Chapter - 3

Characteristics of Radiator Coolants

Characterization of various coolants i.e water, EG, PG, nanofluid, hybrid nanofluids, sugarcane juice, optimum brine solution of 25% PG, 25% of ethylene glycol, 25% PG with nanofluids and hybrid nanofluids for louvered, wavy and rectangular fins automotive radiator have been done. Coolant preparation and measurement of thermophysical properties are presented in this chapter.

Effect of operating parameters on thermophysical properties i.e density, specific heat, viscosity and thermal conductivity for various coolants i.e water, ethylene glycol, PG, sugarcane juice, nanofluid and hybrid nanofluids are discussed as well.

3.1 Theoretical determination of thermophysical properties

Thermophysical properties can also be calculated based on empirical, semiemperical correlations $0<\phi<1$ % (v/v) assuming Newtonian fluid behaviour.

3.1.1 Nanofluids

Thermophysical properties relations for 1% volume fraction of nanofluids are

Density of nanofluid can be expressed as [14]

$$\rho_{nf} = (1-\phi)\,\rho_{bf} + \phi\rho_p \tag{3.1}$$

Specific heat of nanofluid can be expressed as [14]

$$c_{p,nf} = \frac{(1-\phi)\,\rho_{bf} c_{p,bf} + \phi\rho_p c_{p,p}}{\rho_{nf}} \tag{3.2}$$

Thermal conductivity of nanofluid can be expressed as [17]

$$\frac{k_{nf}}{k_{bf}} = \frac{k_{np} + 2k_{bf} + 2\phi(k_{np} - k_{bf})}{k_{np} + 2k_{bf} - \phi(k_{np} - k_{bf})} \tag{3.3}$$

Viscosity of nanofluid can be expressed as [33]

$$\mu_{nf} = \mu_{bf}\left(1 - 0.19\phi + 306\phi^2\right) \tag{3.4}$$

Prandlt number of nanofluid can be expressed as

$$Pr_{nf} = \frac{\mu_{nf} * Cp_{nf}}{k_{nf}} \tag{3.5}$$

3.1.2 Hybrid nanofluids

Thermophysical properties relations for hybrid nano fluids are

$$\phi = \phi_{\mathrm{np}\,1} + \phi_{np\,2} \tag{3.6}$$

Density of hybrid nanofluid can be expressed as [7]

$$\rho_{hnf} = \phi_{\mathrm{np}\,1} * \rho_{\mathrm{np}\,1} + \phi_{np\,2} * \rho_{np\,2} + (1 - \phi) * \rho_{bf} \tag{3.7}$$

Specific heat of nanofluid can be expressed as[7]

$$c_{hnf} = (\phi_{\mathrm{np}\,1}\rho_{\mathrm{np}\,1}c_{p,\mathrm{np}\,1} + \phi_{np\,2}\rho_{np\,2}c_{p,np\,2} + (1 - \phi)c_{p,bf})/\rho_{hnf} \tag{3.8}$$

Thermal conductivity of nanofluid can be expressed as [7]

$$\frac{k_{hnf}}{k_{bf}} = \frac{((\phi_{\mathrm{np}\,1}k_{\mathrm{np}\,1}+\phi_{np\,2}k_{np\,2})/\phi+2k_{bf}+2(\phi_{\mathrm{np}\,1}k_{\mathrm{np}\,1}+\phi_{np\,2}k_{np\,2})-2\phi k_{bf})}{((\phi_{\mathrm{np}\,1}k_{\mathrm{np}\,1}+\phi_{np\,2}k_{np\,2})/\phi+2k_{bf}+2(\phi_{\mathrm{np}\,1}k_{\mathrm{np}\,1}+\phi_{np\,2}k_{np\,2})-2\phi k_{bf})} \tag{3.9}$$

Viscosity of hybrid nanofluids expresses as [12]

$$\mu_{hnf} = \left(1 - \frac{\phi}{\phi m}\right)^{-\eta * \phi m}. \qquad \text{where } \phi_m = 0.65 \tag{3.10}$$

3.1.3 Density of base fluids, nanofluids and hybrid nanofluids as coolants

Variations in density of pure water, PG, ethylene glycol, sugarcane juice and brine solutions of 25% PG and 25% ethylene glycol as coolants are shown in Fig.3.1. Density of all considered coolants decreases with increase in temperature. Also, among all the studied base fluids, sugarcane juice has higher density and followed by EG, PG, 25% PG brine and 25% EG brine as coolants.

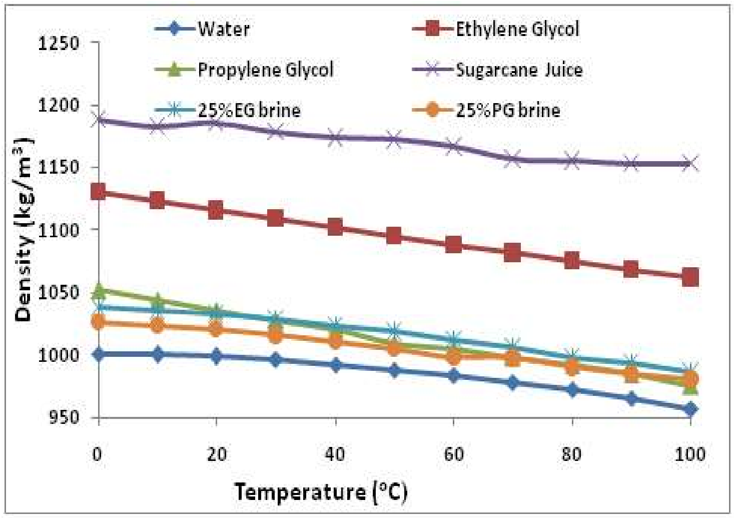

Figure 3.1: Density variation for base fluids

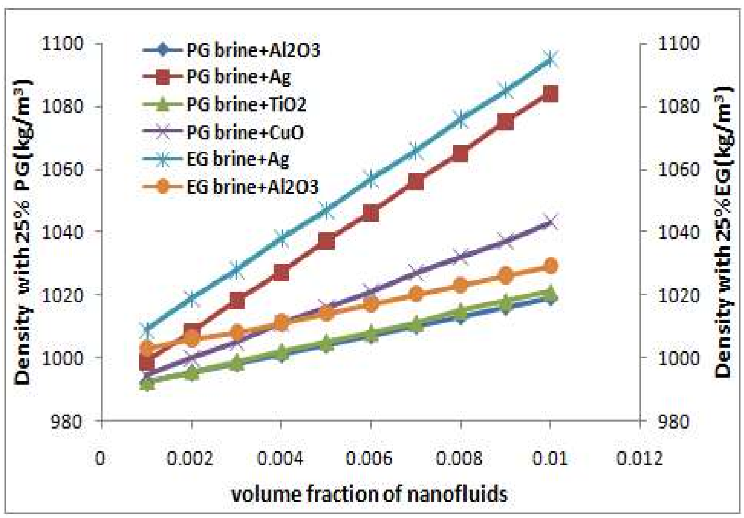

Figure 3.2: Density variation for 25% PG &EG brine based nanofluids

Comparisons of density for 1%volume fraction of various nanofluids i.e Al_2O_3, TiO_2, CuO, Ag in base fluid 25% PG and 25% EG brine is shown in Fig.3.2. Among all the studied nanofluids, Ag nanofluid in 25% EG brine having higher density of 1090 kg/m^3 followed by 1% volume concentration of PG brine based nanofluids.

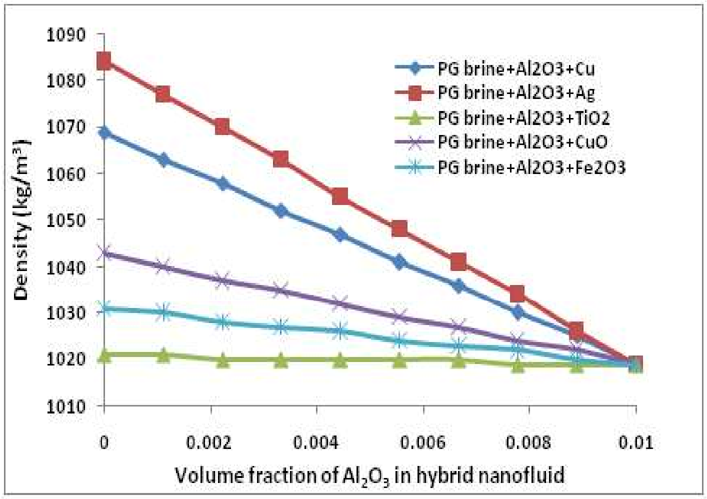

Figure 3.3: Density variation for 25% PG based hybrid nanofluids

The density variation of 1% volume fraction i.e (0.5% Al_2O_3+0.5%Ag) hybrid nanofluids in base fluid of 25% PG is shown in Fig.3.3. Ag hybrid nanofluids with 25%EG brine has higher density of 1070 kg/m^3 as compared to hybrid nanofluids with 25% PG brine (density of 1065 kg/m^3) and followed by Cu, CuO, Fe_2O_3, TiO_2 hybrid nanofluids in 1% volume fraction of Al_2O_3.

3.1.4 Specific heat of base fluids, nanofluids and hybrid nanofluids

Variation in specific heat of pure water, EG, PG, sugarcane juice and brine solutions of 25% PG and 25% EG as base liquids are shown in Fig.3.4. Specific heat of all considered coolants increases with increase in temperature. Also among all the studied base liquids, water has higher specific heat and followed by 25% PG, 25% EG, Sugarcane juice, EG and PG, as coolants.

Comparing the specific heat for 1% volume fraction of various nanofluids i.e Al_2O_3, TiO_2, CuO, Ag in base fluid of 25% PG and 25% EG brine are as shown in Fig.3.5. Among all studied nanofluids, Al_2O_3 nanofluid with PG brine is having higher specific heat of 4050 J/kg K followed by 1% volume concentration of EG brine based nanofluids.

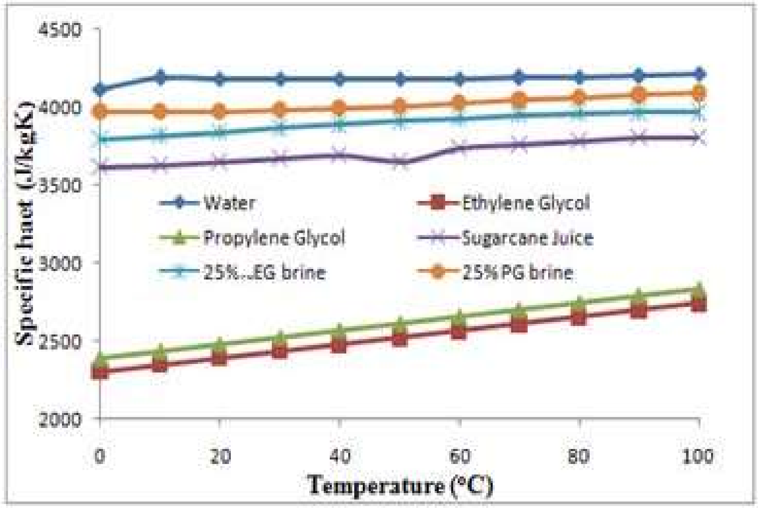

Figure 3.4: Specific heat variation for base fluids

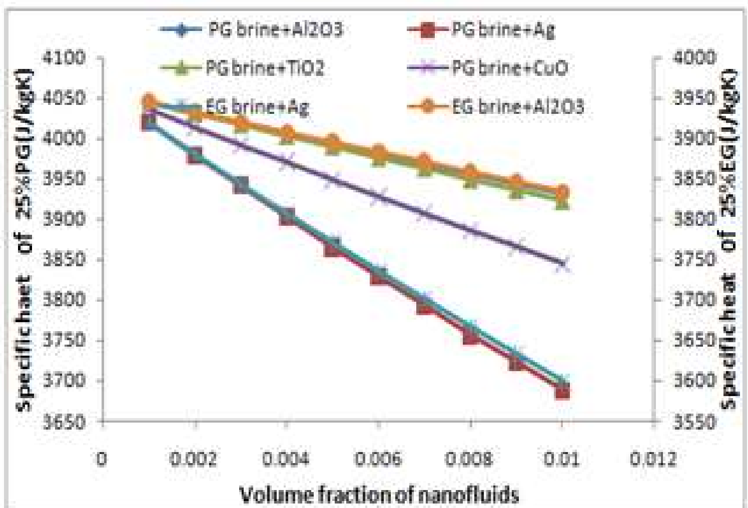

Figure 3.5: Specific heat variation for 25% PG &EG brine based nanofluids

The specific heat variation of 1% volume fraction i.e (0.5% Al_2O_3+0.5% TiO_2) hybrid nanofluids in base fluid of 25%PG is shown in Fig.3.6 and it is observed that TiO_2 hybrid nanofluids in 25% PG brine possess higher specific heat of 3925 J/kg which is followed by Fe_2O_3, CuO, Cu, Ag hybrid nanofluids in Al_2O_3.

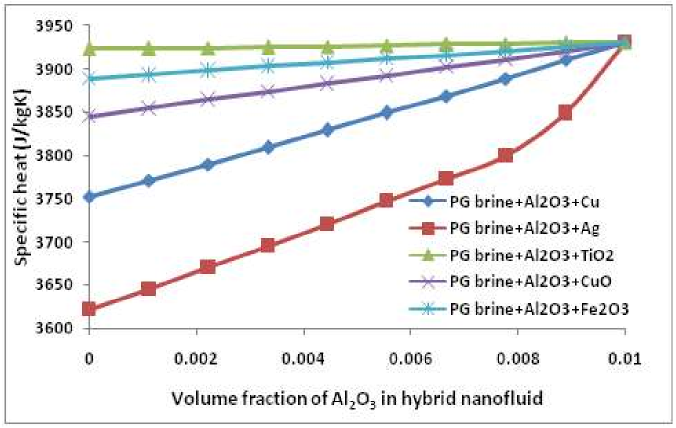

Figure 3.6: Specific heat variation for 25% PG based hybrid nanofluids

3.1.5 Thermal conductivity of base fluids, nanofluids and hybrid nanofluids

Variation in thermal conductivity for pure water, PG, ethylene glycol, sugarcane juice, brine solutions of 25% PG and 25% ethylene glycol as base fluid is shown in Fig.3.7. Thermal conductivity of all considered coolants increases with increase in temperature. Also among all the studied base fluids, water has higher thermal conductivity and followed by 25%PG brine, 25%EG brine, sugarcane juice, ethylene glycol and PG.

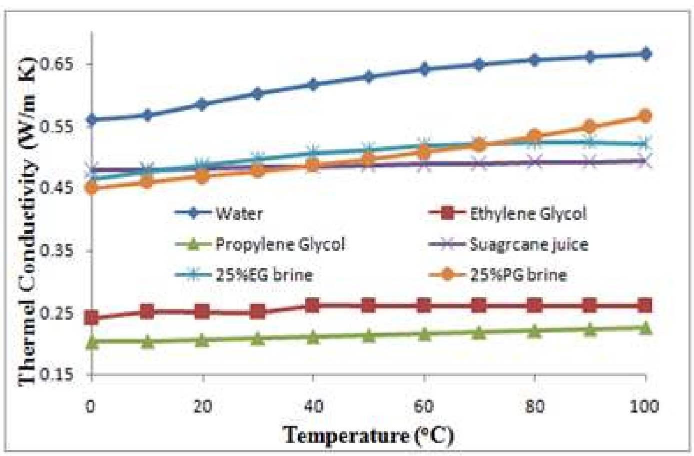

Figure 3.7: Thermal conductivity variation for base fluids

Comparison of the thermal conductivity for 1%volume fraction of various nanofluids i.e Al_2O_3, TiO_2, CuO, Ag in base fluid of 25% PG and 25% EG brine is shown in Fig.3.8.

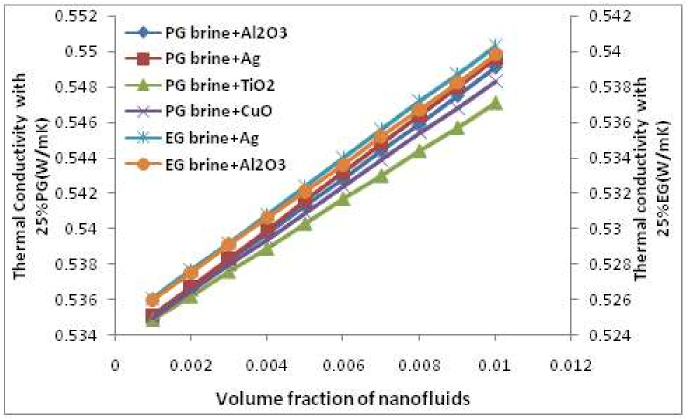

Figure 3.8: Thermal conductivity variation for 25% PG &EG brine based nanofluids

Ag nanofluid in water having higher thermal conductivity of 0.67 W/mK followed by PG brine based nanofluids in 1% volume concentration.

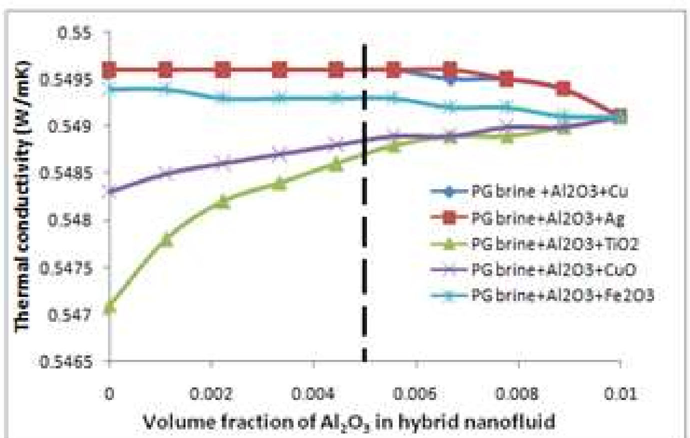

Figure 3.9: Thermal conductivity variation for 25% PG based hnf

The thermal conductivity variation of 1% volume fraction i.e (0.5% Al_2O_3+0.5%Ag) hybrid nanofluids in base fluid of 25%PG brine is shown in Fig.3.9 and it is observed that Ag hybrid nanofluids in 25%PG brine having higher thermal conductivity of 0.549 W/mK and also followed by Cu, Fe_2O_3, CuO and TiO_2 hybrid nanofluids in Al_2O_3 at a temperature of 80°C.

3.1.6 Dynamic viscosity of base fluids, nanofluids and hybrid nanofluids

Viscosity for all considered coolants decreases with temperature as shown in Fig.3.10. Also among all the studied base fluids, PG has higher viscosity and followed by ethylene glycol, 25%PG brine, 25%EG brine, sugarcane juice and water as coolants.

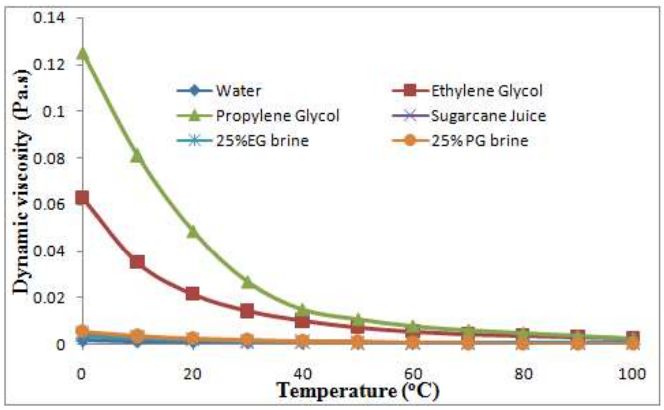

Figure 3.10: Dynamic viscosity variation in base fluids [179-181]

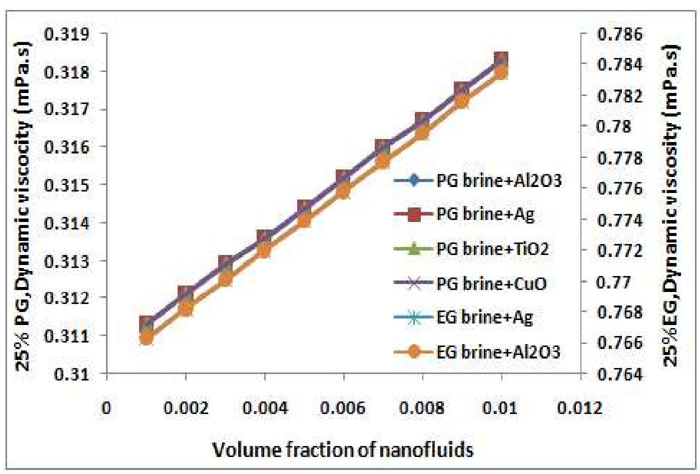

Figure 3.11: Dynamic viscosity variation for 25% PG &EG brine based nanofluids

Viscosity for 1%volume fraction of various nanofluids i.e Al_2O_3,TiO_2, CuO, Ag in base fluid of 25%PG and 25%EG brine is shown in Fig.3.11, it is observed that Ag nanofluid in 25% EG brine having higher viscosity of 0.784 Pa.s followed by PG brine and water 1% volume concentration.

The viscosity variation of 1% volume fraction i.e (0.5% Al_2O_3+0.5%Ag) hybrid nanofluids with base fluid of 25%PG is shown in Fig.3.12 and all studied PG brine based hybrid nanofluids have viscosity of 0.318 Pa.s at a mean coolant temperature of 80^o C .

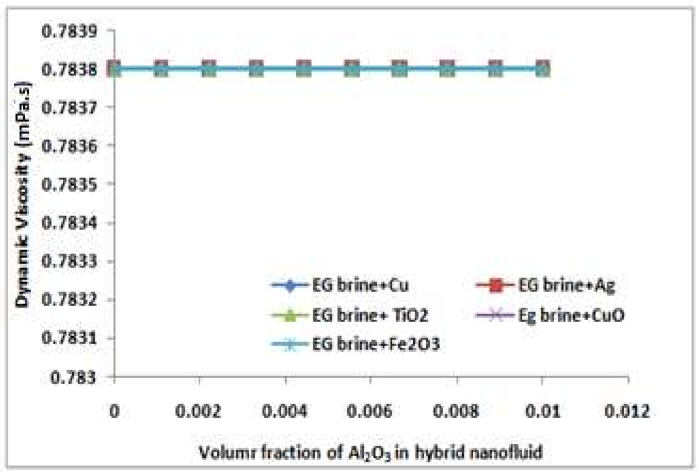

Figure 3.12: Dynamic viscosity variation for 25% PG brine based hnf

3.2 Measurement of thermophysical properties and comparison with the predicted data

All the thermophysical properties of considered base fluid, nanofluids as well as hybrid nanofluids have been measured in laboratory using viscometer for viscosity, hot disc thermal properties analyzer for measurement of thermal conductivity and heat capacity and weighing balance for measuring density.

3.2.1 Coolant preparation

25 % PG brine as coolant has been prepared by adding 25% of pure PG in 75% of water by volume and the same preparation method is applicable for the preparation of 25% EG brine. However, by using two step method PG brine based

nanofluids are prepared. 1 % volume fraction of nanofluid and 1% span 80 as dispersant mixed with 25% PG brine and then kept under ultrasonic vibration in ultrasonic vibrator (Lark, India) generating ultrasonic pulses in the power of 180W at 40 kHz continuously for 3h for the preparation of nanofluid. Also, for the preparation of PG brine based hybrid nanofluids, with this prepared nanofluid another nanofluid is mixed and kept under ultrasonic vibration for another 3 hours, to get a uniform dispersion and stable suspension, which determine the final properties of nanofluids and hybrid nanofluids.

3.2.2 Experimental procedure

3.2.2.1 Viscosity Measurement

Measurements of viscosity of various nanofluids will be conducted using the LVDV-II+ Pro Brookfield digital viscometer (cone and plate) as shown in Fig.3.13 with a computer controlled temperature bath to set the nanofluid temperature at different values. The viscometer allows changes in rotational speed such as different torques can be attained for differing viscosities. Generally, low viscosity nanofluids require spindles with larger surface areas and at high rotational speeds.

Figure 3.13: Brookfield DV1 Viscometer for viscosity measurement

The cone is connected to the spindle drive while the plate is mounted in the sample cup. Spindle used was CP-42, which can be used for samples in the viscosity starting from 0.3cP. The minimum amount of nanofluid required for viscosity measurements is 1 ml. As the spindle is rotated, the viscous drag of the fluid against the spindle is measured by the deflection of the calibrated spring. The spindle type and speed combination will produce satisfactory results when the applied torque is between 10% and 100% of the maximum permissible torque.

3.2.2.2 Thermal Conductivity Measurement

Thermal conductivity of nanofluid has been measured using a hot disk apparatus shown in Fig.3.14. The hot disk measures the thermal conductivity and thermal resistivity from the rate of temperature increase of the probe for a constant heating rate. The needle serves as both thermometer and a heating source in this case. The sensor needle contains both a heating element and a thermistor. The controller module contains a battery, a 16-bit microcontroller/AD converter, and power control circuitry. The sensor needle used was KS-1 which is made of stainless steel having a length of 60 mm and a diameter of 1.3 mm, and closely approximates the infinite line heat source which gives least disturbance to the sample during measurements.

Figure 3.14: KD2 Thermal properties analyzer

The sensor needle can be used for measuring thermal conductivity of fluids in the range of 0.2–2 W/mK with an accuracy of ±5%. To ensure the best accuracy, the KD2 probe was attached to a table stand and oriented as vertically as possible. The minimum amount of nanofluid required for thermal conductivity measurements is 45 ml. The coolant was filled in the beaker and attached to the holder. The TPS sensor was dipped in the sample and thermal conductivity readings were recorded from the screen.

3.2.2.3 Density Measurement

In order to measure the density, 250 ml of sample was taken in a cylindrical beaker and its weight was measured using weighing balance as shown in Fig.3.15 with least count of the device is 0.1g. Comparison with the theoretical results shows a deviation within 5% (Table-3.1) .

Fig. 3.15: Weighing Balance for density measurement

The theoretical and experimental thermophysical properties comparisons of coolants are listed in Table 3.1-3.3 and the theoretical thermophysical properties of coolants has been shown in Table 3.4. Theoretical results have been calculated from the various empirical correlations for base fluid, nanofluid and hybrid nanofluids from Chapter 3. It can be noted that all the measuring instrument have been calibrated by measuring the properties of DI water at 80^{o}C before measurement.

Table 3.1 : Density and Specific heat comparison (Theoretical and Experimental) at 80°C

Sl. No	Radiator Coolants	Density (Theo.) (kg/m^3)	Density Expt.) (kg/m^3)	% Differ	Specific heat (Theo.) (J/kg K)	Specific heat (Expt.) (J/kg.K)	% Differ
1	Water	997	976	2.11	4200	4103	2.36
2	25% PG brine	989	973	1.64	4059	3915	3.67
3	25% EG brine	997	985	1.20	3958	3834	3.23
4	(25% PG brine +0.1%Al_2O_3) nanofluid	1019	986	3.24	3931	3813	3.09
5	25% EG brine +0.1%Al_2O_3) nanofluid	1039	990	4.91	3866	3683	4.73
6	(25% PG brine+ 0.5%Al_2O_3+ 0.5 % CuO) hybrid nanofluid	1050	998	5.21	3808	3641	4.39
7	(25%PG brine+ 0.5%Al_2O_3+ 0.5 % TiO_2) hybrid nanofluid	1020	987	3.24	3320	3189	3.95

Table3.2: Dynamic viscosity comparison (Theoretical and Experimental)

Sl No	Radiator Coolants	Dynamic viscosity (mPa.s) (Theoritical)	Dynamic viscosity(mPa.s) (Experimental)	% Differ
1	Water	0.121	0.118	2.48
2	25% PG brine	0.314	0.290	7.61
3	25% EG brine	0.760	0.750	6.80
4	(25% PG brine + 1%Al_2O_3) nano fluid	0.318	0.291	8.41
5	25% EG brine + 1% Al_2O_3) nano fluid	0.766	0.652	6.83
6	(25% PG brine+ 0.5%Al_2O_3+0.5 CuO)hybrid nano fluid	0.315	0.311	7.82
7	(25%PG brine+ 0.5%Al_2O_3+ 0.5 %TiO_2)hybrid nanofluid	0.615	0.591	3.91

Table3.3: Thermal conductivity comparison (Theoretical and Experimental)

Sl No	Radiator Coolants	Thermal conductivity (W/mK) (Theoritical)	Thermal conductivity (W/mK) (Experimental)	% Differ
1	Water	0.621	0.593	4.84
2	25% PG brine	0.492	0.462	6.52
3	25% EG brine	0.285	0.262	3.85
4	(25% PG brine + 1%Al_2O_3) nanofluid	0.541	0.527	5.66
5	25% EG brine + 1%Al_2O_3) nano fluid	0.542	0.512	5.56
6	(25% PG brine+ 0.5%Al_2O_3+ 0.5 % CuO) hybrid nanofluid	0.548	0.513	5.56
7	(25% PG brine + 0.5% Al_2O_3+ 0.5 %TiO_2) hybrid nanofluid	0.513	0.502	6.76

Table – 3.4 : Theoritical thermophysical properties other radiator Coolants at 80^0C.

Sl No	Radiator coolants	Density (kg/m^3)	Specific heat (J/kg.K)	Dynamic viscosity mPa.s	Thermal conductivity (W/mK)
1	Ethylene Glycol(EG)	1100	2550	0.710	0.262
2	PG (PG)	1000	2680	0.120	0.213
3	Sugarcane Juice	1180	3800	0.135	0.482
4	(Water+1%Al_2O_3) nanofluid	1030	4100	0.130	0.643
5	(25%PGbrine+1%Ag) nanofluids	1084	3680	0.318	0.549
6	(25% PGbrine+1% TiO_2)nanofluid	1021	3923	0.318	0.546
7	(25%PG brine + 1% CuO) nanofluid	1043	3689	0.318	0.553
8	25% EG brine + 1% Ag) nanofluid	1109	3550	0.786	0.331
9	(PG brine + 0.5% Al_2O_3 + 0.5% Ag) hybrid nano fluid	1080	3690	0.315	0.549
10	(PG brine + 0.5% Al_2O_3+ 0.5%Cu) hybrid nanofluid	1070	3750	0.315	0.549
11	(PG brine +0.5% Al_2O_3 +0.5%Fe_2O_3) hybrid nanofluid	1045	3825	0.315	0.544
12	(PG brine +0.5% Al_2O_3+0.5% Fe_3O_4) hnf	1020	3320	0.315	0.541