A REVIEW ON PERFORMANCE OF SOLAR THERMAL FLAT PLATE COLLECTOR USING DIFFERENT HEAT TRANSFER FLUIDS

[1]Jeena John, [2]Nidhi M J
[1]PG Student , [2]Assistant Professor
Amal Jyothi College of Engineering Kanjirapally, Kottayam, Kerala
Email:[1]jeenjohn91@gmail.com, [2]mjnidhi@amaljyothi.ac.in

Abstract— Energy use and energy security are greatly inter related and corresponds to a main concern in the Indian power sector. Renewable energy sector occupies an inevitable role in the sustainable development technologies in which the needs of present generation are met without compromising the ability of the future generation to meet their own needs. Drastically increasing energy demand and environmental issues have motivated many international researchers for searching an alternative option to fulfil the future energy demand. In such a case, solar energy appears as the most attractive option due to its abundance and clean feature. Today solar thermal technologies are the most popular advanced techniques. The performance of solar thermal technology is dependent on certain factors. Among these factors, heat transfer fluids like water, air, antifreezes like ethylene glycol, propylene glycol, hydrocarbon oils etc. have a very crucial role in producing power through the effective utilisation of solar thermal energy. The system efficiency depends on temperature of the different heat transfer fluids used. Hence their performance analysis also holds greater importance in this context. In the thesis work, a performance analysis on the at plate collector system with different heat transfer fluids is being illustrated. The experiment is conducted using varying concentrations of heat transfer fluid mixture. The simulation of the same system is done with a software named TRNSYS.

***Index Terms*— Ethylene glycol, heat exchanger, heat transfer fluid, heat transport, propylene glycol, solar thermal system, thermal efficiency, thermal energy storage, thermal envelope.**

I. INTRODUCTION

Most of the conventional systems extracting solar thermal energy mainly uses water as the heat transfer fluid. Commonly, the fluid owing through the tubes of at plate collector is water. Water is nontoxic and inexpensive. With a high specific heat, and a very low viscosity, it is easy to pump. Since water has a relatively low boiling point and a high freezing point, it is the most commonly used fluid in solar thermal systems. It can also be corrosive if the pH (acidity/alkalinity level) is not maintained at a neutral level [1]. Water with a high mineral content (hard water) can cause mineral deposits to form in collector tubing and system plumbing. That is why fluids other than water also hold importance in the field of solar thermal collectors.

In a solar thermal collector, the solar heat absorbed by the absorber plate is transferred to the transport medium in the fluid tubes to be carried away for storage in the storage tank or use. The underside of the absorber plate and the side of casing are well insulated to reduce conduction losses. The liquid tubes can be welded to the absorbing plate, or they can be an integral part of the plate. The liquid tubes are connected at both ends by large diameter header tubes.

Glycol/water mixtures have a 50/50 or 60/40 glycol-to-water ratio. The ratio can be varied according to the user's interest. Ethylene and propylene glycol are antifreeze solutions. These mixtures provide effective freeze protection as long as the proper antifreeze concentration is maintained. Antifreeze fluids degrade over time and normally should be changed every 3 to 5 years. Synthetic oils have a higher viscosity and lower specific heat than water. They require more energy to pump [2]. These oils are relatively inexpensive and have a low freezing point. Nanofluids can also be incorporated within the proposed system for better thermal performance. But these nanofluids are comparatively costly in nature.

In sunny and warm locations, where freeze protection is not necessary, a batch type solar water heater can be extremely cost effective. In higher latitudes, there are often additional design requirements for cold weather, which add to system complexity. This has the effect of increasing the initial cost (but not the life cycle cost) of a solar water heating system, to a level much higher than a comparable water heater of the conventional type. The biggest single consideration is therefore the large initial financial outlay of solar water heating systems. Offsetting this expense can take several years and the payback period is longer in temperate environments where the insolation is less intense. But in the case of obtaining a larger solar radiation intensity, the initial investment will be paid back quickly i.e., say within 3 to 5 years [3]. Thus, when the initial costs of a solar system are properly financed and compared with energy costs, then in many cases the total monthly cost of solar heat can be less than other more conventional types of water heaters (also in conjunction with an existing water heater). At higher latitudes, solar heaters may be less effective due to lower solar energy, possibly requiring larger dual heating systems. In addition, government incentives can also be significant.

II. LITERATURE REVIEW

Flat plate collectors are generally designed for applications with typical working temperatures between 40^0C and 60^0C, which is mainly the case of domestic hot water systems. By using highly selective absorbers, FPC can currently work up to 80^0C with good efficiency. FPC have important advantages over the other collector types because they are easier to manufacture, they collect radiation coming from all directions (both direct and diffuse radiations), and therefore, they can be stationary on any given roof. In the last two decades, various investigation works have tried to increase the application range of this kind of solar collectors by reducing their heat losses to the ambient.

The construction of a flat plate collector is shown in figure 1 illustrated below. The basic parts noted are a full aperture absorber, transparent or translucent cover sheets, and an insulated box. The absorber is usually a sheet of high thermal conductivity metal with tubes or ducts either integral or attached. Its surface is painted or coated to maximize radiant energy absorption and in some cases to minimize radiant emission. The cover sheets, called glazing, let sunlight pass through to the absorber but insulate the space above the absorber to prohibit cool air from owing into this space. The insulated box provides structure and sealing and reduces heat loss from the back or sides of the collector.

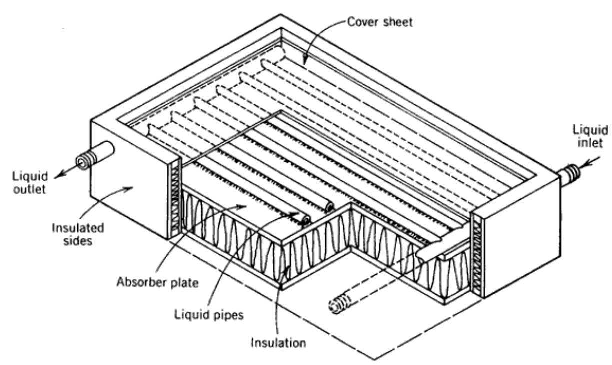

Fig. 1: A typical liquid flat plate collector

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 at plate solar collector was investigated experimentally by F. Davod et al. The experiments were carried out using five different PG concentrations in water including 0%, 25%, 50%, 75%, and 100%. The procedure of ASHRAE standard was applied to test the thermal performance of at plate solar collector.

Propylene glycol has extremely low environmental, health, fire and corrosion risk [11]. It may be a good choice if energy use and life cycle costs are not over riding concerns. The efficiency obtained with PG as heat transfer fluid was around 50 to 60%.

The schematic diagram of a an FPC is illustrated in figure 2. The amount of antifreeze concentration in solar systems usually depends on required freeze protection temperature

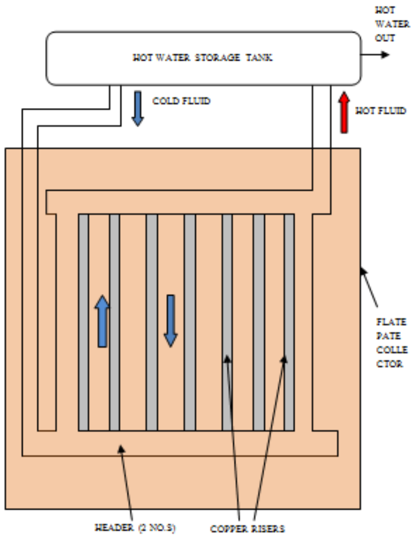

Fig. 2: Schematic diagram of a flat plate collector

or corrosion inhibition [2]. The heat transfer rate of a heating system containing 50 wt.% ethylene glycol will be 54% less than that of an equivalent water system, and with an ethylene glycol concentration of 70 wt.%, this difference increases to 67%. If 50 wt.% propylene glycol is used, the heat transfer rate will be 60% less than that of an equivalent water system. The schematic diagram for a at plate solar collector is illustrated in figure 2 showing the absorber tube and plate structures [11]. Therefore, in order to maximize the heat transfer rate, excessive glycol concentrations should be avoided, and ethylene glycol is the preferred choice for glycol heating systems.

III. DEVELOPMENTS IN FLAT PLATE COLLECTOR SYSTEM

The studies on solar thermal at plate collector system with an integrated heat pipe revealed that 66% efficiency can be obtained based on energy balance equations for heat transfer process. A transient heat transfer model calculates this efficiency. The working fluid undergoes continuous circulation in evaporation and condensation loop. This process optimizes thermal performance and stability of the system[7]. Working fluid greatly influences the performance of heat pipe in FPC. W. Lingjiao et al. showed experimentally that efficiency with fluid 410A is 58.96%. Also a heat pipe filled with ethanol, aimed to transfer heat from the collector to the water tank directly [12]. A two phase closed loop thermosyphon was utilized with the condensation section placed in the water tank. The maximum instantaneous efficiency of the system reached to about 60%.

Investigation of thermophysical properties of aluminium oxide nanoparticles and its effect on at plate collector revealed that with the increase in temperature, the viscosity of fluid decreases and thermal conductivity starts increasing. By suspending Al_2O_3 nanoparticles in the base fluid (water) the maximum collector exergy efficiency is increased about 1% [10] and also the corresponding optimum values of mass flow rate of fluid and collector inlet fluid temperature are decreased to about 68% and 2%, respectively [4]. The efficiency values initially increases rapidly with increasing mass flow rates, and then reaches a constant level for higher ranges of mass flow rates.

Transparent insulation have been used as additional covers placed between the glass cover and the absorber as a solution to decrease the heat losses by convection and radiation. Indeed, teflon films have been used as inner glazing of double glazed FPC (Flat Plate Collector). Despite the heat deflection mechanical problem that the Teflon presents, new FPC with inner Teflon films have overcome this problem and have shown ability to operate up to 120. with good performance. Silica aerogel, although its high price, was also used and showed satisfactory results to improve the efficiency of FPC as the induced decrease in solar transmittance was compensated by the decrease in thermal losses.

Various prototypes of FPC with honeycomb TIM (Transparent Insulation Material) have been also developed and tested. These studies have demonstrated that convective heat losses are significantly reduced by the use of TIM due to the partition of the space between the absorber and the cover restricting heat transport by convection and thus, a higher performance of

FPC was achieved. The test results were encouraging and a performance comparable to that of evacuated tubes collectors was achieved [5]. Most of these works used TIM made of glass capillary tubes that despite their good resistance to high temperatures, need to be embedded in a double glazing unit which leads to a significant increase in their weight and manufacturing cost.

For commercial solar collectors, plastic TIM can be a good solution since its cost is substantially less than glass capillaries and the weight is highly reduced. The main drawback of the FPC with TIM is the high stagnation temperature that they could reach, especially in summer. Whereas conventional FPC reach stagnation temperatures in the range of 160 to 200^0C. and are designed to withstand component damage at these temperatures, FPC with TIM may reach above 250^0C. If their internal temperature is not limited, their components and especially the plastic TIM can be damaged [4]. Currently, some of the plastic TIM available in the market can withstand up to 140^0C. as a maximum resistance temperature. Recently, Giovanetti et al. presented new types of cellulose triacetate honeycomb TIM that exhibited good temperature stability and Ultraviolet durability making it promising for the use in improved FPC.

Some methods for providing overheating protection for solar collectors have been used in some previous works. For example, Harrison et al. used a ventilation channel for limiting the temperature of standard FPC in climates where there is a potential risk of freezing temperatures and for avoiding corrosion of the system components at the same time [7], 20]. Martinez et al. presented a thermoelectric self cooling system designed to dissipate excess heat from a solar collector system, increasing thus the heat losses by more than 50%. FPC with plastic TIM with passive overheating system based on closed loop heat pipe have been recently introduced to the market showing good thermal performances.

In this context, a low to medium temperature FPC with plastic TIM and equipped with a low cost overheating protection system is presented in the work [3]. The working temperature of the proposed collector is focused on the range from 80 to 120^0C. The proposed overheating system does not induce a significant additional cost and consists of a ventilation channel that is inserted at the rear of the collector between the absorber and the back thermal insulation.

IV. METHODOLOGY

A. To conduct an analysis on the thermal performance of liquid flat plate collector (FPC) with different heat transfer fluids

B. The different heat transfer fluids include:

1. Water
2. Mixture of ethylene glycol and water
3. Mixture of propylene glycol and water

C. TRNSYS software is used to simulate the collector to plot various performance curves

The proposed system is being illustrated in the figure shown below.

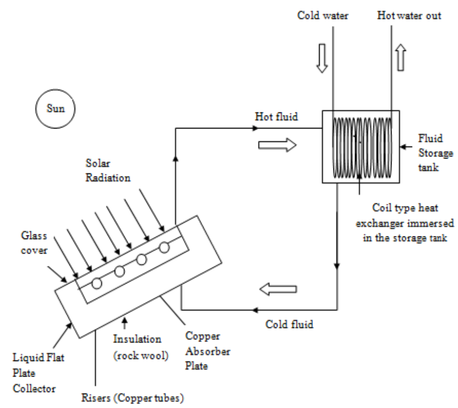

Fig. 3: Proposed system or prototype

In this paper, flow and temperature distribution in a solar collector panel with circular tube configuration is experimentally and theoretically investigated. The TRNSYS software may be used to simulate the collector to plot various characteristic curves. The temperature distribution through the absorber is evaluated by means of temperature measurements at the inlet and outlet of absorber tubes. The fluid present in the pipes heats up instantly. In addition they pipes are painted black on the outside so as to absorb maximum amount of heat. The pipes have reflective silver surface on the back that reflects the sunlight back, thus heating the pipes further. This reflective silver surface also helps in protecting everything that is on the back of the solar panel. The heat thus produced can be used for heating up water in a tank, thus saving the large amount of gas or electricity required to heat the water.

V. HEAT TRANSFER FLUIDS

1. **Coefficient of expansion -** the fractional change in length (or sometimes in volume,

when specified) of a material for a unit change in temperature.

2. **Viscosity -** resistance of a liquid to sheer forces (and hence to flow)

3. **Thermal capacity -** the ability of matter to store heat.

4. **Freezing point -** the temperature below which a liquid turns into a solid.

5. **Boiling point -** the temperature at which a liquid boils.

6. **Flash point -** the lowest temperature at which the vapour above a liquid can be ignited in air.

The properties of different heat transfer fluids is being tabulated in the table 1 given below.

Table 1: Properties of different heat transfer fluids[5]

Fluid type	Density (kg/m^3)	Kinematic viscosity (m^2/s)	Absolute viscosity (Ns/m^2)	Thermal conductivity (W/mK)	Specific heat (J/kgK)
Water(20ºC)	1000	$1.006x10^{-6}$	$1.006x10^{-3}$	0.5978	4178
Air (50ºC)	1.093	$17.95x10^{-6}$	$19.61x10^{-6}$	0.02826	1005
Ethylene Glycol (EG)	1087	$4.747x10^{-6}$	$5.16x10^{-3}$	0.2594	2562
EG-water mixture (80:20)	1068	-	-	-	3862
Propylene Glycol (PG)	1003	$0.9x10^{-6}$	$0.903x10^{-3}$	0.254	4030
PG-water mixture (80:20)	1000	-	-	-	4155.6

In a cold climate, solar water heating systems require fluids with low freezing points. Fluids exposed to high temperatures as in a desert climate should have a high boiling point. Viscosity and thermal capacity determine the amount of pumping energy required. A fluid with low viscosity and high specific heat is easier to pump, because it is less resistant to flow and transfers more heat. Other properties that help determine the effectiveness of a fluid are its corrosiveness and stability. The following are some of the most commonly used heat transfer fluids and their properties.

A. Air

Air will not freeze or boil, and is non corrosive in nature. However, it has a very low heat capacity, and tends to leak out of collectors, ducts and dampers.

B. Water

Water is non toxic and inexpensive. With a high specific heat and a very low viscosity, it is easy to pump. Unfortunately, water has a relatively low boiling point and a high freezing point. It can also be corrosive if the pH (acidity or alkalinity level) is not maintained at a neutral level. Water with a high mineral content (i.e., hard water) can cause mineral deposits to form in collector tubing and system plumbing.

C. Glycol/water mixture

Glycol/water mixtures have a 50/50 or 60/40 glycol to water ratio. Ethylene glycol and propylene glycol are antifreezes. These mixtures provide an effective freeze protection as long as the proper antifreeze concentration is maintained. Antifreeze fluids degrade over time and normally should be changed every 3 to 5 years. These types of systems are pressurized, and should only be serviced by a qualified solar heating professional.

D. Newtonian fluid

In continuum mechanics, a Newtonian fluid is a fluid in which the viscous stresses arising from its flow, at every point, are linearly proportional to the local strain rate. Strain is the rate of change of its deformation over time. Both ethylene glycol and propylene glycol may be considered as newtonian fluids if they are used along with nano sized particles.

E. Hydrocarbon oils

Hydrocarbon oils have a higher viscosity and lower specific heat than water. They require more energy to pump. These oils are relatively inexpensive and have a low freezing point. The basic categories of hydrocarbon oils are synthetic hydrocarbons, paraffin hydrocarbons, and aromatic refined mineral oils. Synthetic hydrocarbons are relatively nontoxic and require little maintenance. Paraffin hydrocarbons have a wider temperature range between freezing and boiling points than water, but they are toxic and require a double walled, closed loop heat exchanger. Aromatic oils are the least viscous among most of the hydrocarbon oils.

F. Refrigerants

Refrigerants or phase change fluids are commonly used as the heat transfer fluid in refrigerators, air conditioners, and heat pumps. They generally have a low boiling point and a high heat capacity. This enables a small amount of the refrigerant to transfer a large amount of heat very efficiently. Refrigerants respond quickly to solar heat, making them more effective on cloudy days than other transfer fluids. Heat absorption occurs when the refrigerant boils (changes phase from liquid to gas) in the solar collector [9]. Release of the collected heat takes place when the now-gaseous refrigerant condenses to a liquid again in a heat exchanger or condenser.

G. Chlorofluorocarbon

For years, chlorofluorocarbon (CFC) refrigerants, such as freon, were the primary fluids used by refrigerator, air-conditioner, and heat pump manufacturers because they are nonflammable, low in toxicity, stable, noncorrosive, and do not freeze. However, due the negative effect that CFCs have on the earth's ozone layer, CFC production is being phased out, as is the production of hydro chlorofluorocarbons (HCFC). The few companies that produced refrigerant charged solar systems have either stopped manufacturing the systems entirely, or are currently seeking alternative refrigerants. Some companies have investigated methyl alcohol as a replacement for refrigerants.

H. Ammonia

Ammonia can also be used as a refrigerant. It's commonly used in industrial applications. Due to safety considerations it's not used in residential systems. The refrigerants can be aqueous ammonia or a calcium chloride ammonia mixture.

I. Silicones

Silicones have a very low freezing point, and a very high boiling point. They are non corrosive and long lasting in nature. Because silicones have a high viscosity and low heat capacities, they require more energy to pump. Silicones also leak easily, even through microscopic holes in a solar loop.

J. Antifreeze

There are different types of antifreeze solutions available like propylene glycol (PG)/water, ethylene glycol (EG)/water, tri-ethylene glycol/ water etc. Antifreeze has three basic functions namely freeze protection, boil over protection, and anti-corrosion and rust protection. Antifreeze is also primarily responsible for heat transfer however, antifreeze itself does not possess acceptable heat transfer characteristics. Therefore, as water is an excellent heat conductor, it is added to the solution. The features of ethylene glycol and propylene glycol solutions along with their harmful effects are tabulated in the table 2 given below.

Table 2: Comparison on fluid properties of EG and PG

Property	Ethylene glycol	Propylene glycol	Comments
Freeze point depression	more effective	less effective	More antifreeze for PG to achieve same freeze point
Heat transfer capability	better	less	EG-more fluid circulation to transfer same amount of energy, PG-higher specific heat
Viscosity	lower	higher	PG increases major head loss (pump head)
Flammability	low	low	-
Chemical oxygen demand	lower	higher	-
Biodegrading	10-30 days	more than 20-30 days	- -
Carcinogenic	no	no	-
Toxicity	High level of acute, target kidneys	Lower level of acute	EG-never be used in drinking water or food processing system
Skin irritant	low	low	PG is used in small amounts in cosmetics

The specific heat capacity of fluids like ethylene glycol and water mixture, propylene glycol and water mixture are found out using the equation shown below.

where, C_{pmix} is specific heat capacity of fluid and water mixture

C_{pA} is specific heat capacity of fluid A

x_A is weight in % for fluid A

C_{pB} is specific heat capacity of fluid B

x_B is weight in % for fluid B

VI. SIMULATION RESULTS

Figure 4 shows the variation of solar radiation with time for the TRNSYS simulated model with water as heat transfer fluid. From the graph, it is clear that the maximum values for solar radiation (watts per square meters) and useful heat gain (watts) are being obtained during the peak hours ie., at the noon time.

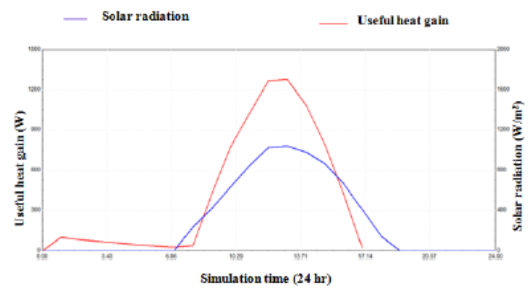

Fig. 3: Variation of collector temperature with time

VII. CONCLUSION

The maximum possible utilization of solar energy is ensured through the performance improvement of the proposed thermal system. For improving performance reflector perfection, receiving system perfection and especially high quality thermal fluid should be ensured. Basically higher fluid temperature ensures higher efficiency of the system. So such type of fluid is necessary, which can sustain at elevated temperature and hence can transfer more heat.

Based on the literature survey, it was concluded that the thermal conductivity of ethylene glycol based water mixture holds good in the area of solar water heating systems. This will be further more and more enhancing with the use of ethylene glycol based nanofluids, aluminium oxide particles etc. The outlet temperatures show a tremendous increase with the use of transparent insulation material like a plastic type absorber.

The maximum outlet temperature observed was about 65^0C with the existing system under a fair atmospheric condition. Experimentally, the efficiency was calculated and found to be almost 58 to 62% with an available solar radiation in the range of 450 to 998 W/m^2. The peak outlet temperature during simulation was around 60^0C with an inlet temperature of 20^0C.

REFERENCES

[1] J.F. Ceron , J. Perez Garcia, J.P. Solano, A. Garcia, R. Herrero Martin, "A coupled numerical model for tube on sheet at-plate solar liquid collectors Analysis and validation of the heat transfer mechanisms", Applied Energy, vol. 140, pp. 275-287, 2015.

[2] A. Zamzamian, M. KeyanpourRad, M. K.. Neyestani, M. T. J. Abad, "An experimental study on the effect of Cu-synthesized/EG nanofluid on the efficiency of flat plate solar collectors", Renewable Energy, vol. 71, pp. 658-664, 2014.

[3] J. Deng , Y. Xu, X. Yang, "A dynamic thermal performance model for flat-plate solar collectors based on the thermal inertia correction of the steady-state test method", Renewable Energy, vol. 76, pp. 679-686, 2015.

[4] L. A.Tagliafico, F. Scarpa, M. D. Rosa, "Dynamic thermal models and CFD analysis for at plate thermal solar collectors: A review", Renewable and Sustainable Energy Reviews, vol. 30, pp. 526-537, 2013.

[5] L.M. Ayompe, A. Duffy, S.J. McCormack, M. Conlon, "Validated TRNSYS model for forced circulation solar water heating systems with at plate and heat pipe evacuated tube collectors", Applied Thermal Engineering, vol. 31, pp. 1536-1542, 2011.

[6] A. Subiantoro, O. K. Tiow, "Analytical models for the computation and optimization of single and double glazing at plate solar collectors with normal and small air gap spacing", Applied Energy, vol. 134, pp. 392-399, 2013.

[7] S. Camelia, S. Dorin, "Optimum tilt angle for at plate collectors all over the World - A declination dependence formula and comparisons of three solar radiation models", Energy Conversion and Management, vol. 81, pp.133-143, 2014.

[8] P. C. Huang, C. C. Chen, H. Y. Hwang, "Thermal enhancement in a at plate solar water collector by flow pulsation and metal-foam blocks, International Journal of Heat and Mass Transfer, vol. 61, pp. 696-720, 2013.

[9] Z. Said, M.H. Sajid, M.A. Alim, R. Saidur, N.A. Rahim, "Experimental investigation of the thermophysical properties of Al_2O_3 nanofluid and its effect on a flat plate solar collector", International Communications in Heat and Mass Transfer, vol. 48, pp. 99-107, 2013.

[10]M.K. Islam, M. Hosenuzzaman, M.M. Rahim, M. Hosenuzzaman, N.A. Rahim,"Thermal Performance Improvement of Solar Thermal Power Generation", IEEE Conference on Clean Energy and Technology (CEAT), pp.158-160, 2013.

[11] C.C. Sorrell, T.C. Palmer, L.J. Bowen, A. Nakaruk, "Solar Thermal Energy Conversion and Storage: Conductive Heat Transfer Using Bulk Graphite", Proceedings of 2009 IEEE International Conference on Applied Superconductivity and Electromagnetic Devices, pp. 197-200, September 25-27, 2009.