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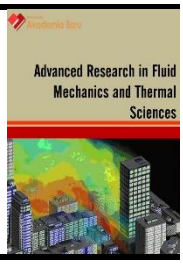

Comparison of Heat Transfer Rate with Aluminium Based Nano Fluid and Magnetised Ferro Fluid in Internal Combustion Engine Heat Exchanger

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ABSTRACT

Automotive radiators are compact heat exchangers used to exchange the heat absorbed from the engine to the cooling media. Purpose-designed nanoparticles of CuO, alumina, titanium dioxide, carbon nanotubes, silica, ferro particles etc dispersed into the carrier liquid enhances the heat transfer capabilities. This paper compares the heat transfer rate using aluminium based nano fluid and nano sized ferrofluid with and without magnetization experimentally in a heat exchanger using water as base fluid. An experimental setup was constructed with facility to measure all required temperatures. Using the obtained data, the optimum heat transfer rate and efficiency of heat exchanger is calculated with different combinations. The size of the particle used for the experiment is 35nm and 29.2nm respectively for aluminium based particle and ferro particle. The temperature difference across the heat exchanger was 6°C when water alone was used as the cooling media. Ferro particles from 1% to 5% were added into the base fluid and it was observed that the optimum temperature difference was noted when 4% ferro particles used with base fluid, the temperature difference increased from 6°C to 11°C at this combination. The ferro particles were then magnetized and when 4% ferro particles were magnetized, the temperature difference increased to 15.6°C. Further increase in ferro particles and magnetization shows reduction in temperature difference. The maximum temperature difference obtained by using aluminium based nano fluid is at 5% addition and the temperature difference is 9.3°C. The comparison shows that magnetized ferrofluid is more efficient than aluminium based fluid in heat exchanging. For validation, the software used is FLUENT and for regression analysis & evaluation, software packages such as MINITAB 18 and MATLAB 16a are used.

Keywords:
IC Engines; heat transfer; efficiency; nano particles

1. Introduction

Automotive radiator is a vital part of engine cooling system, which is a compact heat exchanger. In radiator, the heat is being taken by another media thereby the coolant gets cooled and re-circulated into the system [1]. Conventional fluids like water, oil, ethylene glycol etc have poor heat

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transfer performance therefore high compactness and effectiveness of heat transfer systems are necessary to achieve the required heat transfer [2,3]. A reduction in energy consumption is possible by improving the performance of heat exchange systems and introducing various heat transfer enhancement techniques [4,5].

Nanofluids are not merely dispersion of solid particles in a base fluid [6,7]. The mandate that nanofluid to fulfill includes stable suspension, negligible agglomeration of particles and no chemical change of particles or fluids [8]. Nanofluids are produced by dispersing nano meter scale solid particles into the base liquids such as water, ethylene glycol, oil etc [9].

For conducting the experiment, the materials used to make aluminium based nano particles are Aluminum Nitrate ($Al(NO_3)3{\cdot}6H_2O$) aqueous ammonia ($NH_3{\cdot}H_2O$,13mol/L), and distilled water and the size of the particle obtained is 35nm.The material used for preparation of ferro particles were Ferric chloride ($FeCl_3.6H_2O$), Ferrous sulfate ($FeSO_4.7H_2O$), Ammonium hydroxide (NH_4OH), Oleate sodium and Polyethylene glycol 4000 (PEG-4000)[10,11]and the size of the particle is 29.2nm.

By applying the magnetic field into the ferrofluid, they transform into pseudo solids, which carries more heat than liquids. The spike formed by magnetizing the ferrofluid increases the surface area inturn the heat transfer rate. The temperature difference across the heat exchanger was increased by 11°C when 4% ferro particles were added to the cooling water. When the ferro particles were magnetized, the temperature difference increased to 15.6°C. The optimum was at 4% addition of ferro particles with a magnetic intensity of 300 gauss. Nano/Ferrofluids possess more heat carrying capacity than conventional fluids used in heat exchangers [7,12,13].

Heat carrying property of ferrofluid increases by magnetization up to a particular magnetic intensity. Beyond that bifurcation takes place and obstruction in flow is observed [14]. Nanofluid refers to fluids by suspending nano particles in the base fluid [15,16,17,18]. Heat carrying capacity of liquid is less compared to solids. Ferrofluids have superior properties which includes variable viscosity, improved thermal conductivity and formation of spike like structure in the presence of an external magnetic field [19,20,21].

Addition of ferro particles or nano particles into cooling water of IC Engines increases the heat transfer which results in the size reduction of heat exchanger [22]. This will facilitate reduction of size and overall weight of the engine, which will reduce the fuel consumption. The world is facing scarcity of drinking water, marine engines and huge diesel power plants uses huge quantity of water for cooling the jackets. By using nano sized ferro particles along with cooling water, the quantity of water carried for cooling the jackets can be reduced thereby increasing the heat transfer, reducing the fuel consumption and usage of fresh water. The result incurred that magnetized ferro particles with 4% shows optimum temperature difference and efficiency of heat exchanger.

2. Characterization Properties of Nano Particles used for the Experiment

The properties of particles used for the experiment is given in Table 1.

Table 1
Properties of particles

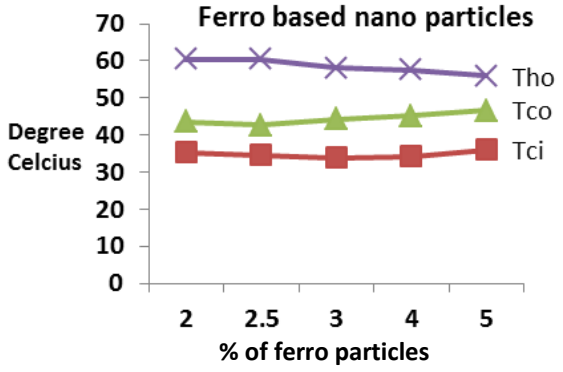
Property	Values	
Material	Aluminum	Ferro fluid
Hydro dynamic size (DLS)(nm)	35	29.2
Carrier	Water	Water
Particle magnetization Md (emu/cc)	Nil	320
Particle density	3.2g/cc	5g/cc

3. Comparison of Heat Transfer Rate between Aluminum Based Nano Fluids and Ferro Fluids

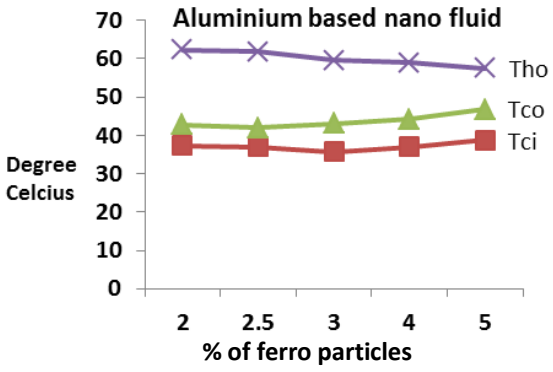
The molecular mass of Aluminum based nano particle {$Al(NO_3).9H_2O$} is 212.9 gm/mol and that of Ferro particle {$FeCl_3$ $6H_2O$)} is 263.7gm/mol. The variation found in the inlet and outlet temperatures corresponding to different percentage of Aluminum and Ferro based nanofluids can be given in Table 2 and its graphical representation is shown in Figure 1(a) and 1(b). The schematic diagram of the experimental device is shown in Figure 1(c).

Table 2
Effectiveness of heat exchanger using Aluminum and Ferro based nano fluids

% of nano fluid used	Weight of ferrofluid w.r.t. molar mass(gm)	Weight of Aluminum w.r.t. molar mass(gm)	Inlet Temperatures				Outlet Temperatures			
			Tci (Fe)	Tci (Al)	T hi (Fe)	T hi (Al)	Tco (Fe)	Tco (Al)	T ho (Fe)	T ho (Al)
2	52.74	74.6	34	36.2	60	60	42.0	41.3	50.5	52.4
2	52.74	74.6	36	37.8	70	70	44.0	43	60.5	61.9
2	52.74	74.6	36	38.1	80	80	44.5	44	70.5	72.7
2.5	65.92	93.25	35	37.2	60	60	42.0	41.4	51.5	52.9
2.5	65.92	93.25	34	36.8	70	70	43.0	42.2	59.5	60.8
2.5	65.92	93.25	35	37.1	80	80	43.0	42.3	70.5	71.6
3	79.11	111.9	31	32.8	60	60	41.0	40.1	48.5	50.1
3	79.11	111.9	34.5	36.7	70	70	44.7	43.3	58.5	59.9
3	79.11	111.9	36	37.8	80	80	47.0	45.9	67.5	68.8
4	105.48	149.2	34	36.7	60	60	45.0	44.4	47.5	49.1
4	105.48	149.2	34.3	37.1	70	70	45.3	44.1	57.5	59.1
4	105.48	149.2	34.3	37.2	80	80	45.3	44.2	67.5	68.8
5	131.85	186.5	34	36.8	60	60	45.3	44.2	47.2	48.9
5	131.85	186.5	33	36.9	70	70	49.5	46.2	57.4	58.8
5	131.85	186.5	41.1	42.6	80	80	51.3	50.1	63.2	64.8



(a)



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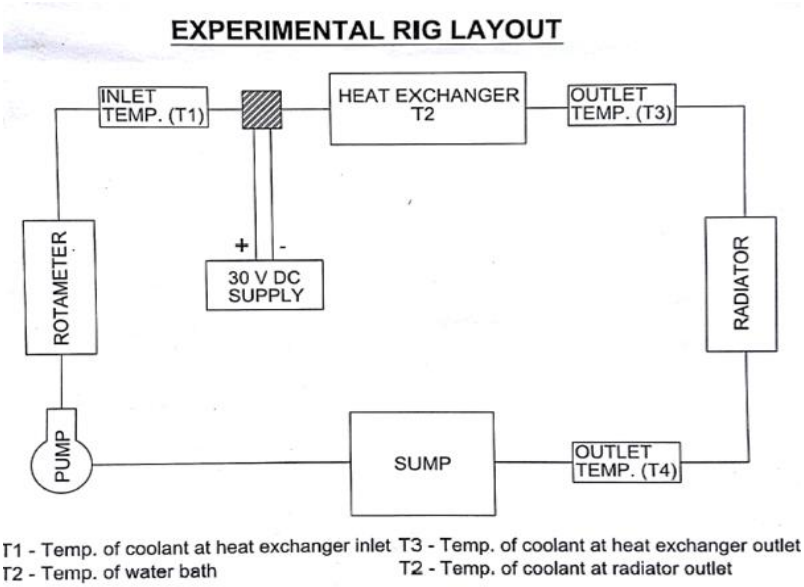
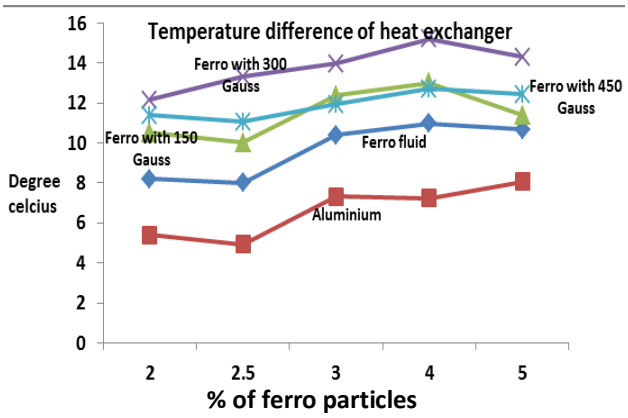


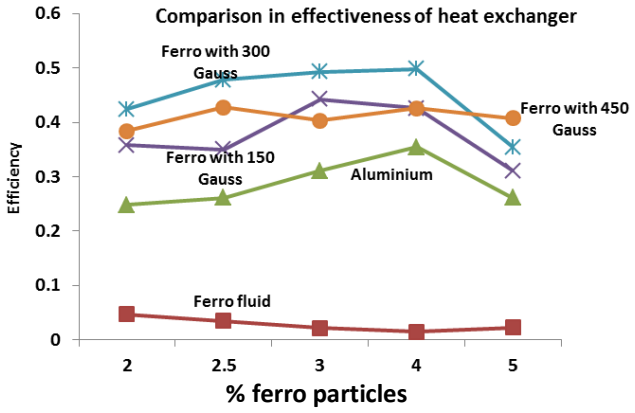
(c)

Fig. 1. (a) ferro based nano particles, (b) aluminium-based nanoparticles and (c) schematic diagram of experimental device

The comparison of effectiveness and temperature difference of heat exchanger with cooling medium as non-magnetized ferro and magnetized ferro based nano fluids with aluminium based nano fluids is given in Table 3 and its graphical representation is shown in Figure 2(a) and Figure 2(b).



(a)



(b)

Fig. 2. (a) Temperature difference of heat exchanger and (b) comparison of effectiveness and with cooling medium as non-magnetized ferro and magnetized ferro based nano fluids with aluminium based nano fluids

Table 3
Effectiveness and Temperature difference of heat exchanger

% of ferro fluid	Gauss	T_{ci} °C	T_{co} °C	T_{hi} °C	T_{ho} °C	ΔT ferro based °C	ΔT Magnetized ferro based °C	ΔT (Al based) °C	ε (Ferro based)	ε (magnetized ferro based)	ε (Al based)	Difference in ε (Al & Ferro)	Difference in ε (Al & mag. Ferro)
2	150	36.0	46.0	60	48.5	8	10.0	5.1	0.360	0.479	0.319	0.040	0.160
2	150	35.0	46.1	70	58.5		11.1			0.328			0.009
2	150	35.0	45.4	80	68.0	8	10.4	5.2	0.279	0.266	0.252	0.058	0.014
2	300	37.0	49.0	60	46.5		12.0			0.586			0.334
2	300	34.0	46.0	70	56.5	8.5	12.0	5.9	0.215	0.375	0.174	0.042	0.201
2	300	35.0	47.5	80	66.0		12.5			0.311			0.137
2.5	150	35.0	43.0	60	50.5	7	8.0	4.2	0.340	0.380	0.311	0.029	0.069
2.5	300	36.0	48.0	60	46.5		12.0			0.562			0.251
2.5	150	34.0	44.0	70	58.5	9	10.0	5.4	0.291	0.319	0.277	0.014	0.042
2.5	300	38.0	51.0	70	55.5		13.0			0.453			0.176
2.5	150	36.0	48.0	80	66.5	8	12.0	5.2	0.257	0.352	0.196	0.061	0.156
2.5	300	39.0	55.0	80	62.5		16.0			0.420			0.224
3	150	35.8	48.1	60	46.5	10	12.3	7.3	0.396	0.559	0.364	0.032	0.195
3	300	35.4	49.5	60	44.5		14.1			0.631			0.267
3	150	38.3	50.4	70	56.5	10.2	12.1	6.6	0.323	0.426	0.303	0.020	0.126
3	300	35.1	49.1	70	54.5		14.0			0.445			0.142
3	150	37.4	50.1	80	65.5	11	12.7	8.1	0.280	0.340	0.265	0.015	0.075
3	300	36.6	52.6	80	62.5		13.5			0.403			0.138
4	150	33.0	46.0	60	45.5	11	13.0	7.7	0.481	0.537	0.468	0.013	0.069
4	300	34.0	49.1	60	43.5		15.1			0.635			0.167
4	150	36.0	49.1	70	55.5	10.9	13.1	7	0.350	0.397	0.331	0.019	0.066
4	300	37.0	51.9	70	53.5		14.9			0.501			0.170
4	150	37.8	50.7	80	65.5	11	12.9	7	0.274	0.343	0.262	0.012	0.081
4	300	36.7	52.3	80	60.5		15.6			0.463			0.201
5	150	36.0	49.3	60	45.2	11.3	13.3	7.4	0.492	0.616	0.478	0.014	0.138
5	300	37.0	50.3	60	43.2		13.3			0.612			0.134
5	150	36.0	44.0	70	55.2	10.5	8.0	9.3	0.340	0.435	0.338	0.002	0.097
5	300	38.3	53.3	70	53.2		15.0			0.530			0.192
5	150	40.2	53.1	80	65.2	10.2	12.9	7.5	0.431	0.372	0.406	0.025	-0.034
5	300	40.3	53.0	80	67.2		12.7			0.323			-0.083

The graphical representation of effectiveness of heat exchanger based on the cooling medium as aluminium, non-magnetized ferro and magnetized ferro nanofluids for various percentages of nano particles are shown in Figure 2(b). From this, it is observed that the effectiveness of heat exchanger with respect to aluminium, non-magnetized ferro and magnetized ferro based nano fluids are not equal. Magnetised ferro fluid shows increased trend in effectiveness because when the ferro particles are magnetized, the particles forms conical spikes, which increases the surface area and inturn the heat carrying capacity. For testing statistically, the statistical tool ANOVA is used. The null hypothesis used for testing is

H_0: Effectiveness of heat exchanger with respect to aluminium, non-magnetized ferro and magnetized ferro based nano fluids are equal.

H_1: Effectiveness of heat exchanger with respect to aluminium, non magnetized ferro and magnetized ferro based nano fluids are not equal.

After the analysis, the value of F-ratio is greater than P-value (Table 4). Therefore, the null hypothesis *H0* is rejected. The effectiveness of heat exchanger with respect to aluminum, non-magnetized ferro and magnetized ferro fluids are not equal.

Table 4
Analysis of Variance

Source of Variation	Degrees of freedom	Sum of squares	Mean Sum of squares	F-ratio	P-value
Treatment	4	0.5685	0.14212	6.269	0.001
Error	20	0.45353	0.02267		
Total	24	0.1.0398			

From the Figure 2(b), it is evident that magnetized ferro fluid with a magnetic intensity of 300 Gauss has highest efficiency than all other nano fluids. Also, the least effective is non magnetized ferro fluid and then aluminium based nano fluid. The effectiveness of heat exchanger is highest for magnetized ferro fluid compared to non-magnetized ferro fluid and aluminium based nano fluid. This result is statistically proved with the help of statistical tool such as testing of hypothesis.

The analysis here is done with respect to the effectiveness of magnetized ferro fluid with 300 Gauss and aluminium based nano fluids.

Let x_1 be the effectiveness of heat exchanger with respect to magnetized ferro based nanofluids of 300 Gauss andx_2 be the effectiveness of heat exchanger with respect to aluminium based nanofluids corresponding to different percentage of nano fluids used. For testing of hypothesis we test the null hypothesis $H_0: \mu_1 = \mu_2$against the alternative hypothesis $H_1: \mu_1 > \mu_2$, where μ_1 is the mean effectiveness of heat exchanger with respect to magnetized ferro based nanofluids of 300 Gauss and μ_2 be that of aluminium based nanofluids corresponding different percentage of nano fluids used. The test statistic used is t-statistic and is

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{n_1 {s_1}^2 + n_2 {s_2}^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \sim t_{n_1+n_2-2}$$

Here $n_1 = n_2 = 5$ and we reject H_0 if $t > t_\alpha$. The value of t is 4.81 and $t_\alpha = 0.002$. Therefore, we reject the null hypothesis and accept the alternative hypothesis. i.e thus we can generalize the result to the population that the mean effectiveness of heat exchanger with respect to magnetized

ferro based nanofluids of 300 Gauss is higher than that of aluminum based nanofluids corresponding different percentage of nano fluids used.

5. Conclusion

The experiment shows that the temperature difference (ΔT) across the heat exchanger is only 6°C when the cooling media used is water alone for heat exchanging and the efficiency of the heat exchanger is 29.2% at 60°C. The ferro particles are then added to the base fluid from 2% to 5%. The optimum temperature difference is observed at 4% and the value is 11°C. The efficiency of heat exchanger (ε) is 48.1% at this composition and the size of the heat exchanger may be reduced with this temperature difference. When ferro particles are magnetized, spikes are generated which increases the surface area and thereby heat carrying capacity. The ferro fluid is then magnetized with a magnetic intensity of 150, 300 and 400 Gauss, the particle percentage also varied from 2% to 5%. The optimum temperature difference was recorded at 4% magnetized ferro particles with a magnetic intensity of 300 gauss. The temperature difference (ΔT) at this composition is 15.6°C and the efficiency of heat exchanger is 46.3%. The size of the heat exchanger may be further reduced with this composition. Above 300 gauss, it is observed that the shape of the particles changes from conical spikes to hexagon, which exerts restrictions in flow of cooling water and therefore the work done by the cooling water pump to re-circulate the fluid increases.

The Aluminium based nano fluid shows maximum temperature difference at 5% addition and the value is 9.3°C. The efficiency of heat exchanger at this composition is 33.8%. So there is a difference of 12.5% in efficiency at optimum composition between magnetized ferro particles and aluminium based nano particles. From the experiment it is incurred that magnetized ferro fluid carries more heat compared to aluminium based nano fluid. ANSYS FLUENT [21] is used for validation and for regression analysis & evaluation, software packages such as MINITAB 18 and MATLAB 16a are used. The results were analyzed using statistical tool ANOVA and the optimum effectiveness of heat exchanger was obtained by solving linear programming problem (LPP).

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