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ARTICLE OF PROFESSIONAL INTERESTS

Corrosion and Heat Transfer Characteristics of Water Dispersed with Carboxylate Additives and Multi Walled Carbon Nano Tubes

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Abstract This paper summarizes a recent work on anticorrosive properties and enhanced heat transfer properties of carboxylated water based nanofluids. Water mixed with sebacic acid as carboxylate additive found to be resistant to corrosion and suitable for automotive environment. The carboxylated water is dispersed with very low mass concentration of carbon nano tubes at 0.025, 0.05 and 0.1 %. The stability of nanofluids in terms of zeta potential is found to be good with carboxylated water compared to normal water. The heat transfer performance of nanofluids is carried out on an air cooled heat exchanger similar to an automotive radiator with incoming air velocities across radiator at 5, 10 and 15 m/s. The flow Reynolds number of water is in the range of 2500–6000 indicating developing flow regime. The corrosion resistance of nanofluids is found to be good indicating its suitability to automotive environment. There is a slight increase in viscosity and marginal decrease in the specific heat of nanofluids with addition of carboxylate as well as CNTs. Significant improvement is observed in the thermal conductivity of nanofluids dispersed with CNTs. During heat transfer experimentation, the inside heat transfer coefficient and overall heat transfer coefficient has also improved markedly. It is also found that the velocity of air and flow rate of coolant plays an important role in enhancement of the heat transfer coefficient and overall heat transfer coefficient.

Keywords Nano particles · Multi walled carbon nano tubes · Thermal conductivity enhancement · Heat transfer enhancement · Overall heat transfer coefficient

Introduction

In an operation of an automotive engine only 30–35 % of fuel power is converted into machine power and it is estimated that 20–30 % of heat is taken away by the liquid of cooling system. With newer design of IC Engines in recent years the heat load on coolant has increased significantly and conventional coolants cannot handle that much heat loads. This increase in load on coolant results in an undesirable increase in the radiators size. Hence alternative coolant technologies need to be developed for future years.

Nanofluids are fluids dispersed with nano materials consisting of solid nano particles with sizes typically of 1–100 nm can be a promising future generation of heat transfer fluids. Several authors [1–21] investigated the properties of nanofluids dispersed with metal particles like Cu, Ag, Au, Pt, etc. and metal oxides such as Al_2O_3, TiO_2, CuO, SiO_2, etc. in different base fluids, concentrations and temperatures. Based on the investigations, it can be stated that the parameters influencing nano fluid properties are particle density, particle concentration, particle size and temperature and pH of the fluid. All the investigators observed thermal conductivity of nanofluids increases with concentration and temperature. Das et al. [6] utilized a temperature oscillation technique for the measurement of thermal conductivity and experimentally calculated the thermal conductivity of water based nanofluids. The results indicated an increase of thermal conductivity with the

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temperature paving way for the use nanofluids in high energy density applications. Das et al. [16] obtained a comprehensive experimental data set for thermal conductivity of nanofluids with variation in nanoparticle material, base liquid, particle size, particle volume fraction and suspension temperature. The results emphasize higher enhancement in thermal conductivity with decrease in particle size and increase in temperature. It was also found that thermal conductivity enhancement is more at lower volume fractions of nanofluids.

Experimental research on the convective heat transfer performance of nanofluids has been published with various combinations of base fluids and suspensions [21–30]. The suspended nano material remarkably increased the forced convective heat transfer performance of the base fluid. At the same Reynolds number, the heat transfer of the nano fluid found to be increased with the particle volume fraction. Sahu and Chougule [26] have done studies on convective heat transfer enhancement of CNT-water nanofluid inside an automobile radiator. They found that both nano coolants exhibit enormous change in Nussult number compared to normal water. It is observed that coolant with lower pH exhibits better performance compared to coolant with pH above 7. Sahu and Chougule [27] in another paper studied the forced convective heat transfer performance of two different nanofluids Al_2O_3-water and CNT-water in an automobile radiator. The coolant flow rate is varied in the range of 2–5 l/min. It is found that the heat transfer performance of CNT-water nanofluid was found to be better than Al_2O_3-water nano coolant. Teng and Yu [30] studied the convective heat transfer characteristics of ethylene glycol water mixture dispersed with CNTS in an air cooled radiator. The maximum enhanced ratio of heat exchange under is found to be 12.8 % with a coolant flow rate of 8.5 LPM. Further, other researchers found that dispersion of MWCNTs is good compared to the SWNTs as the agglomerate size for the same base nano fluid is much smaller for MWNTs than for SWCNTs.

Most of the researchers studied the effect of normal distilled water with nano particle addition. However, normal water is not suitable as coolant in automotive systems due to its poor corrosion properties. Addition of corrosion inhibitors to water or ethylene glycol water mixtures is a normal practice to improve corrosion resistance automotive coolants. Organic additive technology is one of the methods to protect cooling system components including cylinder liners. Organic additive technology uses carboxylate corrosion inhibitors dispersed in coolants to provide protection. Carboxylate additives provide corrosion protection by chemically interacting with the metal surfaces wherever needed unlike conventional and hybrid coolants which form layers on the metals surfaces. The common carboxylate additives are sebacic acid, 2-ethylhexanoic acid, dodecanedioic acid etc., in combination with sodium nitrite as stabilizer and sodium hydroxide as pH buffer. Further, tolyltriazole a well-known copper corrosion inhibitor is also a common additive used in engine coolants. The influence of corrosion inhibitors on nano fluids is hitherto not cited in the literature. This paper aims to study the influence of carboxylate additives along with carbon nanotube on the physico-chemical, corrosion and heat transfer characteristics of water based automotive coolant. The flow rates of coolant are maintained in the range of 10–20 LPM higher than that mentioned in the literature.

Experimental Investigations

Materials

The MWCNTs are of 20–40 nm in outer diameter, 1–25 μm in length and 80 % purity. As received, CNTs are impure in nature containing metal particles and soot. Further because of impurities and soot they are entangled making them insoluble in water as seen from HRSEM image and EDX spectrum in Figs. 1 and 2. The soot and metal particles would spoil the surface of radiator rendering it useless. All other reagents were of analytical grade and were used without further purification.

Purification and Oxidation of CNTs

Multi-walled carbon nanotubes are highly hydrophobic in nature and do not disperse in aqueous solutions. Agglomeration would form clusters which can possibly erode the surface. Hydrophobic carbon nanotube gets deposited on the radiator surface forming black layers on the surface thereby affecting the performance of the radiator. Studies [31–39] show that oxidative techniques are best suitable to

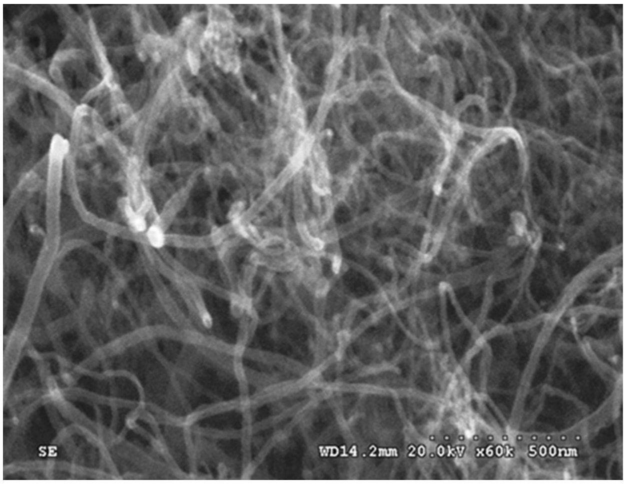

Fig. 1 HRSEM image of purified carbon nano tubes

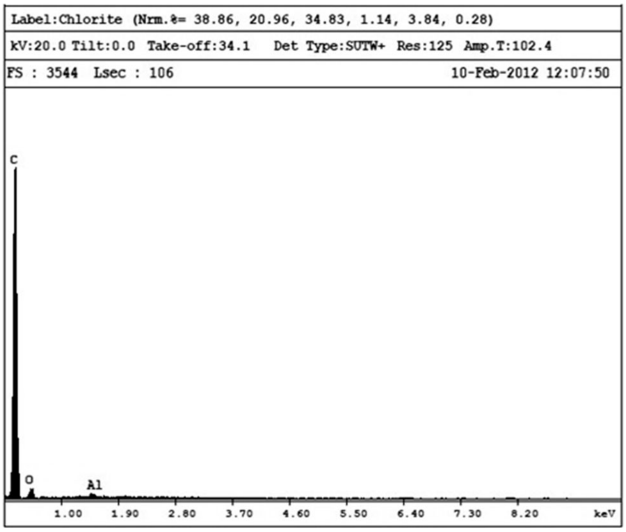

Fig. 2 EDX spectrum of pristine CNTs

purify and induce functional groups on the surface of the CNTs thereby making them hydrophilic. Pristine MWNTs were heated in air at 550 °C approximately for 2 h and were refluxed with concentrated hydrochloric acid for 12 h to remove metal particles and other impurities The mixture was then washed repeatedly with distilled water until pH of 7 is achieved.

The chemical oxidation process of purified MWNTs was done by refluxing CNTs in solution of 4 Molar HNO_3 and H_2SO_4 (1:3 volume ratio) for 4 h. Then, the black mixture was diluted with distilled water and washed thoroughly with DI water until neutral pH value is obtained. The black solid was dried in the vacuum oven at 50 °C for overnight. Oxidation of CNTs introduces carboxyl groups on the surface which make them readily dispersible in water and other polar solvents. Low concentrations of acids and less reflux time are employed to prevent damage of chemical structure.

The CNTs are characterized using HRSEM–EDX for structure & Chemical composition. Figure 3 shows HRSEM–EDX image of purified entangle free CNTs. and Fourier Transform infrared spectroscopy for presence of functional groups. Figure 4 shows FTIR Spectrum of oxidized CNTs. The Treated CNTs show peaks at 1120 and 1750 cm–1, which denote carbonyl and carboxyl groups formed over the surface.

Preparation of Base Fluids

Base fluids are prepared with water and carboxylates of sebacic acid/2-ethylhexanoic acid with sodium nitrate as stabilizer and sodium hydroxide as pH buffer. Further to organic inhibiters, 0.1 % of Tolyltriazole is added to the solution for enhanced copper and other alloy corrosion protection. The pH of the solution is adjusted to 8. sebacic acid and 2-ethylhexanoic acid are mixed in concentrations of 1 and 2 % in water and named as COOLANT 1, COOLANT 2, COOLANT 3 and COOLANT 4 respectively. The fluids are tested for corrosion resistance as per ASTM D 1384 Glassware corrosion test.

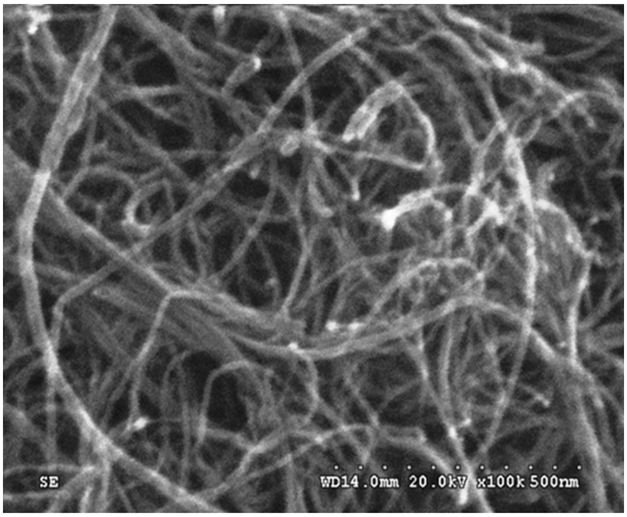

Fig. 3 HRSEM image of purified and oxidized carbon nano tubes

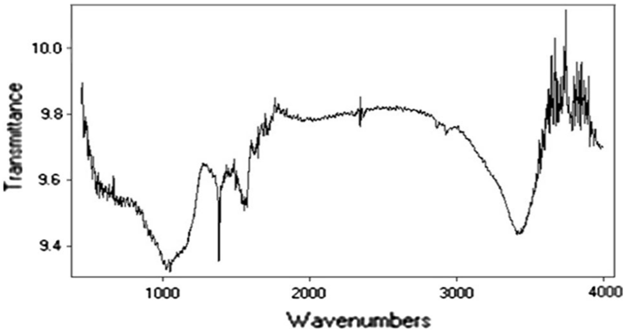

Fig. 4 FTIR spectrum of oxidized CNTs

Glassware Corrosion Tests

This test method employed to evaluate coolants that are definitely deleterious to automotive environment due to corrosion. The test also analyzes the corrosive behavior of CNTs in automotive coolants. In this test method, specimens of metals typical of those present in engine cooling systems viz., copper, solder, brass, cast iron, mild steel and aluminum are totally immersed in aerated engine coolant solutions mixed with corrosive water for 336 h (14 days) at 88 °C. The corrosion inhibitive properties of the test solution are evaluated on the basis of the weight changes incurred by the specimens. Each test is run in triplicate, and the average weight change is determined for each metal. The results obtained are tabulated in Table 1.

Table 1 Corrosion results of base coolants

Coupon	Weight loss (mg)				
	Standard values	COOLANT 1	COOLANT 2	COOLANT 3	COOLANT 4
Copper	10	0.33	1.33	0.83	1.83
Solder	30	52.33	11.33	422.33	233.33
Brass	10	2.83	2.83	6.83	5.33
Mild steel	10	0.66	6.66	8.66	9.66
Cast iron	10	1.33	0.68	12.33	47.83
Aluminium	30	72.16	21.16	367.21	267.66

Table 2 Corrosion results of coolant dispersed with CNTs

Coupon	Weight loss (mg)			
	Base fluid (COOLANT2)	Base fluid + 0.025 % CNTs	Base fluid + 0.05 % CNTs	Base fluid + 0.1 % CNTs
Copper	1.33	1.33	1.33	1.33
Solder	11.33	10.33	10.667	10.667
Brass	2.83	2.667	2.66	2.667
Mild steel	6.66	6.33	6.33	6.33
Cast iron	0.68	0.55	0.667	0.667
Aluminium	21.16	20.667	20.167	20.333

From the results, it can be found that water COOLANT 2 which is a mixture of 2 % sebacic acid, sodium nitrite, sodium hydroxide and tolyltriazole gave best protection against corrosion to all the metal.

Hence COOLANT 2 is selected as base coolant for dispersion with nano materials.

Nanofluid Preparation

Nanofluids are prepared by dispersing low weight fractions of CNTs with COOLANT 2 as base fluid using an Ultra probe sonicator. Low weight fractions are chosen since higher weight fractions will increase the viscosity and thereby increasing the pumping power of the fluid. Oxidized CNTs in are added to water and sonicated for 30 min so that a uniform dispersion is achieved. CNTs in 0.025, 0.05 and 0.1 % weight concentration are dispersed in base fluid and tested for corrosion behavior. The results are shown in Table 2.

From the above results, it can be found that dispersion of CNTs does not affect the anti-corrosive properties of carboxylated water and hence are suitable in automotive environment.

Stability of Nanofluids

The stability of colloidal dispersions is related in terms of zeta potential of the fluid. The zeta potential indicates the degree of repulsion between adjacent, similarly charged particles (OH, COOH groups present in CNTs and the medium. A value of ±25 indicates incipient stability of colloid and any value above 25 and below –25 indicate good stability of the solution. The zeta potential of normal water and carboxylated water dispersed with oxidized CNTs is evaluated to assess the effect of carboxylates on stability.

Table 3 Zeta potential of normal water and carboxylated water with CNTs

Sample	Zeta potential (mV)
Water + 0.025 % CNTs	20.5
Water + 0.1 % CNTs	18.8
Carboxylated water + 0.025 % CNTs	38.2
Carboxylated water + 0.1 % CNTs	30.11

From the results shown in Table 3, it can be found that CNTs are more stable in water with carboxylates than that with normal water.

Mesurement of Thermophysical Properties

The thermo physical properties viz., thermal conductivity, specific heat and dynamic viscosity are of paramount importance in evaluating the performance of heat exchanger. The Thermo physical properties of base fluids and nanofluids are measured and the effect of CNTs dispersion is analyzed.

Thermal Conductivity Measurement

A KD2 Pro thermal property analyzer that uses the transient line heat source method (similar to transient hot wire method) is used to measure thermal conductivity of water and nanofluids. Since water has very less viscosity, turbulence occurs at temperatures above 50 °C and hence the measurement could be carried out in the temperature range of 30–50 °C. The following equations give the variation of thermal conductivity with temperature from room temperature to 50 °C.

It is found that the improvement in thermal conductivity from base fluid at 50 °C with 0.025 % CNTs is 8.12 %, with 0.05 % CNTs is 14.58 % and with 0.1 % is 17.85 %. The data for different mass fractions is correlated using 2nd order polynomial equations as given below. The validation of Eqs. 1, 2, 3 and 4 can be seen in Fig. 5.

Water:

$$k = 0.5652 + 1.801\text{E}{-3}[\text{T}] - 5.183\text{E}{-6}[\text{T}]^2 \qquad (1)$$

Water + 0.025 % CNTs:

$$k = 0.5685 + 2.654\text{E}{-3}[\text{T}] - 1.854\text{E}{-7}[\text{T}]^2 \qquad (2)$$

Water + 0.05 % CNTs:

$$k = 0.579 + 3.318\text{E}{-3}[\text{T}] - 7.341\text{E}{-6}[\text{T}]^2 \qquad (3)$$

Water + 0.1 % CNTs:

$$k = 0.593 + 3.872\text{E}{-3}[\text{T}] - 6.351\text{E}{-6}[\text{T}]^2 \qquad (4)$$

The data of thermal conductivity variation with temperature is found to be following the trend of 2nd order polynomial. Hence, the data is further extrapolated so that the equations can be used for mathematical modeling of heat transfer data.

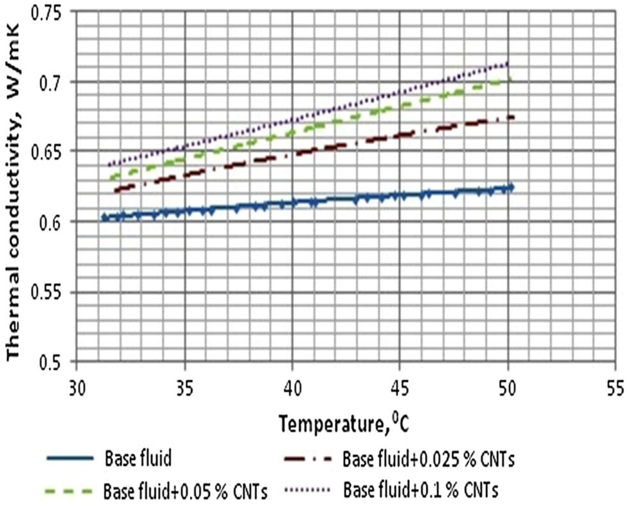

Fig. 5 Validation of Eqs. 1, 2, 3 and 4

Table 4 Specific heat results of base fluid and various combinations of nanofluids

S. no	Fluid	Specific heat (Cp)
1	Base fluid	4.223
2	Base fluid + 0.025 % CNTs	4.185
3	Base fluid + 0.05 % CNTs	4.178
4	Base fluid + 0.1 % CNTs	4.165

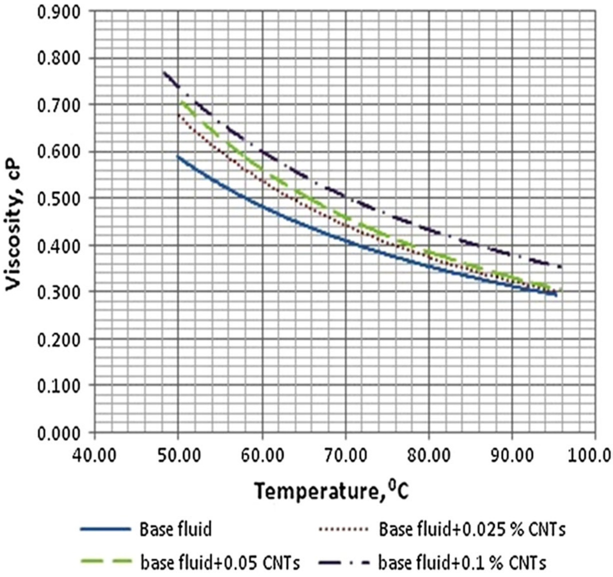

Fig. 6 Variation of viscosity with temperature

Measurement of Specific Heat and Absolute Viscosity

KD2 pro setup can also be used to measure the specific heat of carboxylated water and nano fluids. Since the CNTs are dispersed in very low concentrations, the effect of CNTs on specific heat is marginal. The specific heat results are tabulated in Table 4.

The absolute viscosity of carboxylated water and nanofluids is measured using Brookfield cone & plate LVDV-iii+ ultra rheometer. The absolute viscosity is measured in the range of 50–95 °C. The variation of viscosity with temperature is shown in Fig. 6.

As evident from the graph, at lower temperature, the increase in viscosity is considerably and it is around 13.5, 16 and 24 % respectively for 0.025, 0.05 and 0.1 % mass fractions.

However, at higher temperatures, the increase in viscosity is marginal at 1, 4.5 and 7.5 % respectively. The increase in viscosity is less since lesser mass fraction of CNTs are used in preparation of nanofluids.

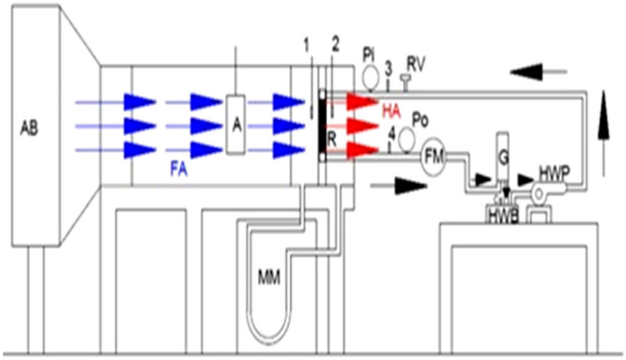

Fig. 7 Schematic diagram of test rig

Experimental Set Up for Heat Transfer Enhancement

The test rig used in the study is an air cooled heat exchanger similar to a car radiator. The Schematic diagram of the test rig is shown in Fig. 7. Heat transfer coefficients & overall heat transfer coefficient will be measured and the performance of the fluid will be rated.

The experimental test rig contains an Air Flow Duct, Air Blower (AB), Anemometer (A), Radiator (R), Flow Meter (FM), Geyser (G), Hot Water Boiler (HWB), Hot Water Pump set (HWB), Regulating Valve (RV), Manometer (MM), Pressure Gauge At Inlet Of Radiator (PI), Pressure Gauge At Outlet Of Radiator (PO). Further, thermocouple 1, 2, 3 and 4 measure the temperatures of air at Inlet (T_{C1}), Out Let (T_{C2}) and temperature of coolant at inlet (T_{H1}) & outlet (T_{H2}) of Radiator. The sensitivity of thermocouple is 0.1 °C with an error of 0.2–0.3 %.

Air blower is fitted at one end of the duct and the other end is fitted with the radiator. Anemometer is fitted between blower and radiator to measure the speed of air. A flow meter is fitted at the out let of the radiator to measure the flow rate of the coolant coming out of the radiator. Air is blown at velocities of 5, 10 and 15 m/s similar to the automobile motion against the air. The coolant is heated using a combination of hot fluid Geyser and Hot water boiler before the inlet of the radiator. The maximum heat that can be given to the fluid or the fluid loses is 5 kW.

The radiator consists of 36 tubes with OD 7 mm and ID 5.5 mm. The length of the tubes is 294 mm. A total of 212 fins are on the radiator core with fin thickness 0.6 mm, Fin Width 23 mm and Fin Length 329 mm. The maximum discharge of coolant is 20 LPM. The hydraulic diameter used to calculate the flow Reynolds number of coolant is taken as 5.5 mm which is the inner diameter of the radiator tubes. Twelve number of thermocouples (T5–T16) are fitted in radiator core at different locations to measure temperatures on the tubes and fins as shown in Fig. 8. The average of T5–T1 will give the mean wall temperature T_W of the core of radiator. Using the energy balance between the air and the coolant the heat transfer parameters are evaluated.

The experiments are conducted with carboxylated water as base fluid and base fluid dispersed with MWCNTs at various concentrations of MWCNTS 0.025, 0.05 and 0.1 %. The data is taken with a varying air velocity of 5, 10 and 15 m/s the flow rate of fluid is varied as 10, 15 and 20 LPM corresponding to a flow Reynolds number of 2500–6000. The Temperature of fluid is maintained in the range of 80–95 °C. At each parameter setup all the temperatures are noted using Data logger attached to the test rig. The experiment is repeated for all possible variations of the set up varying the three parameters viz., concentration of MWCNTs, velocity of air over radiator and the flow rates of coolant or nano fluid in the radiator.

Evaluation of Heat Transfer Coefficient, h_i and Overall Heat Transfer Coefficient, U_i

The heat transfer coefficient h_i and overall heat transfer coefficient 'U' is a measure of the overall ability of a series

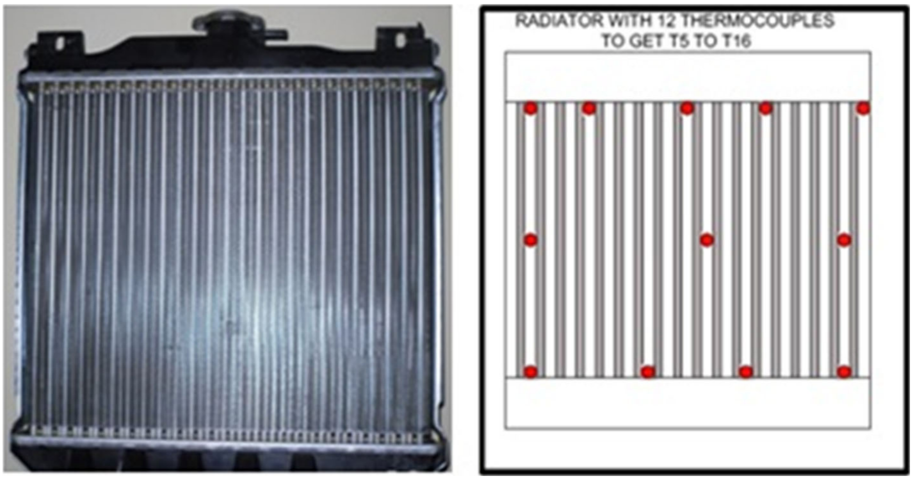

Fig. 8 Radiator with locations of 12 thermocouples on core

Table 5 Percentage enhancement of U_i for various concentrations of MWCNTs at 5 m/s air velocity

V (m/s)	Re	Base fluid	Base fluid + 0.025 % MWCNTs		Base fluid + 0.05 % MWCNTs		Base fluid + 0.1 % MWCNTs	
		Ui (W/m^2 K)	Ui (W/m^2 K)	% Change	Ui (W/m^2 K)	% Change	Ui (W/m^2 K)	% Change
5 m/s	2500	453.16	662.08	46.1	826.05	82.3	883.07	94.9
	3000	483.61	682.83	41.2	858.00	77.4	930.72	92.5
	3500	514.06	703.58	36.9	889.95	73.1	978.37	90.3
	4000	544.51	724.33	33.0	921.90	69.3	1026.02	88.4
	4500	574.96	745.08	29.6	953.85	65.9	1073.67	86.7
	5000	605.41	765.83	26.5	985.80	62.8	1121.32	85.2
	5500	635.86	786.58	23.7	1017.75	60.1	1168.97	83.8
	6000	666.31	807.33	21.2	1049.70	57.5	1216.62	82.6
	6500	696.76	828.08	18.8	1081.65	55.2	1264.27	81.4
Average		574.96	745.08	30.8	953.85	67.1	1073.67	87.3

Table 6 Percentage enhancement of U_i for various concentrations of MWCNTs at 10 m/s air velocity

V (m/s)	Re	Base fluid	Base fluid + 0.025 % MWCNTs		Base fluid + 0.05 % MWCNTs		Base fluid + 0.1 % MWCNTs	
		Ui (W/m^2 K)	Ui (W/m^2 K)	% Change	Ui (W/m^2 K)	% Change	Ui (W/m^2 K)	% Change
10 m/s	2500	493.30	697.55	41.4	785.90	59.3	834.37	69.1
	3000	548.25	743.75	35.7	849.10	54.9	901.47	64.4
	3500	603.20	789.95	31.0	912.30	51.2	968.57	60.6
	4000	658.15	836.15	27.0	975.50	48.2	1035.67	57.4
	4500	713.10	882.35	23.7	1038.70	45.7	1102.77	54.6
	5000	768.05	928.55	20.9	1101.90	43.5	1169.87	52.3
	5500	823.00	974.75	18.4	1165.10	41.6	1236.97	50.3
	6000	877.95	1020.95	16.3	1228.30	39.9	1304.07	48.5
	6500	932.90	1067.15	14.4	1291.50	38.4	1371.17	47.0
Average		713.10	882.35	25.4	1038.70	47.0	1102.77	56.0

of conductive and convective barriers to transfer heat. It is closely related to heat transfer performance of heat exchangers. It is evaluated using the following equations

$$q = \dot{m}C_{Pnf}[T_{h1} - T_{h2}] = h_i A_i (T_B - T_w) = U_i A_i \Delta T_{lm} \tag{5}$$

where

$$\Delta T_{lm} = \frac{[(T_{H1} - T_{C1}) - (T_{H2} - T_{C2})]}{\ln[(T_{H1} - T_{C1})/(T_{H2} - T_{C2})]} \tag{6}$$

$$\text{Reynolds number, Re} = \frac{4\,\dot{m}}{\pi D \mu_l} \tag{7}$$

Results and Discussion

The specific heat and viscosity of carboxylated water and nano fluids are taken from the measured values as given in the previous section. The variation of, inside heat transfer coefficient (h_i) and inside overall heat transfer coefficient (U_i) with Reynolds number of carboxylated water and air velocity is analysed for carboxylated water and different combinations of carboxylated water and MWCNTs.

Dispersion of CNTs in carboxylated water has a profound effect on both inside heat transfer coefficient and overall heat transfer coefficient. The enhancement with addition of CNTs is significant at every value of Reynolds Number. The results from the data collected at 5 m/s are tabulated for various Reynolds Numbers in Table 5. The results from the data collected at 10 m/s are tabulated for various Reynolds Numbers in Table 6. Compared to an air velocity of 5 m/s the improvement in U_i and h_i is slightly lower at 10 m/s velocity. The results from the data collected ay 15 m/s are tabulated for various Reynolds Numbers in Table 7. The enhancement in U_i and h_i with addition of CNTs with 15 m/s air velocity is lower than that with 5 and 10 m/s velocity.

The results clearly indicate the influence of air velocity and flow Reynolds number of the coolant. As the air velocity and flow Reynolds number increases, there is a slight reduction in the improvement. Further, with increase

Table 7 Percentage enhancement of U_i for various concentrations of MWCNTs at 15 m/s air velocity

V (m/s)	Re	Base fluid	Base fluid + 0.025 % MWCNTs		Base fluid + 0.05 % MWCNTs		Base fluid + 0.1 % MWCNTs	
		Ui (W/m^2 K)	Ui (W/m^2 K)	% Change	Ui (W/m^2 K)	% Change	Ui (W/m^2 K)	% Change
15 m/s	2500	567.11	782.48	38.0	909.00	60.3	967.16	70.5
	3000	646.46	846.98	31.0	965.80	49.4	1028.71	59.1
	3500	725.81	911.48	25.6	1022.60	40.9	1090.26	50.2
	4000	805.16	975.98	21.2	1079.40	34.1	1151.81	43.1
	4500	884.51	1040.48	17.6	1136.20	28.5	1213.36	37.2
	5000	963.86	1104.98	14.6	1193.00	23.8	1274.91	32.3
	5500	1043.21	1169.48	12.1	1249.80	19.8	1336.46	28.1
	6000	1122.56	1233.98	9.9	1306.60	16.4	1398.01	24.5
	6500	1201.91	1298.48	8.0	1363.40	13.4	1459.56	21.4
Average		884.51	1040.48	19.8	1136.20	31.8	1213.36	40.7

in flow Reynolds number of the fluid from 2500 to 6500 the improvement in the heat transfer coefficient and overall heat transfer coefficient from base fluid has gradually reduced. The effect of mass fraction of CNTs is also markedly visible as evident from Tables 5, 6 and 7. The improvement overall heat transfer coefficient (U_i) and inside heat transfer coefficient (h_i) is more as the mass fraction increases.

Conclusions

From the study the following conclusions are drawn as follows.

1. Water dispersed with 2 % sebacic acid could give good corrosion protection.
2. CNTs dispersed in carboxylated water did not alter the corrosion behavior and hence are suitable to automotive environment.
3. The zeta potential of carboxylated water dispersed with CNTs is found to be better compared to normal water dispersed with CNTs.
4. Dispersion of CNTs could improve the thermal conductivity and thereby the heat transfer characteristics of nanofluids
5. Carboxylated water dispersed with 0.025, 0.05 and 0.1 % of CNTs could improve the heat transfer characteristics of nanofluids.
6. Improvement in heat transfer is dependent upon the air velocity and flow Reynolds number of the liquid.
7. The improvement overall heat transfer coefficient (U_i) and inside heat transfer coefficient (h_i) is affected by mass fraction of CNTs.
8. The improvement in heat transfer coefficient and overall heat transfer coefficient with nanofluids is more in near laminar region.

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