

Numerical Investigation of Exergy Analysis using Nano- fluids Coolant for Wavy Fin Automobile Radiator

Vikram Kumar Gupta¹

Assistant Professor, Department of Mechanical Engineering, Prestige Institute of Engineering Management and Research Indore, Madhya Pradesh, India. ¹

ABSTRACT: The field of Compact heat exchangers is gaining more and more attention, as for the increased requirement of heat transfer rate. For the reason, there is an abundance of research that is being carried out in the field of heat transfer for compact heat exchangers. Now-a-days, compact heat exchangers are widely used with conventional coolants viz. water and ethylene glycol, in many thermal and fluid systems. However, the conventional coolants offer low thermal conductivity, and moreover the traditional techniques to increase the cooling capacity of compact heat exchangers employing various fin geometries are becoming obsolete. Hence, a new and innovative fluid for improving heat transfer rate via compact heat exchangers is the need of the day. But, thanks to advancement in nanotechnology, for developing new generation of heat transfer fluids known as 'Nano-fluids', which offer high thermal conductivity as compared to conventional coolants. This study is focused on the application of water based nano-fluids (Al_2O_3 and ZnO) in an automotive cooling system, and compared their performance for wavy fin geometry with considering the Effect of various operating parameters such as inlet mass flow rate of air, inlet mass flow rate of coolant, inlet temperature of air and inlet temperature of coolant on radiator for exergy analysis. It was observed that Second law efficiency in the engine cooling system increased with the usage of nano-fluids compared to water coolant only. It was also observed that, about 6 to 7% increment in the second law efficiency by using nano-fluids in wavy fin automobile heat exchanger.

KEYWORDS: Nano-fluids, Nano-particles, Second Law Efficiency, Al_2O_3 Nano-Particles, ZnO Nano-Particles, Compact Heat Exchanger, Automobile Radiator.

I. INTRODUCTION

1.1 Nano-fluids

Nano-fluids are nano-technology-based heat transfer fluids that are derived by stably suspending nanometer-sized particles (with typical length scales of 1 to 100 nm) in conventional heat transfer fluids usually liquids. Nano-fluids consisting of such particles suspended in liquids (typically conventional heat transfer liquids) to enhance the thermal conductivity and convective heat transfer performance of the base liquids. The thermal conductivities of the particle materials are typically order-of-magnitude higher than those of the base fluids such as water, ethylene glycol, and light oils, and nano-fluids, even at low volume concentrations, result in significant increases in thermal performance.

1.2 Manufacturing of Nano-fluids

The advancement of fabrication technology has made possible the fabrication of materials up to nano scale level. The Nano-particles belongs to the family of nano-sized materials, which exhibit unique physical and chemical properties as compared to those of macro-sized particles. Nano-particles can be obtained from a variety of materials with the use of two production techniques viz. physical process production and chemical process production both involving either two steps or single step processes.

Nano-particles have been obtained from various materials either by physical or chemical techniques. The physical technique consists of mechanical grinding and inert gas condensation, the latter of which was developed by Granqvist and Buhrman of Cornell University. The chemical technique consists of chemical precipitation, chemical vapour deposition, spray pyrolysis, thermal spraying and micro-emulsions. The nano-particles, thus produced are in powdered form, which can then be dispersed into aqueous medium to form nano-fluids. Till date, many types of host aqueous solutions are used, however, ethylene glycol or ethylene glycol-water mixture are the best for automotive applications. The two techniques: the two-step and the single-step technique. The two-step technique starts with nano-particles, produced by one of the physical or chemical technique described previously, and proceeds to disperse them into a host

fluid. The single-step technique simultaneously prepares and disperses the nano-particles directly into the base fluid. Most of the nano-fluids containing oxide nano-particles and carbon nano-particles are produced by the two-step process.

1.3 Compact Heat Exchanger

A compact heat exchanger is a heat exchanger that has high surface area per unit volume, which results in higher efficiency than conventional heat exchangers. The compact heat exchangers find wide usage in thermal fluid systems including automotive thermal fluid systems viz. radiators for engine cooling systems. Of many factors, geometry of fins plays major role in determining the performance of compact heat exchanger. The prominent fin configurations are a) Straight Fins with Rectangular, Trapezoidal or Triangular Passages b) Un-interrupted Wavy Fins and c) Interrupted Fins Viz. Offset Strip, Louvered, Perforated and Pin Fins. The details of each fin type are given below.

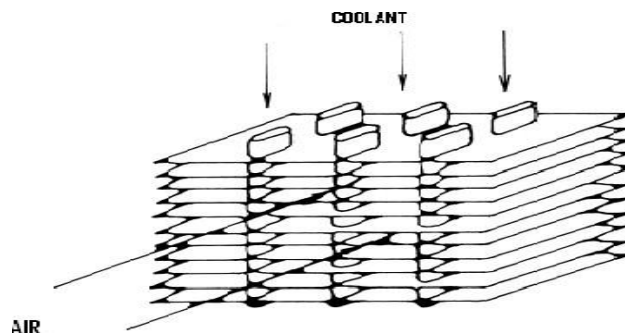


Fig 1: Compact Heat Exchanger [16]

1.4 Uninterrupted wavy fins

The wavy fins are un-interrupted fin surfaces with cross-section like that of Straight fins, however, cyclic lateral shifts perpendicular to the flow direction occurs. These wave-forms, however induces.

Effective interruptions and forms a complex flow field, thereby enhancing heat transfer as for the creation of Goertler Vortices. These Goertler Vortices are counter rotating vortices and produces corkscrew like flow pattern, when the fluid Passes over the concave surfaces. For wavy fin surface, the heat transfer and pressure drop characteristics are in between that of straight and offset strip fins.

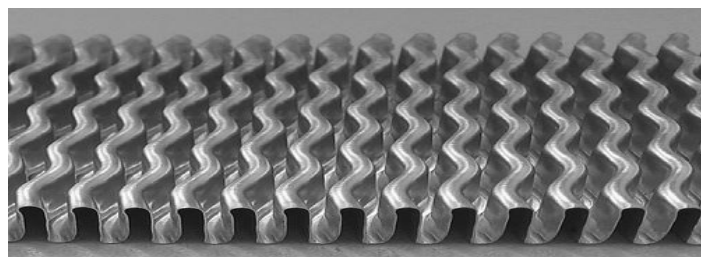


Fig 2: Wavy Fin [15]

II. OBJECTIVE OF THE PRESENT STUDY

- ✓ Numerical Analysis of second law efficiency of automotive radiator by using wavy fin geometry.
- ✓ Second law efficiency of radiator has been compared by considering different nano particle like Al_2O_3 and ZnO in water coolant only.



III. MATHEMATICAL MODELING AND SIMULATION

Based on first law of thermodynamics, the mathematical model has been developed including heat transfer and fluid flow effects. Following assumptions have been taken for analysis:

- 1) Properties related to nano fluid and air assumed constant.
- 2) Air which is flowing inside radiator absorbs total heat rejected by nano fluid.
- 3) Steady state process.

Table 1: Fluid parameters and Normal Operating conditions [16]

S.NO.	Description	Air
1	Fluid mass rate W_a	10-20kg/s
2	Fluid inlet temperature T_{ai}	283-323K
3	Core Width L	0.6m
4	Core height H	0.5m
5	Core depth D	0.4m

Table 2: Surface core geometry of flat tubes, continuous fins [16]

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

Table 3: Thermal physical properties of Air [3]

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

Table 4: Specification of Wavy fin Parameter [15]

1	F_p	2 mm
2	F_h	8 mm
3	L_d	36.6 mm
4	$2A$	1.5 mm
5	L	10.8 mm

Table 5: Thermal physical property of Base fluid [7]

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



Table 6: Thermal physical properties of nano particles [5,19,11]

Physical Properties	Density Kg/M ³	Thermal Conductivity W/m ⁰ C	Specific heat J/kg ⁰ C
Alumina (Al ₂ O ₃)	3970	40	765
Zinc oxide (Z _n O)	5600	514	13

Table 7: Fluid parameters and Normal Operating condition [16]

S.NO.	Description	Coolant
1	Fluid mass rate	4-6kg/s
2	Fluid inlet temperature	353-373K
3	Core Width	0.6m
4	Core height	0.5m
5	Core depth	0.4m

Table 8: Surface core geometry of flat tubes, continuous fin [16]

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. Core mass velocity of air is expressed as[6]

$$G_a = W_a \frac{A_{fr} \sigma_a}{\dots}$$

2. Reynolds number expression [15]

$$Re_a = \frac{G_a D_{ha}}{\mu_a}$$

3. Heat transfer coefficient, h_a can be expressed as [6]

$$h_a = \frac{j_a G_a c_{p,a}}{Pr_a^{2/3}}$$

4. Plate fin efficiency, η can be expressed as [6]

$$\eta = \frac{\tanh ml}{ml}$$



5. Total surface temperature effectiveness, can be expressed as[6]

$$\eta_o = 1 - \frac{f}{A}$$

6 Coolant side Frontal area of $A_{fm} = L * D$

7 Core mass velocity of coolant is expressed as [6]

$$G_{nf} = \frac{W_{nf}}{A_{fr} \sigma_{nf}}$$

8. Viscosity of nanofluid for Water [20]

$$\mu_{nf} = \mu_f (1 - 0.19\phi + 306\phi)$$

9. Reynolds number expression for nanofluid [6]

$$Re_{nf} = \frac{G_{nf} D_{h,nf}}{\mu_{nf}}$$

10. Heat transfer coefficient can be expressed [6]

$$h_{nf} = \frac{Nu_{nf} k_{nf}}{D_{h,nf}}$$

11. K_{nf} of nano-fluid for water [13]

$$K = k_m + 3 * v_p * (k_p - k_m) / [2 * k_m + k_p - v_p * (k_p - k_m)] * k_m + 5 * 10^4 \beta * \rho_m * C_{pm} * v_p * [k_B * T / (2 * \rho_p * r_p)]^{1/2} * [(-134.63 + 1722.3 * v_p) + (0.4705 - 6.04 * v_p) T]$$

Where the partial related empirical parameter

$$\beta = 0.0137 * (100 * v_p)^{-8.229} v_{p < 0.01} + 0.0011 * (100 * v_p)^{-7.272} v_{p > 0.01}$$

Nusselt number for nanofluid is expressed as

$$Nu_{nf} = 0.021 (Re_{nf})^{0.8} (Pr_{nf})^{0.5}$$

12. Prandtl number expression for nano fluid is [6]

13. Overall heat transfer coefficient, based on air side can be expressed as below, where wall resistance and fouling factors are neglected.[6]

$$\frac{1}{U_a} = \frac{1}{\eta_o h_a} + \frac{1}{\left(\frac{\alpha}{a} \right)_{nf}}$$

IV. SIMULATION PROCEDURE

For implementing the analysis, a computer program in C++ has been made for the compact heat exchanger. This program is very useful in calculating the fluid properties at various operating temperatures, surface core geometry of cross flow heat exchanger, heat transfer coefficients, overall heat transfer coefficients and heat transfer rate etc.

V. RESULTS FOR WAVY FIN RADIATOR

5.1 Effect of varying inlet air mass flow rate:

The figure 3 shows the variation of second law efficiency with variation of air mass flow rate over a span of 10 to 20 kg/sec water coolant. When mass flow rate of air increases from 10 Kg/sec to 20 Kg/sec, second law Efficiency decreases because irreversibility increased. Irreversibility is increasing because exergy gain by cold fluid (air) is decreased when other input parameters like mass flow rate of coolant = 5 kg/sec, inlet temperature of air =303 K, inlet temperature of coolant=363 K are keep constant.

It is interesting to write that the cooling capacity of compact heat exchanger goes on increasing as we increase the mass flow rate of air because of increasing heat transfer coefficient and effectiveness. On comparing second law efficiency using Al₂O₃ and ZnO nano-fluids, it has been observed that nano-fluid based on Al₂O₃ has slightly higher second law efficiency as compared to ZnO based nano-fluid and water only.

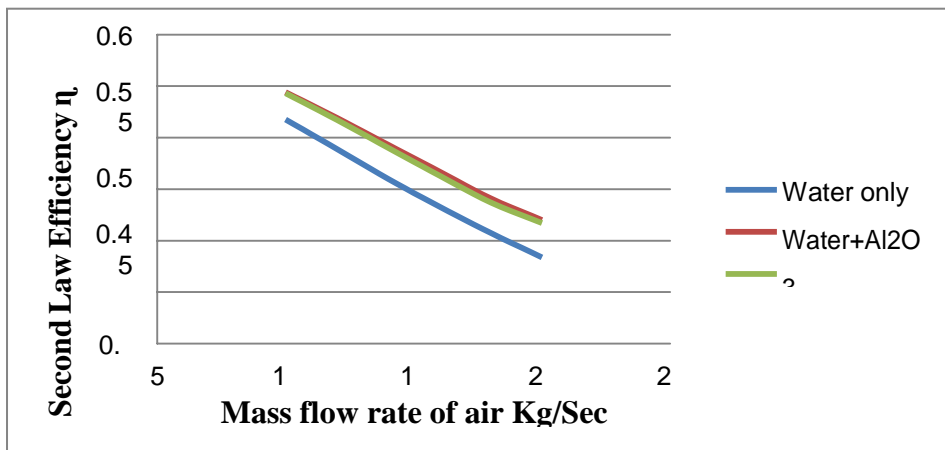


Fig 3 Effect of mass flow rate of air on second law efficiency

4 Kg/sec to 6 Kg/sec, second law efficiency goes on increasing because exergy loss by the hot fluid (nano-fluid) is increasing when other input parameters like mass flow rate of air = 15 kg/sec, inlet temperature of air =303 K, inlet Temperature of coolant=363 K are keep constant. On comparing second law efficiency using Al₂O₃ and ZnO nano-fluids, it has been observed that nano-fluid based on Al₂O₃ has slightly higher second law efficiency as compared to ZnO based nano-fluid and water only.

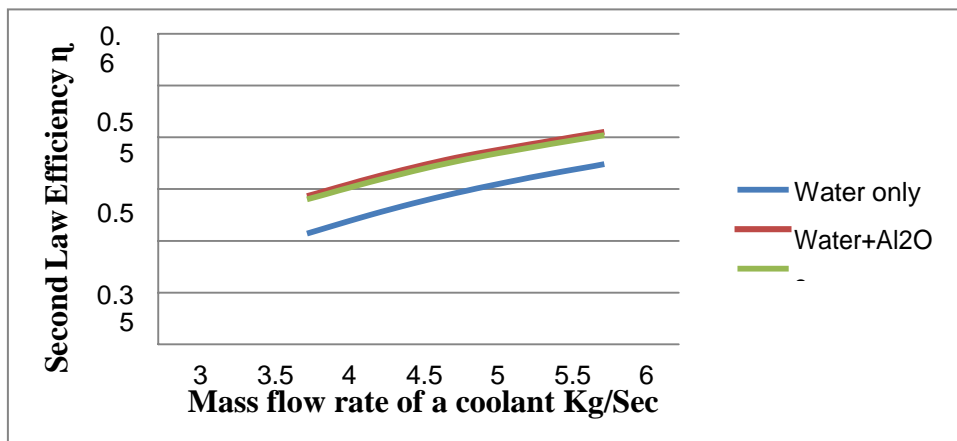


Fig 4 Effect of mass flow rate of coolant on second law efficiency

5.2 Effect of fluctuation of inlet temperature of air

The figure below illustrate the variation of second law efficiency with variation of inlet air temperature over a range of 283 K to 323 K for base fluid water only and base fluid water with nano-particles when other input parameters like mass flow rate of air=15 kg/sec, inlet, mass flow rate of coolant =5kg/sec and inlet temperature of coolant=363 K are keep constant. Value of second law efficiency is shrinking with increasing inlet temperature of air. It is clear from the chart that there is a tiny difference on second law efficiency of water having nano-particles and water only however on comparing second law efficiency it is concluded that water using Al₂O₃ has higher efficiency then water using ZnO.

5.3 Effect of fluctuation of inlet temperature of coolant

The figure below illustrate the variation on second law efficiency with variation of inlet air temperature over a range of 353 K to 373 K for base fluid water only and base fluid water with nano particles when other input parameters like mass flow rate of air = 15 kg/sec, inlet, mass flow rate of coolant = 5 kg/sec and inlet temperature of air =303 K are keep constant. The chart shows that there is a addition in the value of second law efficiency with increase in inlet temperature of coolant. It can be seen that second law efficiency of water using Al₂O₃nano-fluid is larger than as compared to water using ZnO nano- fluid and water only

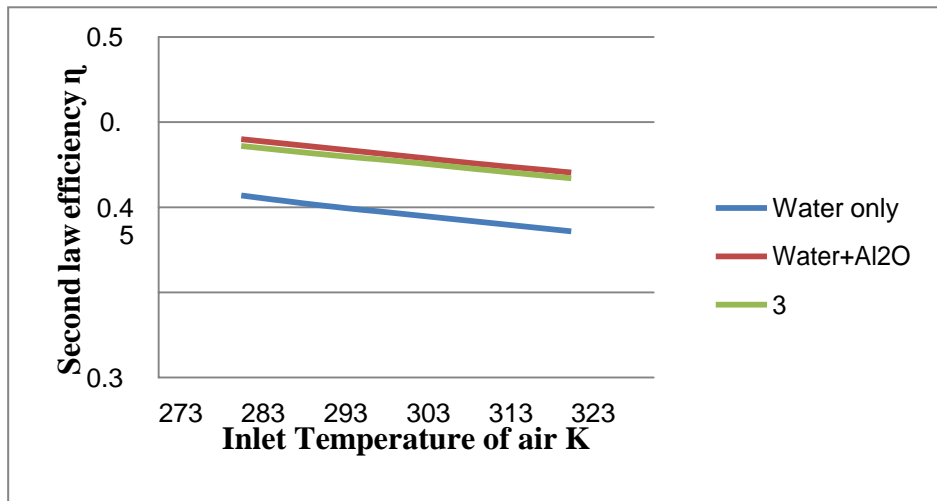


Fig 5 Effect of inlet air temperature of coolant on second law efficiency

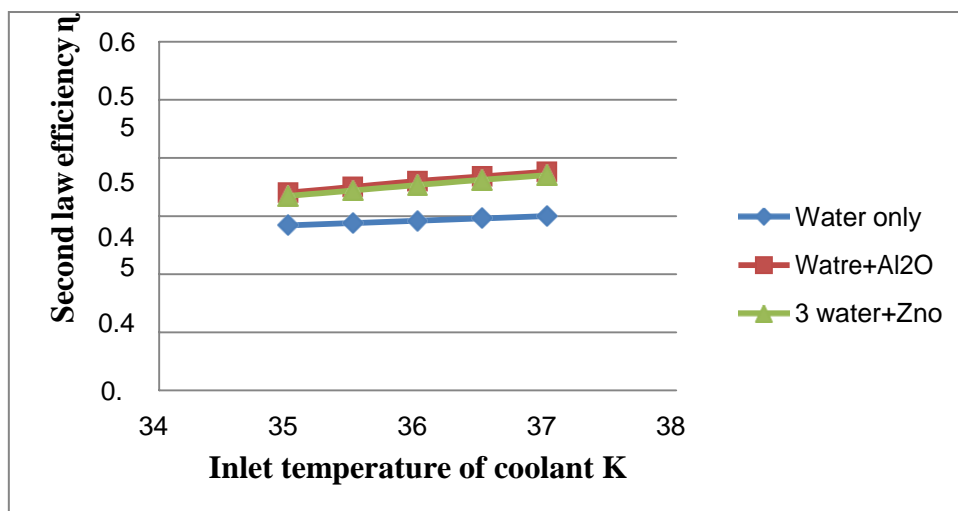
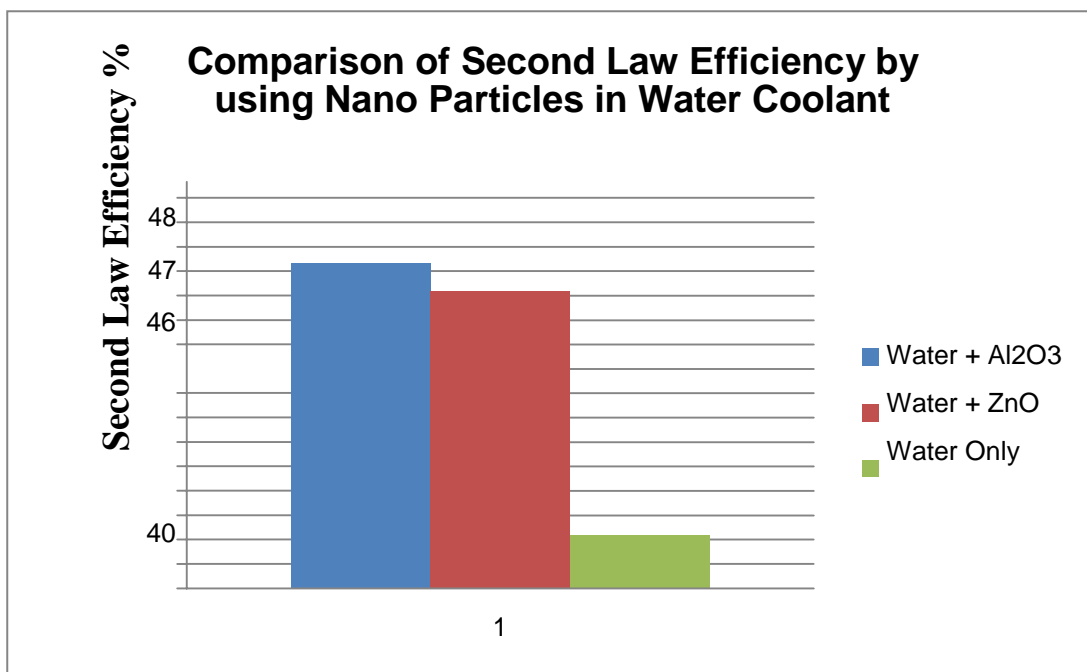


Fig 6 Effect of inlet coolant temperature on second law efficiency

VI. CONCLUSION

A detailed parametric study on automotive radiator has been done by using ϵ -NTU method using two nano fluids (Al_2O_3 and ZnO) in a base fluid Water as a coolant for wavy fin geometries. Detailed correlations used for nano fluid are presented. Based on results and discussion, following conclusion can be made:

- With the increase in mass flow rate and inlet temperature of air, reduction in second law efficiency is observed.
- Second law efficiency increases with increase in mass flow rate of coolant and inlet temperature of coolant.
- About 6.97% increment in cooling capacity with the use of Al_2O_3 nano particles In Water as compared to water only.
- About 6.31% increment in cooling capacity with the use of ZnO nano particles In Water as compared to water only. About 0.70% increment in cooling capacity with the use of Al_2O_3 nano particles as compared to ZnO nano particles in water.



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