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Analysis of Cooling Performance of Automobile Radiator Using Nano-Fluid Al_2O_3 and Water

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Abstract

This paper aims to increase the heat transfer rate of the coolant with the help of nano particles (Al_2O_3). It further increases the efficiency of the radiator, coolant & the engine. The best proportion of flow rate and concentration of nano- particles (Al_2O_3) have been achieved to maximize the heat transfer rate of the coolant. The proposed model of radiator test rig consists of radiator (1000cc) enclosed in a duct of GI sheet of 18 gauge. A centrifugal pump was used for the circulation of nano-fluid in the radiator tubes. PT-100 sensors were used for checking the temperature at different points of the radiator in the radiator test rig & a laboratory thermometer was employed for checking the coolant temperature in the reservoir. The coolant and the nano-particles were well stirred with the help of an agitator (hand grinder) to make a homogeneous mixture. The coolant when circulated at different flow rates and concentration through the radiator tubes, the max heat transfer rate was obtained at a flow rate of 4lt/min & 0.15% concentration of Al_2O_3.

1. Introduction

Nowadays, the problem of engine overheating is one of the major drawbacks in the engine. If the coolant level falls below the normal then engines tends to fail due to improper cooling and hence resulting in knocking & pre-ignition of fuel[1].To overcome this problem the heat in the engine needs to be dissipated and the thermal conductivity of the coolant plays an important role in dissipating the heat produced by the engine. Radiator is the element responsible for the circulation of the coolant in the engine. By using nano-particles in the coolant, the problems faced by the engine due to low level of the coolant hence resulting in overheating are eliminated. Moreover the size of the radiator can be decreased and also helps in decreasing the cost of the vehicle. The heat transfer coefficient is determined for Al_20_3-H_2O combination in the concentration range falling between 0.1-0.3% & mass flow rate between 2-5Lt per min and inlet temp falling in the range of 30-50^o C.

2. Solution Proposed

The proposed model discloses improved results in nusselt number, Reynolds number and heat transfer coefficient of the coolant. To increase the performance of the heat dissipation of the engine, two methods can be used either by adding Nano-particles in the coolant so that the heat carrying capacity of the coolant is enhanced or by increasing the rate at which coolant is circulated in the radiator [2].

Experiment was conducted at different flow rates [3] and concentrations to obtain the most efficient heat transfer coefficient at a particular flow rate and concentration of nano-

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particles [4]. In total the experiment was conducted at 3 different flow rates (2.27lt/min,3.41lt/min,4.0lt/min) and 3 different concentration(0.1%,0.15%,0.2%). A permutation of flow rates and concentrations were made so that the result can be obtained for every flow rate at all the 3 concentrations.

3. Experimental Setup

The constructional features have been shown in the form of a line diagram for better understanding of the constructional features and working of the rig in Figure 1. There are several components attached to the setup which is explained below. The objective is to analyze and study the effect of nano-particles on the heat transfer rate of the coolant in the radiator and hence to find out the optimum parameters for maximum efficiency [5]. Experimental setup consists of aluminium sheets ducts, 1000 cc car radiator, thermocouples, pump, heating element, fan and storage tank. [6]

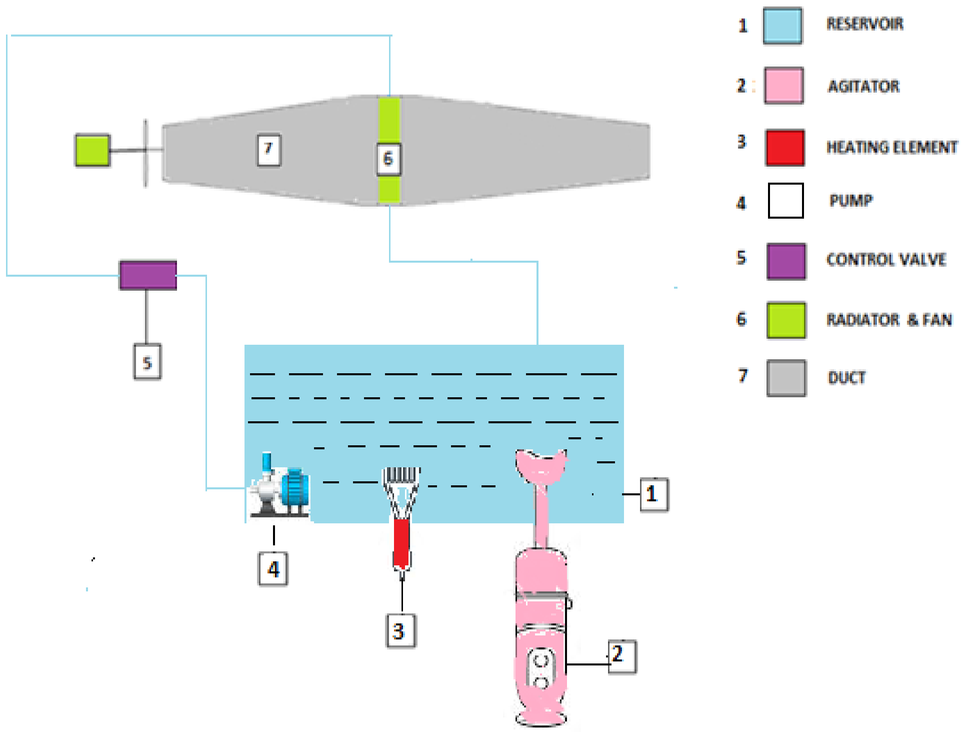

Figure 1. Experimental Setup of the Proposed Solution

3.1. Reservoir

A plastic bucket was used as a reservoir for storing the coolant. The same was used for mounting pump, agitator & the heating element and is shown in Figure 2.

Figure 2. Snapshot of Reservoir

3.2. Agitator

Agitator is used for proper suspension and mixing of nano-particles in the base fluids. It is shown in Figure 3. The nano-particles are suspended in the base fluids. These particles are settled down in the reservoir and in the pipes. Agitator fixes this problem of choking the pipe. It mixes the nano-particles in the base fluids.

Figure 3. Agitator [7]

3.3. Heating Element

Electric rod is used as a heating element for the experimentation and is shown in Figure 4. Power consumption of the rod is 1500 W. It is made of copper tube with nickel plating. This type of heating element is used for water and other fluids.

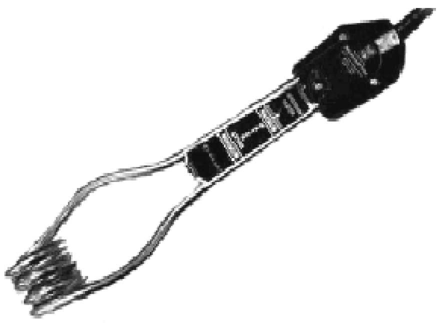

Figure 4. Heating Element [8]

3.4. Pump

The pump shown in Figure 5 is used in experimental setup to circulate the hot nano-fluid. Agitator was fitted in storage tank to mix and circulate the water in tank itself because when nano-fluid was suspended, it remains in suspension in base fluid. It avoids evaporation and local heating of fluid near and across the surface of heating rod.

Figure 5. Snapshot of Pump

Table 1. Specification of Pump

Power consumption	19 W
Voltage required	AC 220 V, 50 Hz
Nozzle size at outlet	½ inch or 12 mm
Maximum flow	740 l/h
Maximum head	ft.

3.5. Control Valve

Control valve shown in Figure 6 controls and regulate the inlet flow to the radiator. The different flow can be adjusted with the help of a control valve.

Figure 6. Snapshot of Control Valve

3.6. Radiator

Test section contains 1000 cc car radiator which was made of copper fins and brass tubes. Radiator shown in Figure 7 was attached with a duct at one end and other end; it was attached with a force draft fan, whose speed was constant. There were 25 tubes in one row and there were 2 rows presented in radiator. Hot fluid entering from upper side pipe and was flowing in downward direction and it was collected in base of radiator.

Figure 7. Snapshot of Radiator

Table 2. Specification of Radiator

Radiation areas	Tube	0.208 m^2
	Airways	1.69 m^2
	Total	1.9 m^2
Front face area	Total	0.03 m^2
Length of fin	1740 mm	
Width of fin	30 mm	
Thickness of fin	0.05 mm	
Fin type	Corrugated fins	
Tube rows	2	
Tubes	50	
Tube thickness	0.15 mm	
Tube space	7.33 mm	

3.7. Fan

A fan shown in Figure 8 is used for cooling the nano-fluid in the radiator. Fan is operated at dc supply with the automobile battery (220v).

Figure 8. Snapshot of Fan

3.8. Duct

Duct shown in Figure 9 was fabricated from GI sheet of 18 gauges. Duct was sealed to eliminate air leakage from any joint made in duct with White stiff. There was fabricated a honey comb structure placed to achieve uniform flow inside the duct. Structure or radiator was placed where the converging part met.

Figure 9. Snapshot of Duct

4. Flow Chart of Proposed Solution

The flow chart of the solution is demonstrated in the Figure 10.

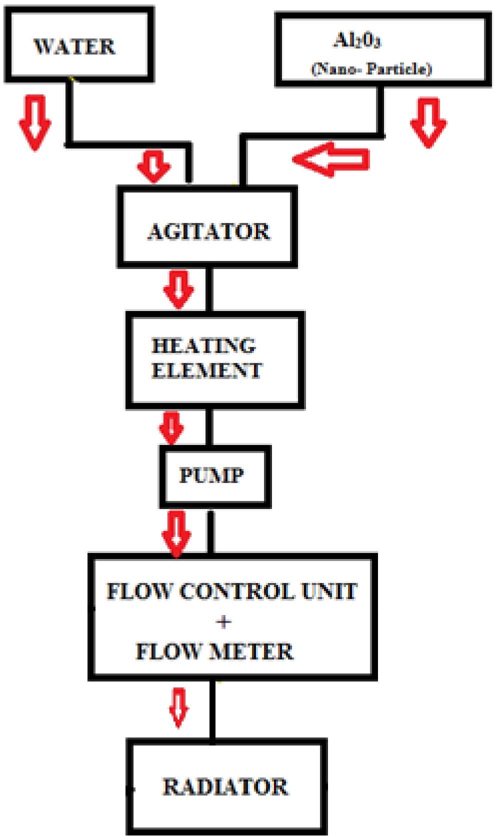

Figure 10. Block Diagram of Solution

1. First the fluid is prepared by mixing nano particles (Al_2O_3) in three different concentrations (0.1%, 0.15%,0.2%) with distilled water(10Lts).
2. For proper mixing of the nano particle and distilled water an agitator is employed.
3. The prepared fluid is heated to a temperature of 50°c with the help of an immersion rod.
4. For proper circulation of the nano fluid a centrifugal pump is installed.
5. To check the flow rate, a flow meter is installed and the flow control unit is used to alter the flow rate of the nano fluid.
6. To check the temperature of the nano fluid temperature sensors (PT-100) are used at the inlet, outlet, front side, back side of the radiator.
7. The radiator fan is switched on and the fluid passes in the radiator at three different flow rates. The temperature of the fluid decreases as a result of forced convection and conduction.
8. The temperature dip is recorded by the sensors and tables are plotted.

5. Experimental Calculations

In this experiment, heat transfer rate is analysed by using three parameters *i.e.* heat transfer coefficient (h), Reynolds number(Re), nusselt number(Nu)[9]. These parameters are evaluated by calculating Density and specific heat capacity[10], by using the following formulas.

Density of the nano-fluid (ρ_{nf}) is calculated by using the given formula[11]:-

$$\rho_{nf} = \varphi\rho_p + (1 - \varphi)\rho_w \quad (1)$$

Where ρ_w = density of water (1000kg/m^3)

ρ_p = density of Al_2O_3 (3900 kg/m^3)

φ= Nano Fluid volume concentration % (at three different values 0.1%, 0.15% and 0.2%)

ρ_{nf} = density of Nano fluid (kg/m^3)

Now, the specific heat capacity of the Nano- coolant is calculated as[12]:

$$C_{nf} = \frac{(1-\varphi)(\rho C)_w + \varphi(\rho C)p}{(1-\varphi)(\rho C)_w + \varphi\rho_p} \quad (2)$$

C_{nf}= specific heat capacity of the nano coolant(J/Kgk)

C_w= Specific heat capacity of water(4180 J/kgk)

C_p= Specific heat capacity of Al_2O_3 (880 J/kgk)

Heat transfer rate is calculated as by given equation:

$$Q = mC_{nf}(T_{in} - T_{out}) \quad (3)$$

Where, m = mass flow rate [13]of the nano-coolant(Kg/min)

T_{in}= Inlet temperature (^{o}c)

T_{out}= outlet temperature (^{o}c)

Heat transfer coefficient is calculated by using the given equation

From Newton's law of cooling:

$$Q = hA(T_b - T_s) \quad (4)$$

Where Q is the heat transfer rate(watt)

h = heat transfer coefficient(w/m^2k)

A is the surface area of the tube of radiator (217cm^2)

T_b is the bulk temperature (^{o}c) which is calculated by taking the average of T_{in} and T_{out}

$$T_b = \frac{T_{in}+T_{out}}{2} \quad (5)$$

$T_s$is the average wall temperature of the radiator measured from various transverse and longitudinal locations of radiator(^{o}c)

$$h_{exp} = \frac{mC_{nf}(T_{in}-T_{out})}{nA(T_b-T_s)} \quad (6)$$

Where n = number of tubes (50)

The average Nusselt number can be calculated as:

$$N_u = \frac{hD_h}{k} \quad (7)$$

Where D_h= hydraulic diameter of the tube and is calculated as

$$D_h = \frac{4\left[\frac{\pi d^2}{4} + (D-d)d\right]}{\pi d + 2(D-d)} \quad (8)$$

D and d are the width and height of radiator tube.

Here d=1.8 mm; D=15.5mm.

Finally the Reynolds number can be calculated as:

$$R_e = \frac{\rho_{nf} v D_h}{\mu} \quad (9)$$

Whereρ_{nf} =density of nano-fluid (kg/m^3)

μ = dynamic viscosity of the nano coolant (Ns/m^2)

v= Fluid velocity (m/s)

5.1. Observations

The analysis of Reynolds vs. Nusselt number for Al_2O_3 based nano-fluid is shown in Table 3. Results are deduced for three different flow rates at different concentrations of nano-fluid. From the observation Table 3, it has been found that at 0.15% concentration (**φ**) of Al2O3 in water at a flow rate of 4lt/min, the efficiency parameters of the radiator (h, Nu, Re) are found to be more efficient than other concentrations and flow rates. In Figure 11, graph for Reynolds number vs. Nusselt number at three different concentrations & flow rates is plotted.

Table 3. Heat Transfer Characteristics of Al_2O_3 based Radiator Coolant at Different Flow Rates

φ (%)	Flow rate(lt/min)	h (w/m^{2}k)	N_u	R_e
0.1	2.27	52.32	1.61	4807
	3.41	109.29	3.177	4807
	4	122	3.5	4807
0.15	2.27	102.81	2.46	3249
	3.41	159.57	3.822	3249
	4	194.4	4.66	3249
0.2	2.27	93.87	1.91	2804
	3.41	145.8	2.97	2804
	4	150	3.06	2804

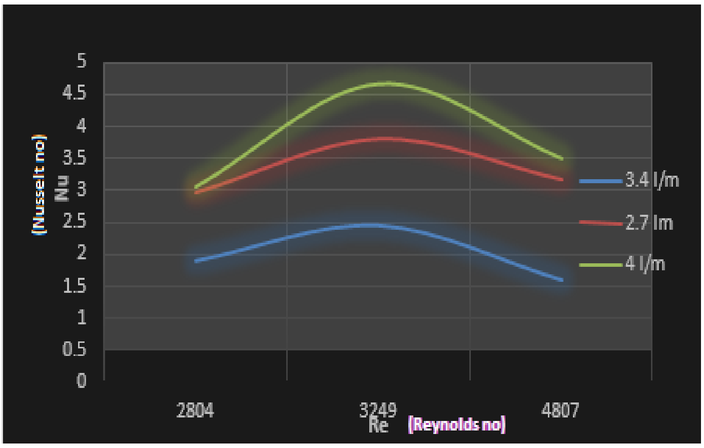

Figure 11. Representing the Variation in Reynolds number vs. Nusselt Number at Different Flow Rates and Concentrations

Now the inlet temperature, outlet temperature and temperature of front (wall 1) and rear wall (wall 2) is measured at different flow rates and volume concentrations. The Table 4 and Figure 12 represents the reading of temperature and time for Al_2O_3 at 2.7 l/min flow rate and 0.10% volume concentration at regular time intervals. From the Table, it is clear that it took approx 17 minutes to attain inlet temperature 30 ^{o}c, wall 1 and wall 2 temperatures as 22 ^{o}c and outlet temperature 25.9oc.

Table 4. Temperature and Time for Al_2O_3 at 2.7 l/m and 0.10 % Volume Concentration

Time(Min)	Inlet temp(°c)	Wall temp 1(°c)	Wall temp 2(°c)	Outlet temp(°c)
0	50	29.3	27	39.6
2.5	44.3	27.2	25.2	35.1
5	40.5	25.7	24.1	33.1
7.5	37.9	24.6	23.5	31.3
10	35.4	23.8	23.1	29.6
12.5	33.3	23.8	23.1	28.2
15	31.4	22.5	22.5	26.9
17.16	30	22.1	22.3	25.9

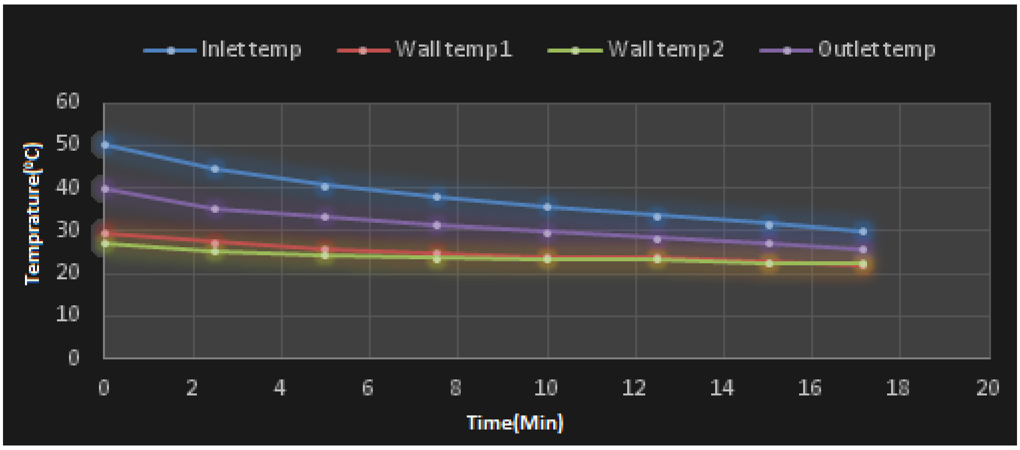

Figure 12. Temperature vs. Time for Al_2O_3 at 2.7 l/m and 0.10 % Volume Concentration

The Table 5 and Figure 13 represent the reading of temperature and time for Al_2O_3 at 3.4 l/min flow rate and 0.10% volume concentration at regular time intervals. . From the table, it is clear that it took approx 16 minutes to attain inlet temperature 30 ^{o}c, wall 1 temperature as 24.2^{0}c and wall 2 temperatures as 24.6^{o}c and outlet temperature 26.2^{0}c.

Table 5. Temperature and Time for Al_2O_3 at 3.4 l/m and 0.10 % Volume Concentration

Time(Min)	Inlet temp(°c)	Wall temp 1(°c)	Wall temp 2(°c)	Outlet temp(°c)
0	50	35.6	□4.9	41.4
2.5	44.8	32.6	32.3	37.5
5	40.8	30.4	30.3	34.4
7.5	37.3	28.4	28.3	31.9
10	34.6	26.9	27	29.9
12.5	32.3	25.5	27.9	28.1
15	30.5	24.4	24.9	26.7
16.06	30	24.2	24.6	26.2

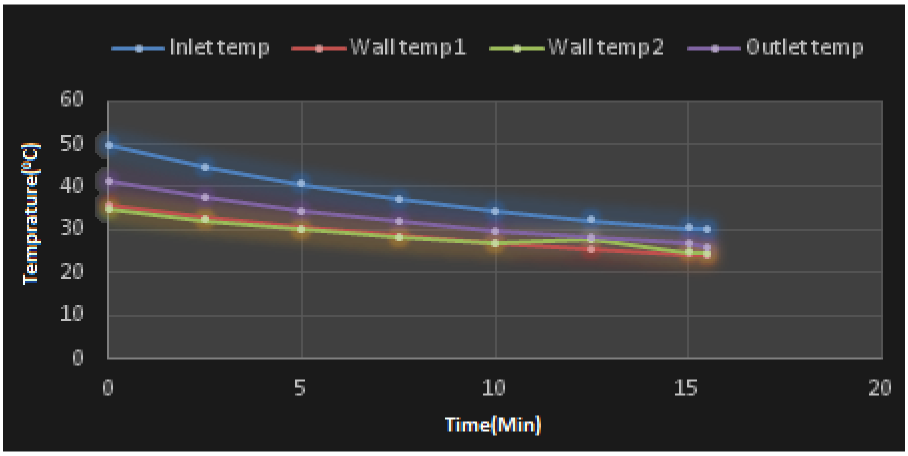

Figure 13. Temperature vs. Time for Al_2O_3 at 3.4 l/m and 0.10 % Volume Concentration

The Table 6 and Figure 14 represents the reading of temperature and time for Al_2O_3 at 4 l/min flow rate and 0.10% volume concentration at regular time intervals. From the table, it is clear that it took approx 17 minutes to attain inlet temperature 30 ^{o}c, wall 1 temperature as 24.8^{0}c and wall 2 temperatures as 25.3 ^{o}c and outlet temperature 26.5^{0}c.

Table 6. Temperature and Time for Al_2O_3 at 4 l/m and 0.10 % Volume Concentration

Time(Min)	Inlet temp(°c)	Wall temp 1(°c)	Wall temp 2(°c)	Outlet temp(°c)
0	50	35.3	35.6	41.8
2.5	44.9	33.5	33.9	38.2
5	40.9	31.3	31.5	35
7.5	37.5	28.5	29.2	32.4
10	34.3	27.1	27.6	30
12.5	32.5	25.9	26.5	28.5
15	30.7	25	25.6	27
16.57	30	24.8	25.3	26.5

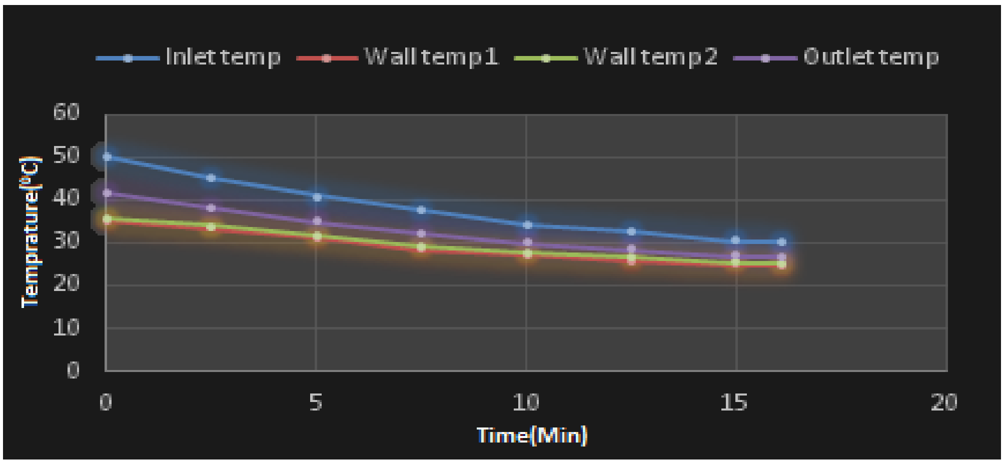

Figure 14. Temperature vs. Time for Al_2O_3 at 4 l/m and 0.10 % Volume Concentration

The Table 7 and Figure 15 represents the reading of temperature and time for Al_2O_3 at 2.7 l/min flow rate and 0.15% volume concentration at regular time intervals. According to the table, the coolant took18.43 minutes to reach at an inlet temperature of 30^{0}c, wall1 temperature 27.8^{0}c, wall2 temperature 25.7^{0}c, outlet temperature25.8^{0}c.

Table 7. Temperature and Time for Al_2O_3 at 2.7 l/m and 0.15 % Volume Concentration

Time(Min)	Inlet temp(°c)	Wall temp 1(°c)	Wall temp 2(°c)	Outlet temp(°c)
0	50	35.1	38.3	39.2
2.5	44.5	31.9	34.9	35.5
5	40.7	30	32.6	33.1
7.5	37.8	28.1	30.7	31.1
10	35.3	26.8	29.1	29.4
12.5	33.5	26.2	27.9	28.2
15	31.9	25.3	26.8	27.1
17.5	30.5	24.7	26.1	26.2
18.43	30	27.8	25.7	25.8

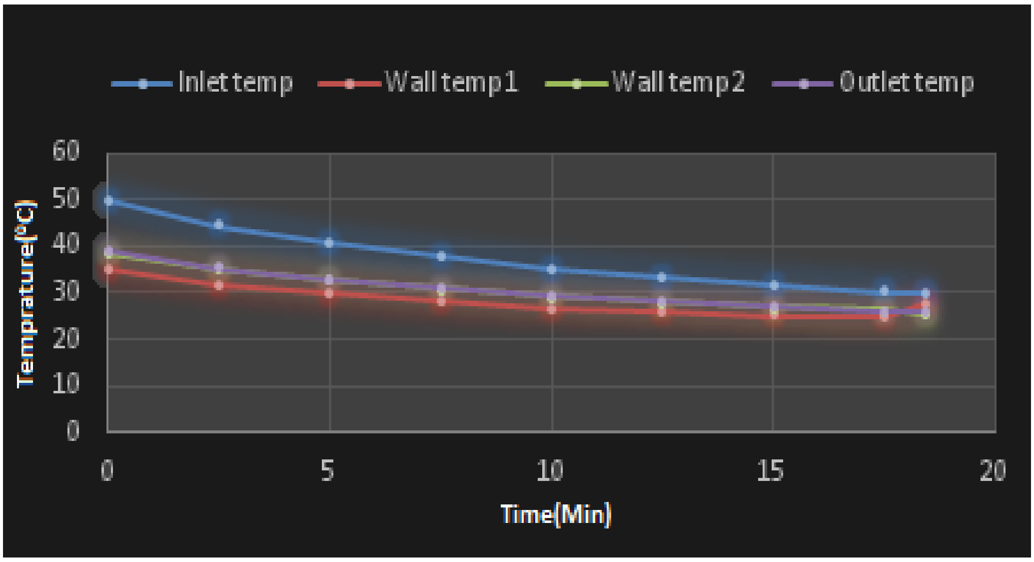

Figure 15. Temperature vs. Time for Al_2O_3 at 2.7 l/m and 0.15 % Volume Concentration

The Table 8 and Figure 16 represents the reading of temperature and time for Al_2O_3 at 3.4 l/min flow rate and 0.15% volume concentration at regular time intervals. The temperature when measured at four different junction *i.e.* inlet, outlet, front (wall1), rear (wall2) of the radiator, the coolant took 16.51 minutes to attain an inlet temperature of 30^{0}c, wall1 temperature 25.3^{0}c, wall2 temperature 26.5^{0}c and outlet temperature 26.4^{0}c.

Table 8. Temperature and Time for Al_2O_3 at 3.4 l/m and 0.15% Volume Concentration

Time(Min)	Inlet temp(°c)	Wall temp 1(°c)	Wall temp 2(°c)	Outlet temp(°c)
0	50	38.3	42.3	41.8
2.5	44	34.4	37.2	36.3
5	41.2	32.4	35.2	35
7.5	37.8	30.2	32.5	32.3
10	35.1	28.3	30.3	30.2
12.5	32.9	27.1	28.8	28.7
15	31.2	25	27.3	27.2
16.51	30	25.3	26.5	26.4

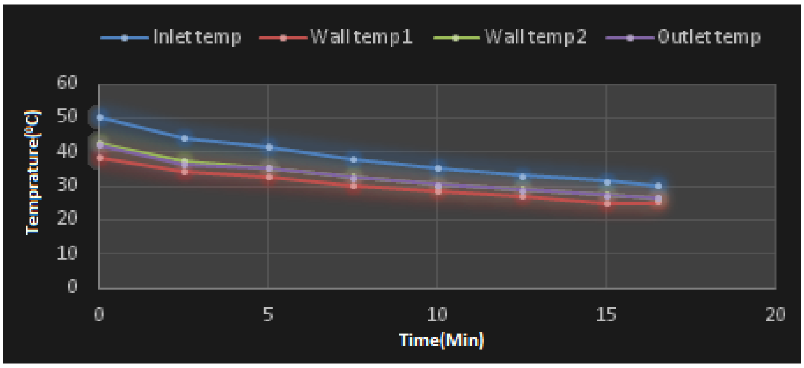

Figure 16. Temperature vs. Time for Al_2O_3 at 3.4 l/m and 0.15 % Volume Concentration

The Table 9 and Figure 17 represents the reading of temperature and time for Al_2O_3 at 4 l/min flow rate and 0.15% volume concentration at regular time intervals. The temperature when measured at four different junction *i.e.* inlet, outlet, front (wall1), rear (wall2) of the radiator, the coolant took 15.51 minutes to attain an inlet temperature of 30^0c, wall1 temperature 25.9^0c, wall2 temperature 27.2^0c and outlet temperature 26.8^0c.

Table 9. Temperature and Time for Al_2O_3 at 4 l/m and 0.15 % Volume Concentration

Time(Min)	Inlet temp(°c)	Wall temp 1(°c)	Wall temp 2(°c)	Outlet temp(°c)
0	50	39.8	43.5	42.8
2.5	44.7	35.9	39.2	38.5
5	40.5	33.1	35.9	35.3
7.5	37.3	30.9	33.2	32.8
10	34.7	29.1	31	30.6
12.5	32.5	27.6	29.2	28.9
14.48	30.8	26.5	27.9	27.5
15.51	30	25.9	27.2	26.8

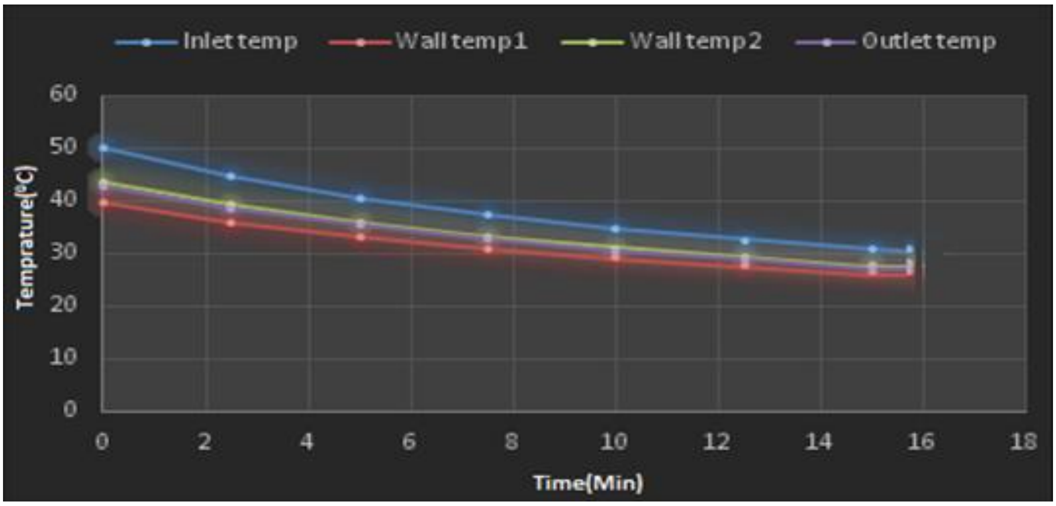

Figure 17. Temperature vs. Time for Al_2O_3 at 4 l/m and 0.15 % Volume Concentration

The Table 10 and Figure 18 represents the reading of temperature and time for Al_2O_3 at 2.7 l/min flow rate and 0.20% volume concentration at regular time intervals. The temperature when measured at four different junction *i.e*. inlet, outlet, front (wall1), rear (wall2) of the radiator, the coolant took 22.3 minutes to attain an inlet temperature of 30^0c, wall1 temperature 25.2^0c, wall2 temperature 26.4^0c and outlet temperature 26.3^0c.

Table 10. Temperature and Time for Al_2O_3 at 2.7 l/m and 0.20 % Volume Concentration

Time(Min)	Inlet temp(°c)	Wall temp 1(°c)	Wall temp 2(°c)	Outlet temp(°c)
0	50	36.1	39.3	39.8
2.5	45.7	33.7	36.6	37
5	42.2	31.8	34.3	34.8
7.5	39.5	30.4	32.7	32.9
10	37.3	29.1	31.1	31.2
12.5	35.5	28.1	29.9	30.1
15	33.9	27.2	28.9	28.9
17.5	32.4	26.3	28	28.1
20	31.2	25.7	26.9	27.1
22.3	30	25.2	26.4	26.3

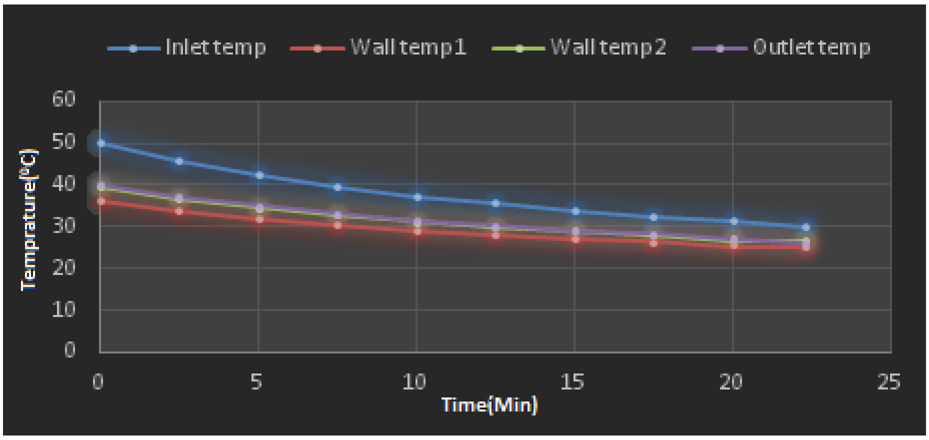

Figure 18. Temperature vs. Time for Al_2O_3 at 2.7 l/m and 0.20 % Volume Concentration

The below mentioned Table 11 and Figure 19 represents the reading of temperature and time for Al_2O_3 at 3.4 l/min flow rate and 0.20% volume concentration at regular time intervals. To attain an inlet temperature of 30^0c the coolant took 18.3 minutes. The same time was taken by the coolant for achieving wall1 temperature at 25.9^0c, wall2 temperature 27.1^0c and outlet temperature at 26.8^0c

Table 11. Temperature and Time for Al_2O_3 AT 3.4 l/m and 0.20 % Volume Concentration

Time(Min)	Inlet temp(°c)	Wall temp 1(°c)	Wall temp 2(°c)	Outlet temp(°c)
0	50	38.8	42.1	41.9
2.5	45	35.3	38.3	38.1
5	41.2	32.9	35.3	35.3
7.5	38.2	31.1	33.1	33
10	36.2	28.5	29.4	29.9
12.5	33.6	28.2	29.4	29.5
15	32	27.1	28.5	28.2
17.5	30.8	26.3	27.5	27.3
18.3	30	25.9	27.1	26.8

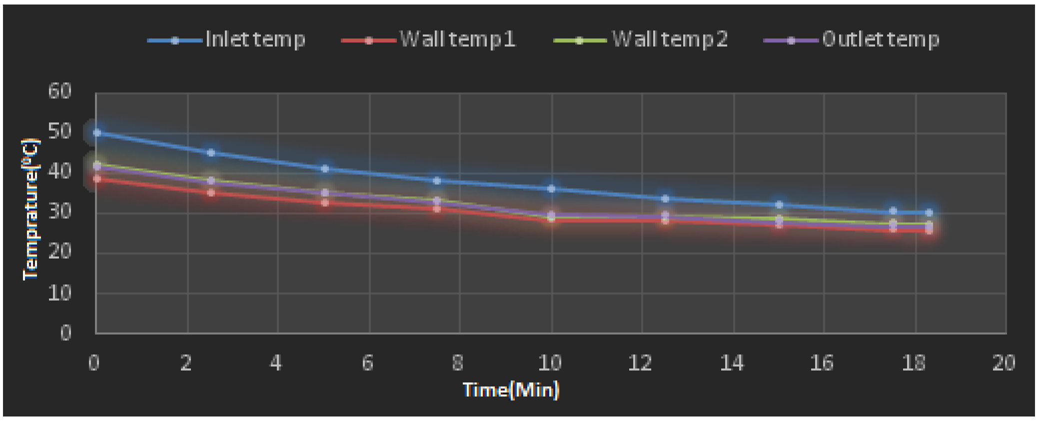

Figure 19. Temperature vs. Time for Al_2O_3 at 3.4 l/m and 0.20 % Volume Concentration

The Table 12 and Figure 20 represents the reading of temperature and time for Al_2O_3 at 4 l/min flow rate and 0.20% volume concentration at regular time intervals. The temperature when measured at four different junction *i.e.* inlet, outlet, front (wall1), rear (wall2) of the radiator, the coolant took 16 minutes to attain an inlet temperature of 30^0c, wall1 temperature 26.1^0c, wall2 temperature 27.4^0c and outlet temperature 27.1^0c.

Table 12. Temperature and Time for Al_2O_3 at 4 l/m and 0.20 % Volume Concentration

Time(Min)	Inlet temp(°c)	Wall temp 1(°c)	Wall temp 2(°c)	Outlet temp(°c)
0	50	39.6	43.3	42.7
2.5	44.6	35.3	39.3	38.5
5	40.9	33.1	36.3	35.6
7.5	37.2	30.9	33.1	32.7
10	34.5	29.1	30.9	30.5
12.5	32.4	27.6	29.2	28.9
15	30.7	26.5	27.9	27.5
16	30	26.1	27.4	27.1

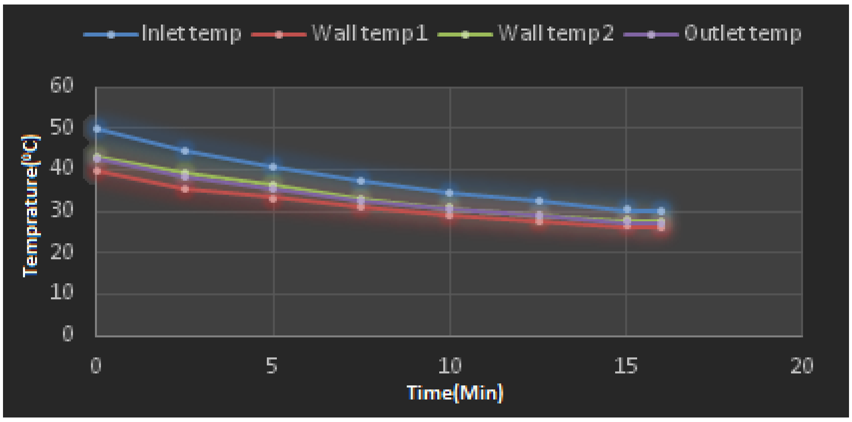

Figure 20. Temperature vs. Time for Al_2O_3 at 4 l/m and 0.20 % Volume Concentration

From Tables 4 to Table 12, it is clear that the heat transfer rate is maximum at 0.15%volume concentration of Al_2O_3 in water at a flow rate of 4lt/min. It took about 15.51 min to achieve a temperature drop of 20^oc while the remaining concentrations and flow rate took more time than taken by the above.

6. Conclusion

The following conclusions have been made by an iterative method.

1. After conducting experiment it has been found that at 0.15% concentration(**φ**) of Al_2O_3 in water and at a flow rate of 4lt/min the efficiency parameters of the radiator(h, Nu, Re) are found to be more efficient than other concentrations and flow rates.
2. It is also found that at 0.15% volume concentration of Al_2O_3 in water and at a flow rate of 4lt/min, the coolant took least time(15.51min) to dissipate heat from 50^oc to 30^oc as compared with other flow rates and concentrations.

3. Hence the result was most efficient at 0.15% volume concentration of Al_2O_3 in water and at a flow rate of 4lt/min.

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