Journal of Energy Research and Environmental Technology (JERET)
Print ISSN: 2394-1561; Online ISSN: 2394-157X; Volume 2, Number 3; April-June, 2015; pp. 256-261

http://www.krishisanskriti.org/jeret.html

Experimental Investigation on the Efficiency of Solar Water Heating System using Binary Working Fluid: A Case Study of Ethylene Glycol–Water

Parmod Vaishnav[1], Neetu Ram[2], Sumit Gupta[3] and V. K Bajpai[4]

[1,2,3]*Student, National Institute of Technology, Kurukshetra-136119, India*
[4]*National Institute of Technology, Kurukshetra-136119, India*
E-mail: [1]parmodvaishnav@gmail.com

Abstract—*This paper presents an investigation of solar water heating system based on flat plate collector. In this experimental set up, radiation from solar simulator are incident on the absorber plate of flat plate collector which absorb heat and transfer it to the heat transfer fluid in copper tubes of flat plate collector. Three different concentration of heat transfer fluid i.e. Water with 0% Ethylene Glycol, water with 20% Ethylene Glycol and water with 30% Ethylene glycol are studied. The efficiency of the system is investigated at three different constant intensities (450 W/m^2, 750 W/m^2 and 1100 W/m^2) and at constant mass flow rate of heat transfer fluid. It is found that the efficiency of system increases with the increase in concentration of Ethylene glycol in water. The efficiency of the system is 5 - 15% higher for 20% Ethylene Glycol concentration in water and 10 - 20% higher for 30 % Ethylene Glycol concentration in water as compare to pure water. It is also found that the system efficiency is maximum at radiation intensity of 450 W/m^2 and minimum at 750 W/m^2.*

Keywords: *Flat Plate Collector,Ethylene Glycol, Heat Exchanger, Solar Simulator, Efficiency.*

1. INTRODUCTION

Flat plate collector converts the energy of the sun directly into heat, which is usually stored, using water as a working fluid. The typical solar heating system consists of a collector; a heat transfer circuit that includes the fluid and the means to circulate it; and a storage system including a heat exchanger. In climates wherethere is a potential for freezing temperatures during part of the year, or in climates where fluids are exposed to high temperatures, anti-freeze/anti-boiling (coolant) is used to protect solar systems against corrosion, freezing temperatures, and overheating.

Many researchers have worked on different types of antifreeze solutions in solar collectors. Heinonen et.al [1] assessed the risks of using six different fluids (methanol, ethanol, aqueous potassium acetate, propylene glycol, aqueous calcium magnesium acetate, and aqueous urea) as antifreezes in ground source heat pump (GSHP) systems. Areas assessed included fire hazard; corrosion and leakage; health hazard. It was found that propylene glycol had low risk in all areas, despite having higher energy use; potassium acetate, calcium magnesium acetate, and urea had low to medium risk in all areas except leakage, which was high for all three fluids, and corrosion, which was high for urea; ethanol and methanol had high fire risk in their pure forms (but low risk in diluted form) and corrosion problems with iron compounds. In addition, methanol had high environmental and health risks. Juger and Crook [2] studied the results of laboratory testing comparing the heat transfer performance of heavy duty radiators with Propylene Glycol and Ethylene Glycol based coolants. The tests showed that the performance of 50/50 PG/water is degraded at higher flow rates to a greater degree than either 50/50 EG/water or 100% water.Kiatsiriroat et.al [3] studied thermal performance of a thermosyphon heat pipe using ethanol-water and TEG-water with variations of parameters such as the mixture content, the pipe diameter, and the working temperature. From the experiments, it is found that at low temperature of heat source (less than 80°C), the ethanol-water mixture has a higher heat transfer rate than that of water and close to that of pure ethanol. Nuntaphan et.al [4] investigated the heat flux due to flooding limit of thermosyphon heat pipe using triethylene glycol (TEG)-water mixture. For thermosyphon air preheater at high temperature applications, it is found that with selected mixture content of TEG-water in each row of the thermosyphon the performance of the system could be increased approximately 30-80% compared with pure TEG for parallel flow and 60-115% for counter flow configurations.Sheng Liu et.al [5] investigated the thermal conductivity enhancements in ethylene glycol and synthetic engine oil in the presence of multi walled carbon nano tubes (MWNTs). The volume concentration of CNT–ethylene glycol suspensions is below 1.0 vol. % and that of CNT– synthetic engine oil suspensions is below 2.0 vol. %. The results show that CNT–ethylene glycol suspensions have noticeably higher thermal conductivities than the ethylene glycol base fluid without CNT. The results for CNT synthetic engine oil suspensions also exhibit the same trend. For CNT–

ethylene glycol suspensions at a volume fraction of 0.01 (1 vol. %), thermal conductivity is enhanced by 12.4%. On the other hand, for CNT–synthetic engine oil suspension, thermal conductivity is enhanced by 30% at a volume fraction of 0.02 (2 vol. %). Otanicar et.al [6] studied the absorption limit of four liquids (water, ethylene glycol, propylene glycol, and Therminol VP-1) commonly used in solar thermal energy applications. Water is shown to be the best absorber of solar energy of the four fluids, but it is still a weak absorber, only absorbing 13% of the energy.Al-Amayreh. et.al [7] measured the thermal conductivities of ethylene glycol + water, diethylene glycol + water, and triethylene glycol + water mixtures at temperatures ranging from 25 °C to 40 °C and concentrations ranging from 25 wt. % glycol to 75 wt.% glycol. At certain constant temperature level, the thermal conductivity decreases with increasing the mass percent of glycol in the solution from the 25 wt. % to 75 wt. %. On the hand, at certain constant solution composition, the thermal conductivity increases slightly with increasing the temperature.Shojaeizadeh et.al [8] investigated experimentally the effect of propylene glycol (PG) concentration variation in propylene glycol–water solution at various mass flow rates (0.0167, 0.0333, 0.05 kg/s) on the efficiency of a Flat-plate solar collector. The experiments were carried out using 5 different PG concentrations in water including 0%, 25%, 50%, 75%, and 100%. Results indicate that increasing PG volume concentration from 25% to 75% enhances the efficiency of the Flat-plate solar collector and increasing volume concentration from 75% to 100% reduces the maximum efficiency of the Flat-plate solar collector by 8.3%.

2. EXPERIMENTAL SETUP:

The experiment is performed to investigate the efficiency of solar water heating system using binary fluid (solution of Ethylene Glycol in Water) as working medium. This system consists of a collector; a simulator, a heat transfer circuit that includes the fluid and the means to circulate it; and a storage system including a heat exchanger (Fig.1). The experimental setup consists of following components:

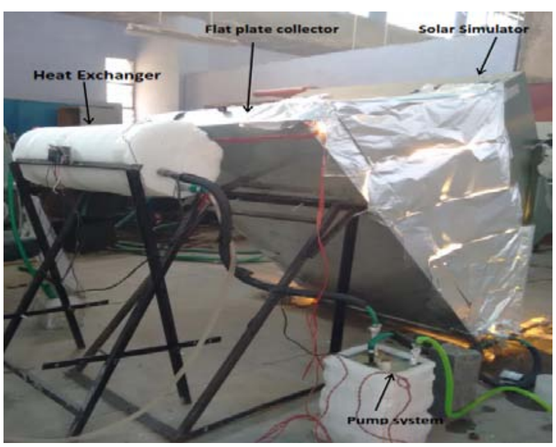


Fig. 1: Experimental Setup

- Flat plate collector
- Storage tank (heat exchanger)
- Mounting frame
- Pump with supply reservoir
- Connecting pipes
- Solar simulator

2.1 Flat Plate Collector

It is a device having an almost flat absorbing surface, with an area equal to the aperture of the collector. The solar radiation is collected on the absorbing surface of the collector. The specification of the Flat-plate solar collector used in this investigation is given in Table 1.

Table 1: The specifications of the Flat-plate collector are as follows

Specification	Dimension	Unit
Occupied area	160 X 90 X 12	cm
Absorber plate area	145 X 85	cm
Header tube(cu)	Φ24	mm
Riser tubes(cu)	Φ12	mm
Heat exchanger tube(cu)	Φ12	mm
Toughened Glass	t = 4	mm

It consists of following main component:

- Absorber plate or Selective surface
- Transparent cover
- Collector insulation
- Heat transfer medium
- Collector casing

2.1.1 Absorber Plate or Selective Surface

It is a metal, glass or plastic surface, mostly black in color. It absorbs and converts radiation into thermal energy and then, by convection and conduction it is transferred to the circulating cold fluid. The cold fluid in this case is a mixture of ethylene glycol and water. The most usual materials of construction are: steel, aluminium, copper, and a combination of copper tube with aluminium fins.

Fig. 2: Aluminum Absorber Plate

The area of the metallic surface that is loaded with solar radiation is painted either with a black paint or coated with a selective surface material. For the coating of a metallic surface with a selective material high precise technology is applied to avoid corrosion phenomena. Here we have used aluminium absorber plate (Fig. 2)with black coating. Length of plate is 145cm and width of plate is 85cm.

2.1.2 Transparent Cover

It is the upper part of the collect or covering the tide absorber plate. It is made from glass or transparent plastic sheet to permit penetration of solar beams. It therefore protects the absorber from environmental damages and decreases thermal losses. This transparent cover allows short wave length radiation to pass through it and trap the long wave length radiations. The thickness of the transparent cover is generally 4mm.

The collector cover is usually glass but can also be a special plastic material, weather proofed and not easily deteriorated by solar radiation. Glass, containing low iron concentrations, is approved transparent material, with high weather durability, good mechanical characteristics and very high solar radiation permeability. Its only disadvantage is its fragility. Plastic materials are not fragile but they are vulnerable to weather changes and UV deterioration which easily decreases their transparency and their mechanical resistance properties. The transparent cover used here is toughened glass (Fig. 3) with length 160cm and width 90cm.

Fig. 3: ToughenedGlass Cover

2.1.3 Collector Insulation

It consists of a material with very low thermal conductivity. It is installed in the bottom and around the sides of the collector, in order to minimize heat loss. Insulation materials usually used are polyurethane, glass wool and Rockwool. Glass and rock wool have to be applied in air and water tide appliances due to their physical nature. For other insulation materials it is of importance to have high heat loss resistance to stagnant temperatures. The insulation material used here is puf (Fig. 4) with thickness 4cm in bottom and 2.5cm on the sides of collector casing. Its thermal conductivity is 0.021W/mk.

Fig. 4: Collector Insulation

2.1.4 Heat Transfer Medium

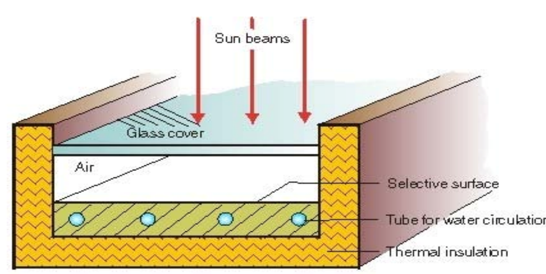
It flows through the collector to transfer the heat from the absorber to the utilization system. It can be either air or a liquid, usually water. But in this case it is a mixture of ethylene glycol and water.

2.1.5 Collector Casing

The frame or shell (Fig. 5) is the most important part because it houses all other collector components. It is constructed usually from aluminum or plastic material having high resistivity to all weather conditions, and to solar radiation intensity. The geometric design and the construction of the shell needs special attention in order to provide high collector stability during the installation, tightness, and a perfect fit between the cover and the shell.

Fig. 5: Collector Casing

The flat plate collector with position of all components is shown in fig. 6.



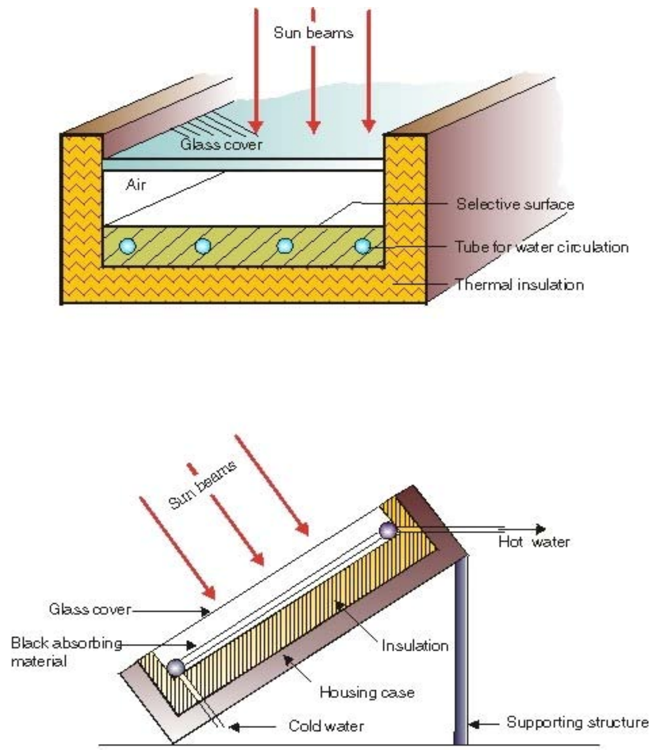


Fig. 6: flat plate collector

2.3 Storage Tank or Heat Exchanger

In storage tank cold water is heated with help of primary fluid which circulate in storage tank through coiled copper tube (Fig. 7). The cold water enters into the storage tank from bottom of one side and remains in lower half of tank. The heated water remains in the upper half of tank due to thermosyphon effect and collected from top of the other side. Insulation 2.5cm is placed over the heat exchanger to reduce the heat loss from the tank to the environment. The diameter of the tank is 30cm and length is 60cm.

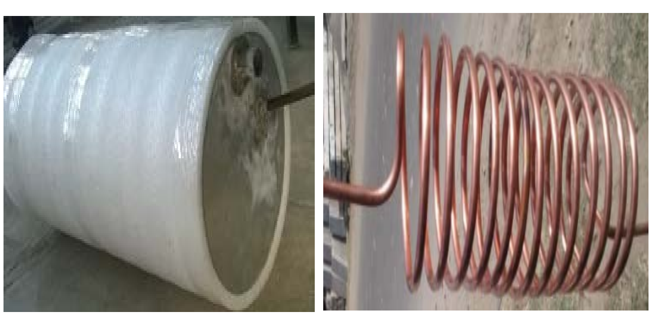


Fig. 7: Heat Exchanger with Coiled Copper Tube

2.4 Mounting Frame

There are two mounting frames (Fig. 8) used. One is used to support flat plate collector at an angle of 60^o and other is used for resting of storage tank above ground.

Fig. 8: Frame to Support Collector (Left) and Heat Exchanger (Right)

2.5 Pump with Supply Reservoir

Pump is use for the circulation of primary liquid through the circuit (between tubes of flat plate collector and storage tank) of the system. This pump is kept in supply reservoir (Fig. 9) from where it pumps up primary liquid through the circuit. Insulation of 2.5cm is pasted on outer surface of the reservoir to reduce heat loss from the reservoir to environment.

Fig. 9: Pump with Supply Reservoir

2.6 Connecting Pipes

These are used to connect flat plate collector with storage tank, storage tank with pump and pump with collector to complete primary circuit. In secondary circuit connecting pipe is used to give cold water supply in storage tank. The internal diameter of connecting pipes (Fig. 6) is 1.2cm.

Fig. 10: Connecting Pipe

2.7 Solar Simulator

It is a device that is used to generate the effect of sun artificially to perform the test in the laboratory. For our experiment we have used a solar simulator consisting of 16 bulbs each of 300 watts.

3. SYSTEM OPERATION

This system is a forced convection system. The flow loop included an electrical pump with supply reservoir, a flat plate solar collector and storage tank. Two thermocouples are used to measure the fluid temperatures in the inlet and outlet of solar collector. The thermal performance of the solar collector is determined by obtaining the values of instantaneous efficiency of the system for different combinations of incident radiation, ambient temperature, and inlet fluid temperature. This requires experimental measurement of the rate of incident radiation as well as the rate of energy addition to the working fluid as it passes through the collector, all under steady state or quasi-steady-state conditions.

4. EFFICIENCY

System efficiency is calculated using the following formula:

$$Q_{in} = I * A$$

$$Q_{out} = m_w[C_p(T_o - T_i)]$$

$$\boldsymbol{efficency} = \frac{\mathbf{Q_{out}}}{\mathbf{Q_{in}}}$$

I = Radiation intensity in W/m^2

A = Absorber plate area (m^2)

m_w= Mass flow rate of water (kg/s)

T_o,T_I = Temperature of hot/cold water (K)

C_p= Specific heat of water (KJ/kgK)

5. RESULTS AND DISCUSSIONS

5.1 Efficiency of the system at thermal radiation of intensity 450 W/m^2

In this case the efficiency of the system is compared at radiation intensity of 450 W/m^2 for three different thermal fluids which are pure water, water with 20% ethylene glycol and water with 30% ethylene glycol. The mass flow rate of each fluid remains constant during the process. The graph shows that the efficiency is maximum for water with 30% ethylene glycol (Fig. 11). Also with time the efficiency first increases to reach its maximum value and then it becomes constant.

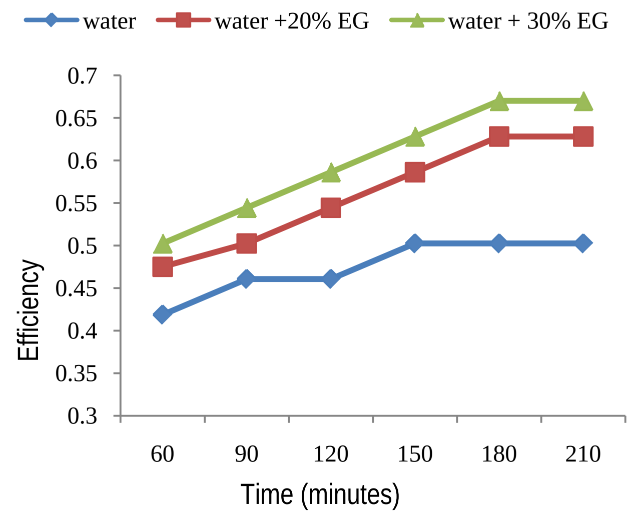


Fig. 11: Efficiency of the system at intensity 450 W/m^2

5.2 Efficiency of the system at thermal radiation of intensity 750 W/m^2

In this case the experiment is performed at radiation intensity of 750 W/m^2.The graph shows that the efficiency is maximum for water with 30% ethylene glycol (Fig. 12). In this case also with time the efficiency first increases to reach its maximum value and then it becomes constant but the maximum value of the efficiency remains less than the previous maximum value of efficiency.

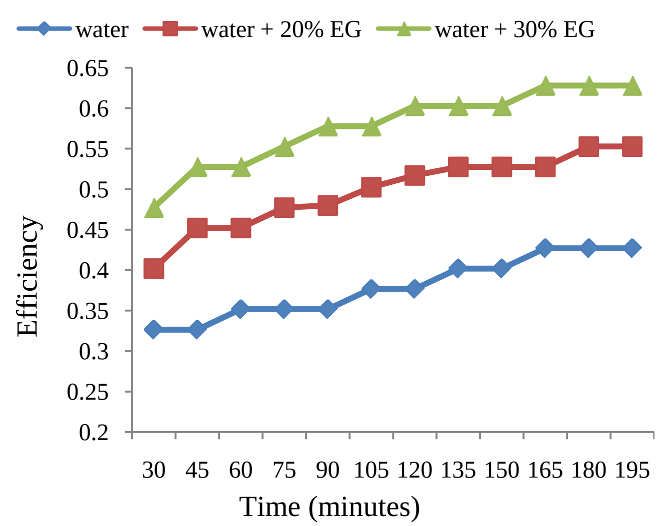


Fig. 12 Efficiency of the system at intensity 750 W/m^2

5.3 Efficiency of the system at solar radiation of intensity 1100 W/m^2

Here the experiment is performed at radiation intensity of 1100 W/m^2.The graph shows that the efficiency is maximum for water with 30% ethylene glycol (Fig. 13). In this case the maximum value of the efficiency remains less than the maximum value of efficiency at 450 W/m^2 but greater than the value at 750 W/m^2.

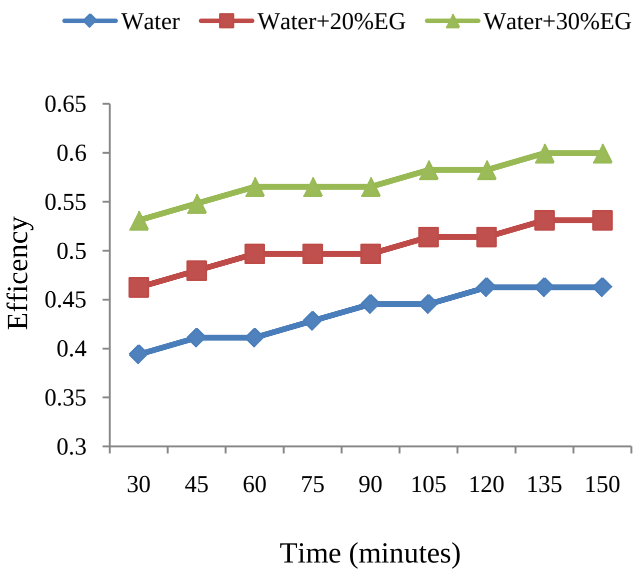


Fig. 13: Efficiency of the system at intensity 1100 W/m^2

6. CONCLUSIONS

It is found the efficiency of the system is 5 - 15% higher for 20% Ethylene Glycol concentration in water and 10 - 20% higher for 30 % Ethylene Glycol concentration in water as compare to pure water.It is also found that the system efficiency is maximum at radiation intensity of 450 W/m^2 and minimum at 750 W/m^2.

REFERENCES

[1] E.W. Heinonen, M.W. Wildin, A.N. Beall, R.E. Tapscott, Assessment of antifreeze solutions for ground-source heat pump systems, ASHRAE Trans. 103 (2) (1997) 747–756.

[2] Juger, J. and Crook, R., "Heat Transfer Performance of Propylene Glycol Versus Ethylene Glycol Coolant Solutions in Laboratory Testing," SAE Technical Paper 1999-01-0129, 1999.

[3] T. Kiatsiriroat, A. Nuntaphan, J. Tiansuwan, Thermal performance enhancement of thermosyphon heat pipe with binary working fluids, Exp. Heat. Transfer 13 (2) (2000) 137–152.

[4] A. Nuntaphan, J. Tiansuwan, T. Kiatsiriroat, Enhancement of heat transport in thermosyphon air preheater at high temperature with binary working fluid: a case study of TEG–water, Appl. Therm. Eng. 22 (2002) 251–266.

[5] Min-Sheng Liu, Mark Ching-Cheng Lin, I-Te Huang, Chi-Chuan Wang, Enhancement of thermal conductivity with carbon nanotube for nanofluids, Heat and Mass Transfer 32 (2005) 1202–1210.

[6] T.P. Otanicar, P.E. Phelan, J.S. Golden, Optical properties of liquids for direct absorption solar thermal energy systems, Solar Energy 83 (2009) 969–977.

[7] M. Al-Amayreh, Experimental study of thermal conductivity of ethylene glycol water mixtures, Eur. J. Sci. Res. 44 (2) (2010) 300–313.

[8] E. Shojaeizadeh, F. Veysi, T. Yousefi, F. Davodi, An experimental investigation on the efficiency of a Flat-plate solar collector with binary working fluid, Experimental Thermal and Fluid Science 53 (2014) 218–226.