Experiemtal Investigation and a Comparative Study on the Thermal Performance of Solar Flat Plate Collector Using Zro_2 Nanofluid

[1] M. DineshBabu, [2] M. Ragupathi, [3] K. Sathish, [4] M. Saravanan.
[1,2,3,4]Dept. of Mechanical Engineering, PanimalarEngneeringCollege,Ponnamalle, Tamilnadu, India

***Abstract*-To perk up the efficiency of solar flat plate collectors auxiliary, a studyhad been carried out wherein the conformist working fluid was replaced by of zirchroniumnano fluids. A 25 litres per day (LPD) solar flat plate collector has been intended and made-up. Rations were made for inserting T-type thermocouples at 15 locations were used for monitoring the thermo siphon system of the solar water heater. The prepared sample with a volume fraction of 0.2%was mixed with water and used in the Flat Plate Collector(FPC). Enhanced heat transfer was observed in the SWH using nanoparticles and hence it is inferred that addition of nano particles does improve the efficiency of the solar water heaters.**

Keyword- Flat plate Solar water Heater, Nanoparticle, Nanofluid, Heat transfer rate, thermal conductivity, surface area-BET by adsorption, Efficiency, Temperature profile, cost analysis, scaling.

I. INTRODUCTION

Solar energy plays a vital role in energy conservation. It has become the well proven and established appliance for providing hot water requirements in thousands of families in India. Solar water heating is a very simple and efficient way to grab energy from the sun and use it. In spite of its low efficiency it occupies a respectful place among the energy users. Therefore any improvement in the construction and operation of solar water heating system would definitely result in saving conventional fuel and cost. Despite this hopeful evaluation of the potential of solar energy, considerable technical and economic problems must be solved before utilization of solar energy can occur. The solar power development will depend on how we deal with a number of serious constraint, including scientific and technological problem, marketing and financial limitations, and political.Shareef et al. [1] examined the impact of volume fraction of 0.5% Al_2O_3-water nanofluid in a solar water heater. The result showed the utmost vaiation of the inlet as well as the outlet temperatures of the solar collector as 14.4˚C while the solar radiance reached roughly 788 W/m^2 but in the situation of water, the utmost temperature variation was 10.7℃ Arunaet al. [2] have made investigated on the performance of solar flat plate collector using TiO_2nanofluids with aparticle size of 40nm of 80 lit/min. The authors observe that using TiO_2nanofluid showed a higher efficiency of 58% compared to that of 32% using water in the solar collector.Also, the time taken to achieve the maximum outlet temperatures forTiO_2nanofluid is observed to be lesser than for conventional working fluid.Madhuri et al.[3] conducted a test in solar collector using two different working fluids water and Boron Nitride (BN)/water nanofluid each having different thermal conductivities. During the conduct of experiments, the result showed that the outlet temperature is increased with a decrease in mass flow rate and the thermal performance of solar collector is higher by 3% in efficiency when BN/water nanofluid is used. Gupta et al. [4] investigated the consequence in efficiency of direct absorption solar collector using Al_2O_3-H_2O nanofluid of particle size 20nm, for a volume fraction of 0.005% at mass flow rates of 1.5, 2, 2.5 lit/min. The result showed the maximum efficiency was achieved for a mass flow rate of 2 lit/min. The results of experiments show that using Al_2O_3-H_2O nanofluid does not have the settling problem which enhances the total thermal accomplishment of the collector. Ghasemil&Ahangar[5] did the comparative examination of Cu-water nanofluid and pure water as working fluids in a parabolic trough collector. Outlet temperature and thermal efficiency of the parabolic collector was carried out at different radiation levels and volume fractions. The result showed that the addition of volume fraction by 0.02% of Cu-nanoparticles yielded an outlet temperature of 322.6K while for water; it was 311.5 K. The thermal efficiency of the nanofluid collector is observed to be 28.7% for pure water and 39.4% of Cu-water nanofluid. Ladjevardi et al. [6] have the premeditated performance of a solar collector the effects of using nanofluid in view of the dissimilar in terms of diameter and volume fractions of graphite nanoparticles. The results show an increase in nanofluid based collector efficiency by about 88% compared to the base working fluid water for the solar collector.Paul et al. [7] focused concisely their investigation on solar collectors using Nanoparticles Enhanced Ionic Liquids (NEILS) as working fluids and their outcome showed an improved thermal conductivity of roughly 5%, which depends on the host fluid as well as concentration(ionic). The nanofluid’s heat capacity by employing Al_2O_3 nanoparticles and silica nanoparticles was enhanced by 23% and 26%, respectively. In addition, the education of engineers will have to changes its focus from non-renewable fossil-fuel technology to renewable power source. Thermal conversion is a technological scheme that utilizes a solar radiation. When a dark surface is placed in sunshine, it absorbs solar energy and heats up. Solar energy collector working with sun facing surfaces will transfer energy to the water that flow through it. To reduce heat loses to atmosphere and to improve it efficiency, one or two sheet of glass are usually placed over the absorbed surface. This type of thermal collector suffers from heat losses due to radiation and convection. Such losses increase rapidly as the temperature of the working fluid increases. Improvement such as the use of selective surfaces, evacuation of the collector to reduce heat losses, and the special glass is use to increase the efficiency of the absorber.

II. DESIGN OF 25LPD SOLAR FLAT PLATE COLLECTOR

A 25 LPD experimental collector set up is fabricated that includes riser tubes with Heat Exchanger as primary loop and hot water storage tank as secondary loop. In primary circuit, 2.5 lit of different volume fraction of nanofluid (Alumina) can be used to improve the efficiency of collector.The secondary circuit is fabricated with 25 litre insulated tank. The schematic diagram is shown in Fig 1.

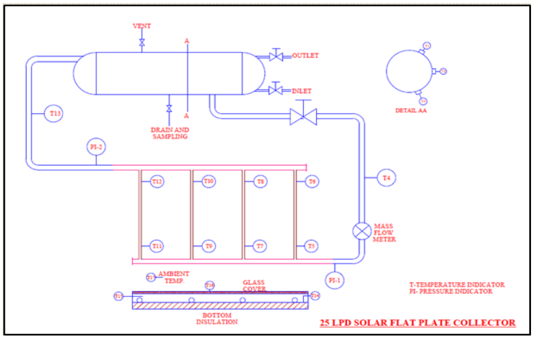

Fig. 1. 25 LPD collector with primary riser tube andsecondary storage tank

The energy balance of the absorber plate yields the following equation for steady state

$$q_u = (Ap\ \ S) - q_l = \dot{m}\text{cp}\ \Delta T$$

q_u = Useful heat gain, i.e. the rate of heat transfer to the working fluid

S = Incident solar flux absorbed in the absorber plate/m^2

Ap = Area of absorber plate, m^2

q_l = Rate at which heat is lost by convection and re-radiation from the top and by convection from the bottom and sides.

$$\text{Area of plate Ap} = \left[\frac{m\ Cp\ \Delta T}{S\ \eta}\right] = \left[\frac{25\ x\ 4187\ x\ 35}{680\ x\ 60x60x7\ 0.4}\right] = 0.534\ \text{m}^2$$

For this area & design purpose, efficiency of the collector is assumed as 40%.Total temperature difference across the storage tank is assumed over the day is 35^o C.For this collector area, available length (L) & breadth (W) are calculated as The effective length of the collector is 0.945m&Effective Width of the collector plate is 0.535m^2 with 4 riser tube placed in 100 mm pitch each other.

For experimental calculation, the total incident (irradiance) radiation falls on the collector can be measured from Pyranometer efficiency

$$(\eta)= \frac{q_u = F_R A_p [S - U_l\ (T_{fi} - T_a)] = m\ C_p\ [T_{fo} - T_{fi}]}{A_p\ I_T}$$

F_R = Heat removal factor, T_{pm} = average temperature of the absorber plate,^{o}C,I_T = Insolation (w/m$^{2)}$$T_a$ = Temperature of surrounding air,^{o}C,T_{fo},T_{fi} = Outlet and Inlet temperature of collector^{o}C.

III. SYNTHESIS AND SURFACE AREA DETERMINATION OF ZrO_2NANOPARTICLE

The Zirchronium with volume fraction of 0.2% mixed with base fluid (water) is used as working fluid and the same has been synthesised by chemical combustion method (urea as fuel and Zirchronium nitrate as raw material).

The required stoichiometric quantity of Urea (Fuel) and nitrate in the molar ratio of 1:1 is measured with the help of Physical balance. Prepared salt mixture is dissolved in 100 ml distilled water to get homogeneous solution. The solution is kept in hot oven at 90^{o}C to remove all the water and other volatile substances in the solution. The resultant paste like mass is removed from the container and transferred in to ceramic crucible.The wetted mass is then dried in a muffle furnace at 200^{o}C to ensure the complete removal of moisture. This process takes place at about 1-1.5 hours in hot oven. The final mixture is taken out and tested for moisture content and colour change.

A. Reaction Zone

The prepared dried mass is then transferred into a ceramic crucible and kept in Muffle furnace at 500 ^{o}C. At this temperature, the entire nitrate is evaporated and the fuel supplied is sufficient for combustion, nitrate salt becomes oxide at this temperature and the resulting complex mixture contains only the oxides of metals in nano meter size without changes in crystal shape, for better particle size distribution of nano particle, the molar ratio of Nitrate and Fuel ratio can be increased from 1:1 to 1:2. The particle size is controlled by reaction zone temperature. But, due to economical consideration, the reaction temperature is limited to 500^{o}C.The prepared chemicals/nano particles are dried in to ambient condition and mixed in the required volume fraction with distilled water. The product solution is so called Nano- fluid and then given for Ultrasonic treatment for better dispersion in base fluid.

B. SEM MICROGRAPHS OF NANOPARTICLES

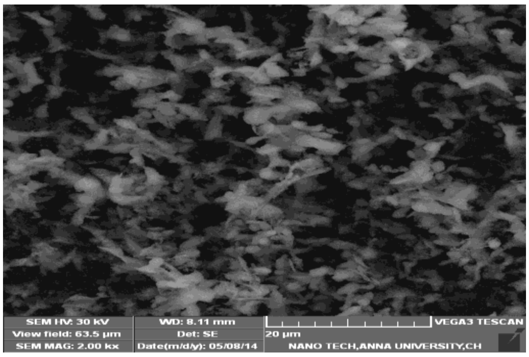

Fig. 2. SEM micrograph of ZrO_2 nanoparticles

Fig.2 shows the micro structure of ZrO_2 nano particle suspended fluid. The particles are in the form of spheres, cylinders and tiny agglomerates in the form of hollow microspheres were obtained.

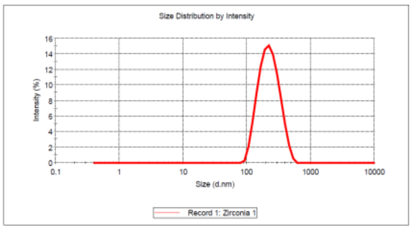

Fig. 3. XRD of ZrO_2

Dynamic Light Scattering (DLS) method was used to measure the size of the nanoparticles in the nanofluids. This method is used to detect the presence of agglomerates. Zetasizer Ver. 6.20 (Malvern Instruments) is used to take DLS measurement on the nanofluids. Figure 3 shows the evolution of the nanoparticles size with the intensity distribution. The measured average particle size in the nanofluids is much larger than that of the primary nanoparticles. The average cluster size for the water based nanofluid was calculated by using Scherrer formula.

IV. PERFORMANCE ANALYSIS OF FLAT PLATE COLLECTOR

The overall thermal performance and efficiencyare characterized by its thermal heat rate that depends on the transmittance, absorption and conduction of solar energy and the conductivity of the working fluid. The fin area in a solar water heater plays a major role in the performance of solar water heaters. Plate efficiency factor (F') and heat removal factor (Fr) are theimportant design parameters in the fabrication of solar collector systems. To optimize the FPC, one should know the actual temperature profile across the Riser tubeand thermal stratification in storage tank.The temperature profile of collector at different location (collector Inlet, outlet and storage tank temperature at top, middle &bottom and Fin& air gap just 10mm above riser tube area) is shown in the following figure 4(Time (hrs) in X-axis & Temperature (^{o} C) in Y-axis)

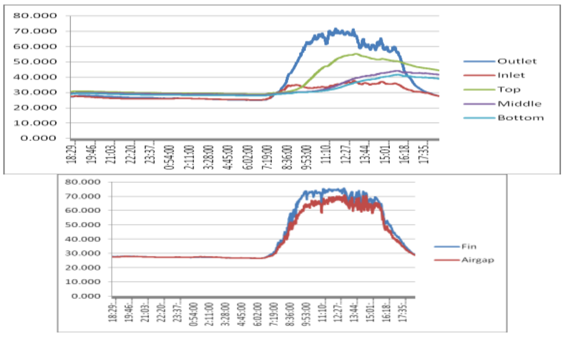

Fig. 4. Temperature profile of collector & storage tank and fin

V. PERFORMANCE OPTIMIZATION

In conventional solar water heating system, the water flows in laminar regime. The overall thermal performance and efficiency are characterized by its thermal performance that depends on the transmittance, absorption and conduction of solar energy and the conductivity of the working fluid. The absorber plate in a flat plate solar water heater plays a major role in the performance of solar water heaters. Plate efficiency factor (F') and heat removal factor (Fr) are the important design parameters in the fabrication of solar collector systems. To optimize the FPC, one should know the actual temperature profile across the Riser tube and thermal stratification in storage tank.

A 25 LPD solar water heater is operated for different insolation rate with and without nanoparticle in base working fluid and its efficiency is arrived as 39 % without nanofluid and its efficiency (overall day performance) is improved to 46% due to nanofluid of 0.4 volume fraction. The hourly efficiency of FPC with respect to time is plotted and it is shown in fig 5.

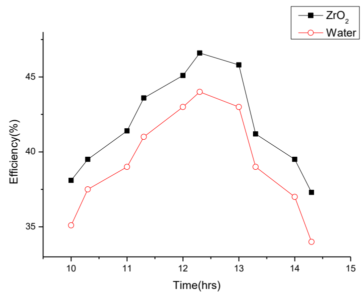

Fig. 5. HourlyEfficiency of FPC Using ZrO_2 Nanofluid

VI. CONCLUSION

The hourlyand overall day performance of FPC is carried out with and without nanoparticle (0.04 – 0.3 volume fraction) in water as base working fluid.The percentage increase in collector efficiency observed as 8% which is more significant.Optimizationof FPC due to nanofluid is effectively done by reduction in collector area because of increase in heat transfer rate. So, the capital cost of the collector mainly depends on Riser tube with fin area, piping and storage tank. Due to increase in collector efficiency, one can reduce the collector area significantly which is the main cost factor in total cost.By using nanofluid, scaling problem in collector riser tube can be reduced significantly which is more important in heat transfer point of view. Scaling tendency increases with increase in temperature due to inverse solubility nature of saline process water which is not in the case of nanofluid.

VII. REFERENCES

[1] Abbas SahiShareef, Mohammed Hassan Abbod&SuraQahtanKadhim 2015, 'Experimental investigation on a flat plate solar collector using Al2O3Nanofluid as a heat transfer agent', International Journal of energy and Environment, vol. 6, no. 4, pp. 317-330.
[2] Aruna, V , Channakaiah&Murali, G 2015, 'A study on a flat plate type of solar water heater with an thermosyphon using different working fluid',International Journal of Engineering Trends and Technology (IJETT), vol. 22, no. 10, pp. 493-496.
[3] Madhuri G Chatur&Nitnaware, PT 2015, 'Experimental Investigation on Efficiency of Flat Plate Solar Collector with BN/H2O Nanofluid', International Journal for Scientific Research & Development(IJSRD), vol. 3, no. 3, pp. 2652-2655.

[4] Hemant Kumar Gupta, Ghanshyam Das Agrawal&JyotirmayMathur2015, 'Investigations for effect of Al2O3–H2O Nano-fluid flow rate on the Efficiency of Direct Absorption Solar Collector', Case Studies in Thermal Engineering, vol. 5, pp. 70-78.

[5] Ghasemil, SE &MehdizadehAhangar, R 2014, 'Numerical analysis of performance of solar parabolic trough collector with Cu-Water nanofluid', International Journal of Nano Dimensions,vol.5,no.3, pp. 233-240.

[6] Ladjevardi, SM, Asnaghi, A, Izadkhast, PS &Kashani, AH 2013, 'Applicability of graphite nanofluids in direct solar energy absorption', Solar Energy, vol. 94, pp. 327–334.

[7] Titan C Paul, Morshed, AKM &Jamil A Khan 2013, 'Nanoparticle enhanced ionic liquids (NEILS) as working fluid for the next generation solar collector',Procedia Engineering, 5th BSME International Conference on thermal engineering, vol. 56, pp. 631-636.