanofluids are defined as suspension of nano particles in a base fluid. Some typical nanofluids are ethylene glycol based copper nanofluids and water based copper oxide nanofluids, Nanofluids are dilute suspensions of functionalized nano particles composite materials developed about a decade ago with the specific aim of increasing the thermal conductivity of heat transfer fluids, which have now evolved into a promising nanotechnological area. Such thermal nanofluids for heat transfer applications represent a class of its own difference from conventional colloids for other applications. Com-pared to conventional solid–liquid suspensions for heat transfer intensifications, nanofluids possess the following advantages.

- High specific surface area and therefore more heat transfer surface between particles and fluids.
- High dispersion stability with predominant Brownian motion of particles.
- Reduced pumping power as compared to pure liquid to achieve equivalent heat transfer intensification.
- Reduced particle clogging as compared to conventional slurries, thus promoting system miniaturization.

1.3:- Objective of the present study

Heat exchangers have wide applications and play a major role in energy conservation opportunity. In automobile radiator is used as compact heat exchanger. Radiator uses coolant to cool the engine. Coolants may be water or mixture of water and ethylene glycol, depends on the application. Water is found very good coolant due to its throughphysical properties. By using nano particles in water, we can enhance its cooling capacity. Cooling capacity further increase by reducing irreversibilities in cooling system and irreversibility can be reduced by doing second law efficiency analysis in cooling system. Increase in cooling capacity and reducing irreversibility in cooling system leads to reduce the size of radiator. Compact radiator surely reduces weight of vehicle which results good efficiency of automobile.

In present study, automobile radiator chosen as compact heat exchanger with nano fluids as coolant. Four type of nano fluids used in this study which are as follow.

1. Al_2O_3 ,Aluminium oxide based nano fluid (water as base fluid)
2. ZnO, Zinc oxide based nano fluid (water as base fluid)
3. MgO, Megnisium oxide based nano fluid (water as base fluid)
4. CuO, Copper oxide based nano fluid (water as base fluid)

Based on above discussion following objective has been set for present research work

1. To calculate the second law efficiency of automobile radiator by using nano fluids as coolants and compare with water coolant only
2. To calculate the irreversibility of automobile radiator by using nano fluids as coolants.
3. To see the effect of various operating parameters such as mass flow rate of air and coolant, inlet temperature of air and coolant and volume concentration of nano particles on second law efficiency.

II. Literature Review

K. Manjunath et.al. [3]

Analytical analysis of unbalanced heat exchangers is carried out to study the second law thermodynamic performance parameter through second law efficiency by varying length-to-diameter ratio for counter flow and parallel flow configurations. In a single closed form expression, three important irreversibilities occurring in the heat exchangers namely, due to heat transfer, pressure drop, and imbalance between the mass flow streams are considered, which is not possible in first law thermodynamic analysis.

The study is carried out by giving special influence to geometric characteristics like tube length-to-diameter dimensions; working conditions like changing heat capacity ratio, changing the value of maximum heat capacity rate on the hot stream and cold stream separately and fluid flow type, i.e., laminar and turbulent flows for a fully developed condition. Further, second law efficiency analysis is carried out for condenser and evaporator heat exchangers by varying the effectiveness and number of heat transfer units for different values of inlet temperature to reference the temperature ratio by considering heat transfer irreversibility. Optimum heat exchanger geo-metrical dimensions, namely length-to-diameter ratio can be obtained from the second law analysis corresponding to lower total entropy generation and higher second law efficiency. Second law analysis incorporates all the heat exchanger irreversibilities

Jung-Yang San et.al. [4]

A second-law analysis of a wet cross flow heat exchanger is performed for various weather conditions. The heat exchanger can be used as an energy-saving device for ventilation in air-conditioning. The heat and mass transfer is solved by using the model developed by Holmberg. The effectiveness, exergy recovery factor and second-law efficiency of the wet heat exchanger are individually defined. The effects of lateral solid heat conduction on the effectiveness, exergy recovery factor and second-law efficiency are numerically investigated for various operating conditions. Two optimum design criteria, one for the maximum second-law efficiency and the other for the maximum exergy recovery factor, are obtained.

J. Sarkar et.al. [8]

This paper presents the exergetic analysis and optimization of a transcritical carbon dioxide based heat pump cycle for simultaneous heating and cooling applications. A computer model has been developed first to simulate the system at steady state for different operating conditions and then to evaluate the system performance based on COP as well as exergetic efficiency, including component wise irreversibility. The chosen system includes the secondary fluids to supply the heating and cooling services, and the analyses also com-prise heat transfer and fluid flow effects in detail. The optimal COP and the exergetic efficiency were found to be functions of compressor speed, ambient temperature and secondary fluid temperature at the inlets to the evaporator and gas cooler and the compressor discharge pressure. An optimization study for the best allocation of the fixed total heat exchanger inventory between the evaporator and the gas cooler based on heat transfer area has been conducted.

The exergy flow diagram (Grassmann diagram) shows that all the components except the internal heat exchanger contribute significantly to the irreversibilities of the system. Unlike a conventional system, the expansion device contributes significantly to system irreversibility. Finally, suggestions for various improvement measures with resulting gains have been presented to attain superior system performance through reduced component irreversibilities.

Prabhat Kumar Gupta et.al. [12]

Performance of highly effective heat exchangers is governed by the various internal and external irreversibilities. In low temperature applications, the performance of these heat exchangers strongly depends on the irreversibilities such as ambient heat-in-leaks, longitudinal heat conduction through separating wall of heat exchanger and conduction through high temperature connecting tubes when they are integrated to the system. The special focus of present analysis is the study of effect of these irreversibilities on the performance of heat exchangers through second law analysis. It is observed that the effect of ambient heat-in-leak is different for the balanced and imbalanced counter flow high NTU heat exchangers. Study also makes it possible to compare the different irreversibilities for varying range of NTU and analyze the influence of external irreversibilities on the performance of heat exchangers when either hot fluid or cold fluid is minimum capacity fluid.

Arun Gupta et.al. [13]

In the present paper second law analysis of cross flow heat exchangers has been carried out in the presence of non-uniformity of flow. This non-uniformity is modeled with the help of axial dispersion model and takes into account the back mixing and flow maldistribution. An analytical model for exergy destruction has been evaluated for the cross-flow configuration. A wide range of study of the operating parameters and non-uniform flow on exergetic behavior of cross flow heat exchangers has been carried out. The results clearly bring out not only the reason behind the maximum entropy paradox in heat exchangers but also the proper perspective of exergy destruction and the consequent optimization of cross flow heat exchangers from the second law viewpoint.

Vasu, Krishna and Kumar [14]

Theoretically analyzed the Al_2O_3 + H_2O nano-fluid as coolant on automobile flat tube plain fin compact heat exchanger. The analysis was carried out using effectiveness-NTU rating method. A detailed flow chart of the numerical method and correlations used for Al_2O_3 + H_2O nano-fluid were also presented along with the graphical presentation of the characteristics.

III. Analytical Modelling and Simulation

Based on the first and second law of thermodynamics, the Numerical model was developed including heat transfer and fluid flow effects. Following assumptions were taken for analysis:

1) All properties of coolants and air are assumed to be constant.
2) Heat rejected by coolants will be fully absorbed by air.
3) All processes are assumed to be steady state.

The louvered fin cross flow radiator is selected as compact heat exchanger for this project, which is diesel engine with turbo-charged of type TBD 232V-12, where fluid is unmixed. The radiator is having of 644 tubes made of brass material with 346 continuous fins made of Aluminium alloy. Thermal conductivity of fin material is 177W/m-K. The coolant used in this study is water with nano particles i.e. nano fluids.

3.1:- Air Side calculation

Table 3.1

Fluid parameters and normal operating conditions [14]

S.NO.	Description	Air
1	Fluid mass rate (Wa)	10-20kg/s
2	Fluid inlet temperature(Tai)	283-323K
3	Core Width (L)	0.6m
4	Core height (H)	0.5m
5	Core depth (D)	0.4m

Table 3.2

Surface core geometry of flat tubes, continuous fins [14]

S. NO.	Description	Air side
1	Fin pitch	4.46fin/cm
2	Fin metal thickness t	0.0001m
3	Hydraulic diameter D_{ha}	0.00351m
4	Min free flow area/frontal area σa	0.780
5	Total heat transfer area/total volume αa	886 m^2/m^3
6	Fin area/Total area β	0.845

Table 3.3:

Thermal physical properties of air [23]

S.NO.	Thermal physical properties	Air
1	Density(kg/m3)	1.1614
2	Specific heat (J/kg K)	1007
3	Viscosity(N-s/m2)	0.00001846

Table 3.4

Specification of louvered fin parameters [9]

1	F_P	2 MM
2	F_H	8 MM
3	L_D	36.6 MM
4	LP	1.2 MM
5	LH	6.5 MM
6	LA	28

1. Air Frontal area

A_{fra}= L* H Eq.1

2. Core mass velocity of air is expressed as [20]

$$G_a = \frac{W_a}{A_{fr}\sigma_a} \quad \text{Eq.2}$$

3. Velocity of air

$$u_a = \frac{G_a}{\rho_a} \quad \text{Eq.3}$$

4. Reynolds number expression [9]

$$Re_a = \frac{G_a D_{ha}}{\mu_a} \quad \text{Eq.4}$$

Hydraulic Diameter

$D_{ha}=4*\sigma_a/\alpha_a$ Eq.5

5. Heat transfer coefficient, ha can be expressed as [20]

$$h_a = \frac{j_a G_a c_{p,a}}{Pr_a^{2/3}} \quad \text{Eq.6}$$

6. Colburn factor [9]

$$ja = 0.26712\, R_{ea}^{-0.1944} \frac{La^{0.257}}{90} * \frac{Fp^{-0.5177}}{Lp} * \frac{Fh^{-1.9045}}{Lp} * \frac{Lh^{1.7159}}{Lp} * \frac{Ld^{-0.2147}}{Lp} * \frac{t^{-0.05}}{Lp}$$

Eq.7

7. Plate fin efficiency, η can be expressed as [20]

$$\eta = \frac{\tanh ml}{ml} \quad \text{Eq.8}$$

Where,

$$m = \sqrt{\frac{2h_a}{kt}}$$

8. Total surface temperature effectiveness, can be expressed as [20]

$$\eta_o = 1 - \frac{A_f}{A}\left(1 - \eta_f\right) \quad \text{Eq.9}$$

3.2:- Nanofluid Side calculation

Table 3.5
Thermal physical property of base fluid [28]

Physical Properties	Water
Density (Kg/M^3)	992
Viscosity (Kg/ms)	0.00065
Thermal Conductivity (W/m^0C)	0.633
Specific heat (J/kg^0C)	4174

Table 3.6
Thermal physical properties of nano particles [15]

S. NO.	Thermal physical properties	(Al_2O_3)	(ZnO)	CuO	MgO
1	Density (kg/m^3)	3970	5600	6500	2900
2	Specific heat (J/kg K)	765	514	535.6	923
3	Conductivity (W/m K)	40	13	20	48.4

Table 3.7
Fluid parameters and normal operating conditions [14]

S.NO.	Description	Coolant
1	Fluid mass rate	3-7kg/s
2	Fluid inlet temperature	355-375K
3	Core Width	0.6m
4	Core height	0.5m
5	Core depth	0.4m

Table 3.8
Surface core geometry of flat tubes, continuous fin [14]

S.NO.	Description	Coolant side
1	Hydraulic diameter D_h	0.373cm
2	Min free flow area/frontal area σ	0.129
3	Total heat transfer area/total volume α	138 m^2/m^3

1. Coolant side Frontal area of

$$A_{frn} = L * D \quad \text{Eq.10}$$

2. Core mass velocity of coolant is expressed as [20]

$$G_{nf} = \frac{W_{nf}}{A_{fr}\sigma_{nf}} \quad \text{Eq.11}$$

3. Velocity of coolant

$$u_{nf} = \frac{G_{nf}}{\rho_{nf}} \quad \text{Eq.12}$$

4. Viscosity of nanofluid for Water and ethylene glycol based coolant is calculated based on following correlation [7]

$$\mu_{nf} = \mu_f\left(1 - 0.19\phi + 306\phi^2\right) \quad \text{Eq.13}$$

5. $C_{p,nf}$ and ρ_{nf} were calculated based on correlations obtained from [10]

$$c_{p,nf} = \frac{(1-\phi)\rho_f c_{p,f} + \phi\rho_p c_{p,p}}{\rho_{nf}}$$

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_p \quad \text{Eq.14}$$

6.Reynolds number expression for nanofluid [20]

$$Re_{nf} = \frac{G_{nf} D_{h,nf}}{\mu_{nf}} \quad \text{Eq.15}$$

7. Heat transfer coefficient can be expressed as [20]

$$h_{nf} = \frac{Nu_{nf} k_{nf}}{D_{h,nf}} \quad \text{Eq.16}$$

8. K_{nf} of nano-fluid for water and ethylene glycol as coolant is calculated based on correlation from [1]

$K_{nf} = k_p+2\, k_{bf}-2(k_{bf}- k_{p)}\, \Phi/\, k_p+2\, k_{pf}+2(k_{bf}- k_{p)}\, \Phi$
$*k_{bf} + 5*10^4\beta*\rho_{bf}*C_{pbf}*\, \Phi\, *[k*Tni/(\rho_{p*}d_p)]^{1/2}$
$*[(- 134.63+1722.3 * \Phi) + (0.4705-6.04* \Phi)\, Tni]$

Where the particle related empirical parameter

$\beta=0.0137*(100* \nu_p)^{-.8229}\Phi_{<0.01}$

$\beta =0.0011*(100* \nu_p)^{-.7272}\, \Phi_{>0.01}$ Eq.17

9. Nusselt number for nanofluid is expressed as [11]

$$Nu_{nf} = 0.021(Re_{nf})^{0.8}(Pr_{nf})^{0.5} \quad \text{Eq.18}$$

10. Prandtl number expression for nanofluid is [20]

$$Pr_{nf} = \frac{\mu_{nf} c_{p,nf}}{k_{nf}} \quad \text{Eq.19}$$

11. Overall heat transfer coefficient, based on air side can be expressed as bellow, where wall resistance and fouling factors are neglected. [20]

$$\frac{1}{U_a} = \frac{1}{\eta_o h_a} + \frac{1}{\left(\frac{\alpha_{nf}}{\alpha_a}\right) h_{nf}} \quad \text{Eq.20}$$

12. Heat exchanger effectiveness for cross-flow unmixed fluid can be expressed as [20]

$$\varepsilon = 1 - \exp\left[\frac{NTU^{0.22}}{C^*}\exp\left(-C^* NTU^{0.78} - 1\right)\right] \quad \text{Eq.21}$$

13. Number of heat transfer unit is expressed as [20]

$$NTU = \frac{U_a A_{fr,a}}{C_a}$$

Where $C^* = \dfrac{C_{min}}{C_{max}}$ Eq.22

14. Total heat transfer rate can be expressed as [20]

$$Q = \varepsilon C_{min}\left(T_{nf,in} - T_{a,in}\right) \quad \text{Eq.23}$$

3.3:- Second law analysis

The Guoy–Stodola theorem provides the basis for calculation of irreversibility in heat exchangers, which is the quantitative measure of the exergy loss in the process and is related to entropy generation as [12]

$$I = T_0 S_{gen} \qquad \text{Eq.24}$$

3.4:- Irreversibility due to fluid friction

The dissipative forces arising on account of fluid friction also contribute significantly to irreversibility, in the form of pressure drop. Taking working fluid as an ideal gas, the thermodynamic loss due to fluid friction is given as [13]

$$(S_{gen})_{\Delta p} = \left[W \frac{\Delta P}{\rho T} \right]_{nf} + (WR)_a \ln \left[\frac{p_{in}}{p_{out}} \right]_a \qquad \text{Eq.25}$$

At the outlet of the heat exchanger, pressure can be considered to be atmospheric.

The exergy loss by the hot fluid (nanofluid) is given by [8]

$$\Delta Ex_{nf} = Q - T_0 \left[W C_p \ln \left(\frac{T_{in}}{T_{out}} \right) - W \frac{\Delta P}{\rho T} \right]_{nf} \qquad \text{Eq.26}$$

Similarly, the exergy gain by cold fluid (air) is given by [8]

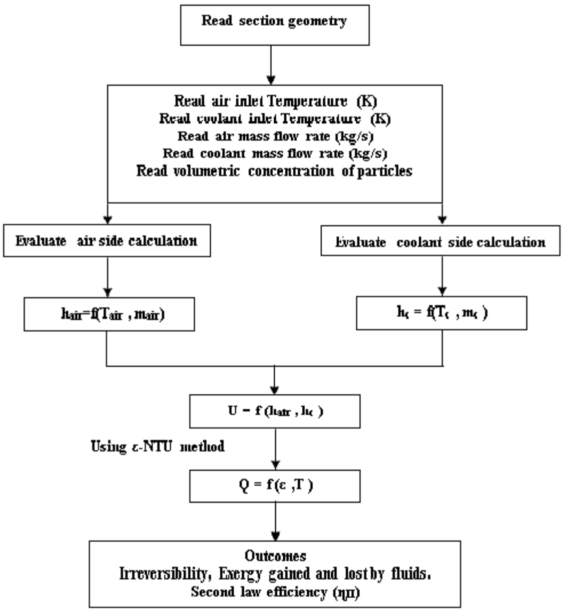
$$\Delta Ex_a = Q - T_0 \left[W C_p \ln \left(\frac{T_{out}}{T_{in}} \right) + W R \ln \left(\frac{P_{in}}{P_{out}} \right) \right]_a \qquad \text{Eq.27}$$

The Second law efficiency (η_{II}) is the ratio of the minimum exergy which must be consumed to do a task divided by the actual amount of exergy consumed in performing the task, is given by [8].

$$\eta_{II} = \frac{\Delta Ex_a}{\Delta Ex_{nf}} = 1 - \frac{I}{\Delta Ex_{nf}} \qquad \text{Eq.28}$$

3.5:- Simulation procedure and validation

For implementing the analysis, a computer program in C++ has been made for the compact heat exchanger (Automobile Radiator). This program is very useful in estimating the fluid properties at various operating temperatures, surface core geometry of cross flow heat exchanger, heat transfer coefficients, second law efficiency, overall heat transfer coefficients and heat transfer rate. The flowchart for the numerical analysis is shown in Fig.4



Flow Chart 1: Flow chart of the numerical method [41]

IV. VALIDATION

The outcome of the simulation for water coolant with Al_2O_3 nano-particles is validated from the theoretical result by V. Vasu et al {14} with 4% mean error. As shown in figure.

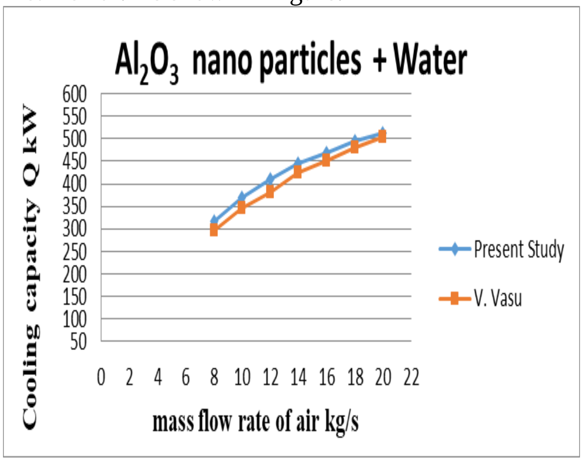


Figure 2: variation cooling capacity with mass flow rate of air.

V. RESULT AND DISCUSSION

5.1:- Effect of varying inlet mass flow rate of air

The figure 3 shows the variation of second law efficiency with variation of air mass flow rate over a span of 9 to 21 kg/sec.

When mass flow rate of air increases from 9 kg/sec to 21 kg/sec, second law efficiency decreases sharply. Second law efficiency decrease`s because irreversibility continuously increased as shown in figure 4. Irreversibility is increasing because exergy gain by cold fluid (air) is decreased as shown in figure 8when other input parameters like mass flow rate of coolant = 5 kg/sec, inlet temperature of air =30 ° C, inlet temperature of coolant=90° C and concentration of nano particles=2% are kept constant.

Second law efficiency of water coolant is less as compared to nano fluid coolants. Nano fluid based on Al_2O_3, CuO, MgO and ZnO having second law efficiency grater then 6.71%,5.59%,7.15% and 5.81% respectively of water coolant only when mass flow rate of air is 15kg/s. The data shows that nano fluids based on MgO have greatest second law efficiency as compared to other nano fluids. CuO and ZnO show almost same behavior.

Irreversibility of water coolant is very high as compared to nano fluids based on Al_2O_3, CuO, MgO and ZnO. Nano fluids based on MgO have higher irreversibility as compared to other nano fluids. As it is clear from figure 8that nano fluids based on CuO have least irreversibility.

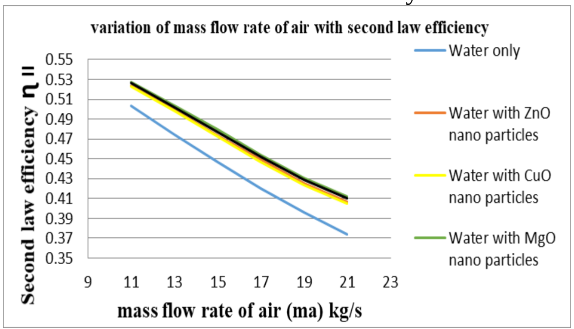


Figure 3

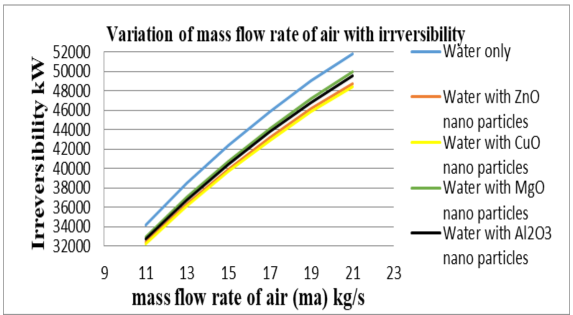


Figure 4

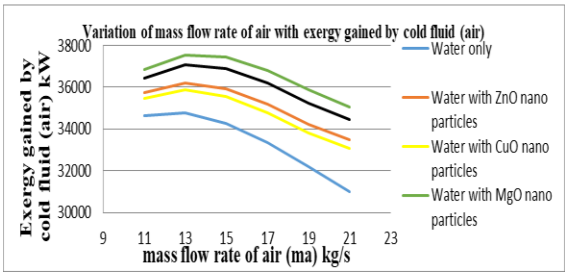


Figure 5

5.2:- Effect of fluctuation of mass flow rate of coolant

The graph 6 below illustrate the variation on second law efficiency with variation of coolant mass flow rate over a range of 3 to 7 kg/sec

When mass flow rate of coolant grow from 3 kg/sec to 7 Kg/sec, second law efficiency goes on increasing because exergy gained by cold fluid (air) and exergy lost by hot fluid (nano-fluid) as shown in figure 7 and 8 is increasing when other input parameters like mass flow of air = 15 kg/sec, inlet temperature of air =30 ° C, inlet temperature of coolant=90° C and concentration of nano particles=2% are kept constant.

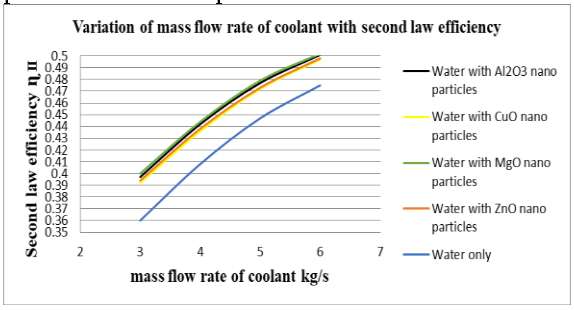


Figure 6

Figure 7 below shows that exergy gained by cold fluid increases sharply. Water coolant gained less available energy as compared to nano fluids. It is clear from chart that MgO based nano fluids absorbed maximum energy from hot fluid.

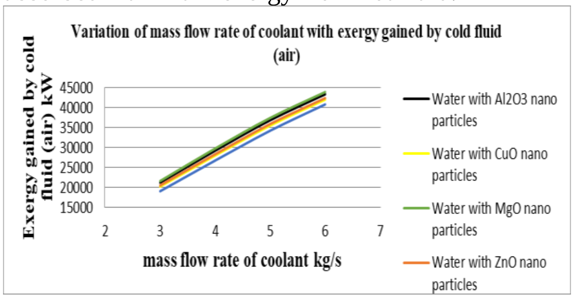


Figure 7

5.3:- Effect of fluctuation of inlet temperature of air

Figure 8 shows variation of second law efficiency with variation of inlet temperature of air from 285 K to 325 K. as it is clear from figure that second law efficiency is decreasing sharply as we increase inlet temperature. Second law efficiency is decreasing because exergy gained by cold fluid and exergy lost by hot fluid both are decreasing, shown in figure 9 and 10 . However, irreversibility is also decreasing because difference between exergy gained by cold fluid and exergy lost by hot fluid both are decreasing. The ratio between irreversibility and exergy lost by hot fluid(Nano fluid) is increasing which ultimetly decrease the second law efficiency.

It is very clear from figure 8 that water coolant has least second law efficiency as compared to nano fluids. MgO based nano fluids shown highest second law efficiency. Whereas CuO and ZnO based nano fluids shows almost same behaviour.

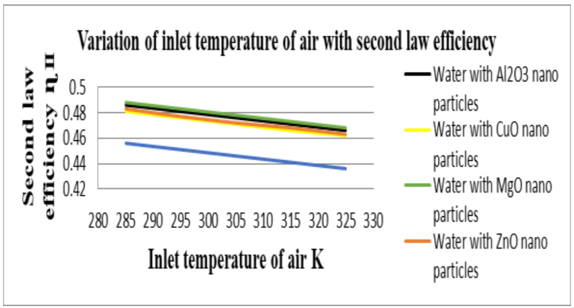


Figure 8

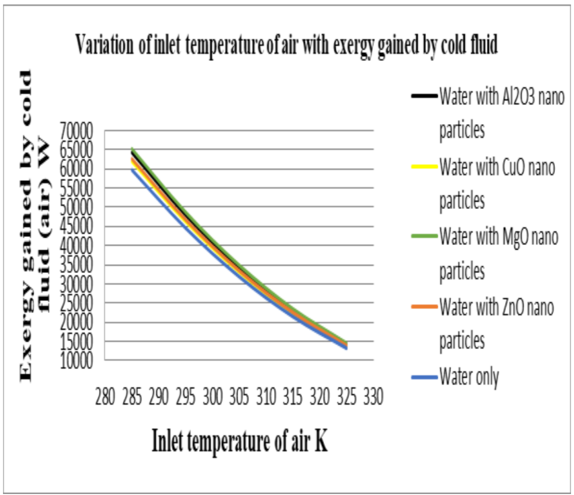


Figure 9

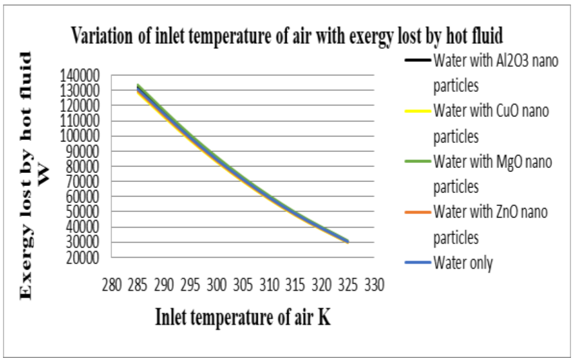


Figure 10

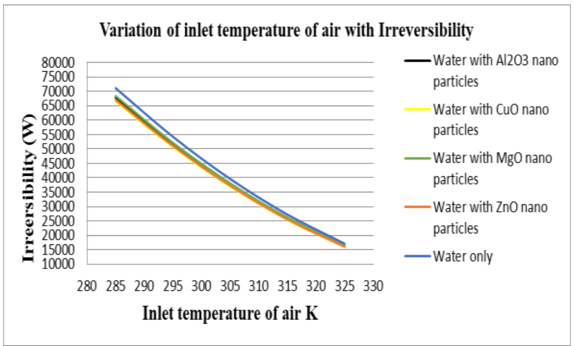


Figure 11

5.4:- Effect of fluctuation of inlet temperature of coolant

As it is clear from figure 12 that second law efficiency increased with variation of coolant inlet temperature from 355 K to 375 K. Exergy gained by cold fluid (air) and irreversibility is also increasing with increase in coolant inlet temperature. Water coolant has low second law efficiency as compared to nano fluids. It shows that by using nano fluids we can easily use maximum available energy into useful work. Nano fluids based on MgO shows better performance as compared to other nano fluids.

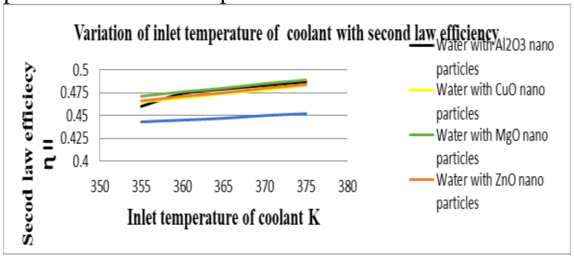


Figure 12

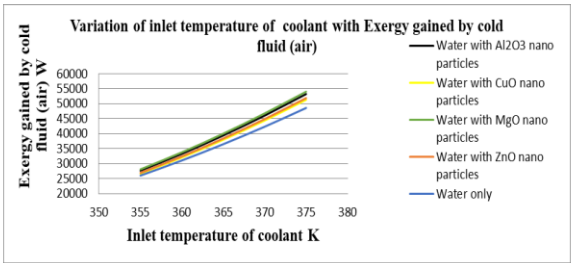


Figure 13

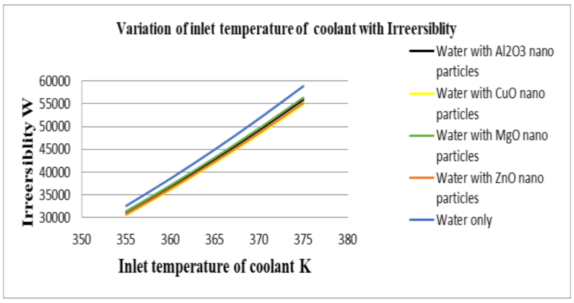


Figure 14

5.5:- Effect of fluctuation of nano particle concentration

The figure 15 to 17 illustrates the variation respectively of cooling capacity, second law efficiency, irreversibility and exergy gained by cold fluid with respect to nano particles concentration over a range of 1% to 5%.

The graph shows that second law efficiency experiences a decrease in the value as we increase the volume concentration of nano sized particles. However with comparing zero percent nano particles i.e. water coolant only, second law efficiency is very high. With increase in volume concentration of nano particles after 2% cooling capacity and second law efficiency experiences a decrease in the value because effect of increasing viscosity is more prominent than the increasing thermal conductivity after optimum concentration value. This unusual phenomenon can also be traced probably to the nano particles sedimentation on the solid wall when the volume fraction of the nano particles is relatively higher and formation of a porous layer which reduces the convection based heat transfer to layer conduction.

At about 1% to 3% of particles concentration, nano fluids showed superior cooling capacity and second law efficiency than water coolant only. MgO based nano fluids have highest second law efficiency and cooling capacity as compared to other nano fluids.

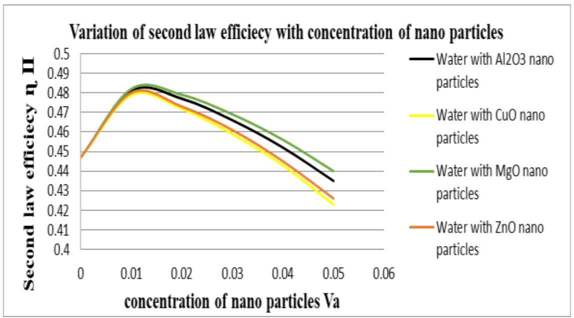


Figure 15

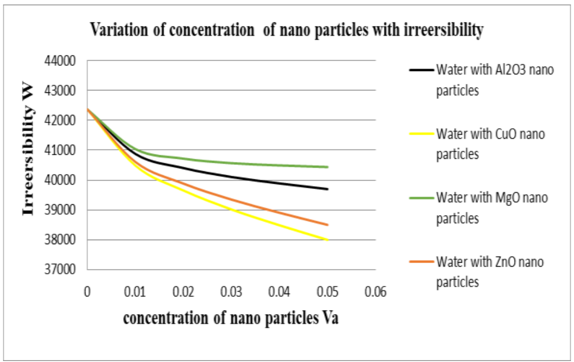


Figure 16

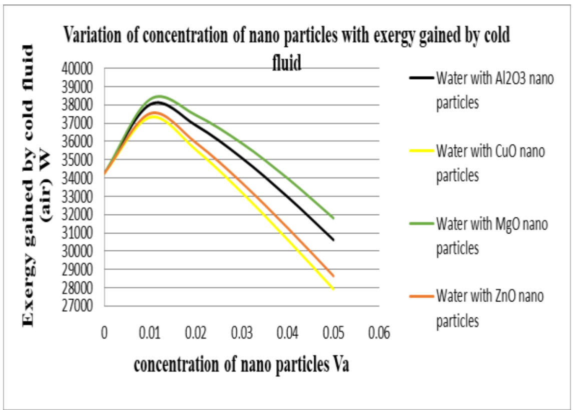


Figure 17

VI. COMPARISION

Table 5.1:
Value of Second law efficiency, exergy gained by cold fluid and irreversibility for comparison

Sr. No	Coolant type	Value of second law efficiency	Value of irreversibility (kW)	Value of exergy gained by cold fluid air (kW)
1	Water only	0.447	42367.1	34253.7
2	Water with Al_2O_3	0.477	40402.8	36882.3
3	Water with CuO	0.472	39650.2	35544.3
4	Water with MgO	0.479	40718.0	37441.0
5	Water with ZnO	0.473	39882.0	35930.2

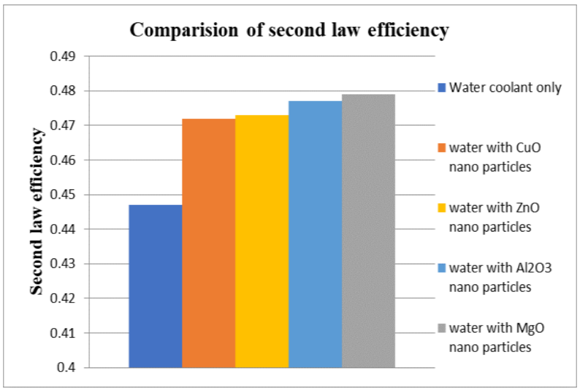


Figure 18

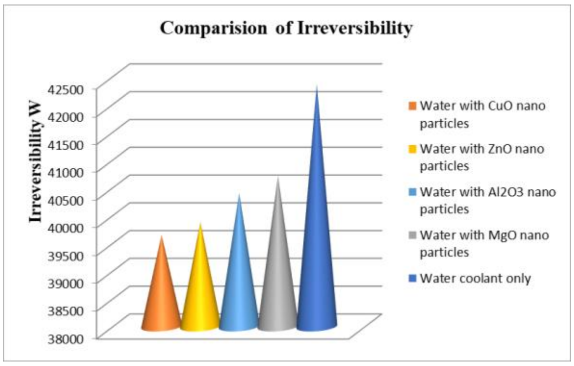


Figure 19

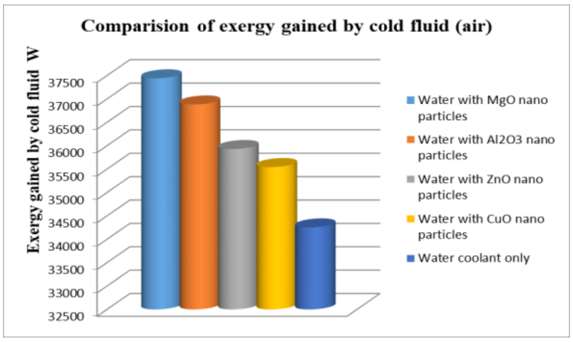


Figure 20

It is cleasr from figure 18,19 and 20 that water coolant have less second law efficiency, higher irreversibility and less exergy gained by cold fluid as compared to nano fluids when operating parameters value held constant i.e Ma=15kg/s, Mc=5kg/s, Tai=303K and Tci=363K. By using nano fluids second law efficiency is incresed by 5.5% to 7.5% . MgO based nano fluids has highest second law efficiency. Irreversibilty can be decreased by 4% to 7% by using nano fluids as compared to water coolant.further, exergy gained by cold fluid i.e use of maximum avilable energy can be increaes by 3 to 9% by using nano fluids.

VII. CONCLUTION

In the present study, keenly parametric study on the louvered fin cross flow radiator, which is diesel engine with turbo-charged of type TBD 232V-12, where fluid is unmixed, was done through ε –NTU method by using four nano-particles viz. Al_2O_3, CuO, MgO and ZnO in the base fluid of water. Computer program in C++ language were made for calculating the Second Law Efficiency, Irreversibility and exergy gained and lost by nano fluids (Appendix A). The following conclusions can be drawn from the study:

1. The second law efficiency of the radiator was greater, when nano-fluids were employed as coolants instead of base fluids water only. An increment of 5% to 7% was seeing in the second law efficiency of the radiator using nano-particles in the water coolant. Nano fluid based on Al_2O_3, CuO, MgO and ZnO having second law efficiency grater then 6.71%,5.59%,7.15% and 5.81% respectively of water coolant only. MgO based nano fluids shows superior utilization of available energy as compared to other nano fluids.
2. The irreversibility of the radiator was less, when nano-fluids were employed as coolants instead of base fluids water only. It can be decreased by 4 to 7% with respect to water coolant only.
3. With increase in mass flow rate of air, second law efficiency is decreased. On the other hand, with increase in mass flow rate of coolant second law efficiency increased.
4. With increase in inlet temperature of air, second law efficiency decreased On the other side, with increase in inlet temperature of coolant, second law efficiency increased.

   With increase in volume concentration of nano particles second law efficiency is firstly increased till 1% of volume concentration of nano particles. But, decrement in second law efficiency has been seen after 1% addition in value of volume concentration of nano particles. However, till 3% volume concentration, value of second law efficiency is increased as compared to water coolant only.

VIII. FUTURE WORK

a. To develop a flexible experimental set up comprising different fin geometries, for astute observations and analysis.
b. To experimentally evaluate of the performance of automobile radiator using nano-fluid as coolant.
c. To enhance the cooling capacity, and second law efficiency of automobile radiator employing hybrid nano-particles e.g. SiC, TiO_2 etc. in base fluids of Water and mixture of water and anti freezing agent.
d. To experimentally evaluate the performance of automobile radiator employing varied base fluids apart from Water.
e. To develop software programs for the aforementioned parameters in computer languages apart from C++.

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