EXPERIMENTAL ANALYSIS OF SOLAR ENHANCED WATER HEATING SYSTEM WITH ENERGY STORAGE

Kenneth Sam Mathew[*1], D.Rajesh[2], Krishnan P.M[3], Rishikrishna. R[4]

[1,2,3,4]Department of Mechanical Engineering, Panimalar Engineering College, Chennai, Tamilnadu, India
kennethmathew0275@gmail.com[*1], rajesh2energy@gmail.com[2], pmkrishnan99@gmail.com[3], rishikrishna2532@gmail.com[4]

Abstract

In the present review paper, the existing solar water heating systems are studied with their applications. Nowadays, hot water is used for domestic, commercial and industrial purposes. Various resources i.e. coal, diesel, gas etc, are used to heat water and for steam production. Solar energy is the chief alternative to replace the renewable energy sources. The solar thermal water heating system is the technology to harness the plenty amount of free available solar thermal energy. With the use of solar lens the temperature of solar water is increased. Due to raise of temperature the overall efficiency of the system is increased. The solar thermal system is designed to meet the energy demands. The size of the systems depends on availability of solar radiation, temperature requirement of customer, geographical condition and arrangement of the solar system, etc. Therefore, it is necessary to design the solar water heating system as per above parameters. The available literature is reviewed to understand the construction, arrangement, applications and sizing of the solar thermal system.

IndexTerms: Solar energy collector, Active & Passive system, Heat transfer fluid, Efficiency, Solar lens.

I. Introduction

Now a days cost of fuel, pollution problem and global warming problems we are using solar based application. The sun has been a powerful presence and force throughout the history of human existence on earth. It has been regarded by many cultures as a god of one form or another, and understood by most to be the ultimate source of life on this planet. It has also been intentionally exploited by many clever means over the centuries, in order to better utilize this life giving energy. As far as renewable energy sources go, the sun represents the best and most stable we have. It is infinite with respect to all practical timescales, immensely powerful, understood and predictable in its overall trends and patterns, and for the foreseeable future beyond anthropogenic effects. In short, the perfect energy source; but it is not without difficulties. Solar heater is a device which is used for heating the water, for producing the steam for domestic and industrial purposes by utilizing the solar energy. Modern systems designed for capturing the suns energy and transferring it to water, either for immediate use or as a storage medium, have been studied and put to use since the 1970's, when they were first used for pool heating in California. Continued research and innovation has resulted in products feasible in much colder and less sunny climates today (Bennet T, 2007).

Solar technologies are commonly grouped into three major categories, generally differing in the ways they collect, store and use energy. Passive solar systems involve direct utilization of the sun's radiation as light or possibly heat. Examples include energy efficient windows, skylights, greenhouses, and hybrid lighting fixtures, which use fiber optic cable to transmit sunlight into interior rooms. Next are solar thermal, which collect and use the sun's energy as heat. They are different from direct heating in their ability to store thermal energy for later use. Modern applications include domestic and industrial water heating, air and space heating, radiant slab heating, and even the operation of heat pumps and sterling engines (Bennet T, 2007). The energy and the temperature level required to be supplied to carry out everyday tasks will vary. Generally, a domestic hot water supply at temperatures in the range of 50 to 60 degree Celsius is considered to be acceptable (SOPAC Technical Report, 1999).

Solar water heating systems are classified depending on how the domestic water is heated or how the heat transfer fluid (water or antifreeze fluid) flows through the collector. Based on this, there are basically two types of solar water heating systems, namely; Direct (open loop) and Indirect (closed loop) water heating systems which can either be passive or active (Roger Taylor, 2006). Direct systems heat up water as it flows directly in the collector whiles indirect systems heat up water through a heat exchanger employed between the collector and the hot water storage tank. Active systems use electrically driven pumps to circulate water or another heat absorbing fluid, and sometimes use electrically operated valves for freeze protection. Passive systems have no electrical pumps. They rely upon convection to circulate hot water through the collector and storage tank (Duffie J.A and Beckman W.A, 1991).

1.1 PASSIVE SYSTEMS

In passive systems, hot water is either stored in the collector itself or is transferred to a storage tank located above the collectors by means of a thermosyphon. Passive systems do not employ pumps to circulate water or collector fluid. Two types of passive systems; thermosyphon systems and integral collector storage systems are briefly described below.

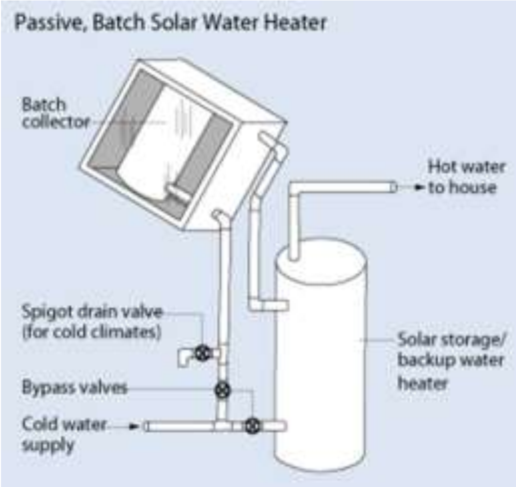

Fig.1 Passive system

1.2 THERMOSYPHON SYSTEM

A typical thermosyphon system is indicated in Figure.2 As the sun shines on the collector, the water inside the collector flow-tubes is heated. As it heats up, this water expands slightly and becomes lighter than the cold water in the solar storage tank mounted above the collector. It also includes isolation valves, which allow the solar system to be manually drained in case of freezing conditions, or to be bypassed completely (Harrison J, Tiedeman T, 1997).

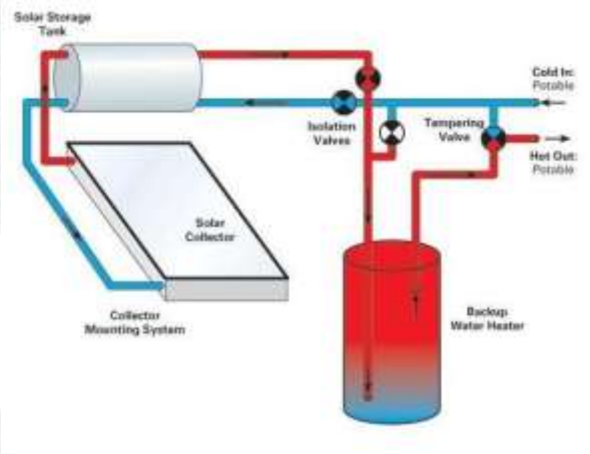

Fig.2 Thermosyphon system

1.3 INTEGRAL COLLECTOR STORAGE (ICS) SYSTEM:

In integral collector storage (ICS) or batch systems, water is heated directly by the sun and the storage tank serves as the solar collector. Batch water heaters are almost always passive systems in which hot water is delivered from the solar heated tank to a backup tank or the point of use by the water pressure in the house. A freeze protection valve installed in the top plumbing near the collector opens to allow relatively warm water to flow through the collector to prevent freezing (Harrison J, Tiedeman T, 1997).

1.4 DIRECT ACTIVE SYSTEMS:

Direct (Open Loop) Active Systems are similar to thermosyphon systems in that they are direct systems that use a solar collector separate from the storage tank. The difference with direct active systems is that they use an electric pump to circulate water from the storage tank to the collector, and back to the storage tank. These systems always require a check valve to prevent reverse thermosyphoning at night (Harrison J, Tiedeman T, 1997).

1.5 INDIRECT ACTIVE SYSTEMS:

Glycol antifreeze systems are active, indirect systems with a heat exchanger. Freeze resistant propylene glycol is circulated through the solar collector(s) and heat exchanger, while household water is circulated from the storage tank through the heat exchanger. The household water is heated inside the heat exchanger and then stored inside the tank until needed. Active system whether direct or indirect can be easily retrofitted to already existing water heaters because the storage tank can be placed at any place unlike thermosyphon systems which require a storage tank always above the collector (Harrison J, Tiedeman T, 1997).

1.6 SOLAR ENERGY COLLECTORS:

Solar energy collectors work in a similar manner to heat exchangers in that they transform one form of energy, solar radiation to another in the form of hot water. The component that allows this exchange of energy is a solar collector. The solar collector absorbs radiation and converts it into heat. The collectors will then remain fixed to this tilt angle all year round and for the lifespan of the system. In a tracking position the collector's inclination will change as the sun's angle in the sky changes hour to hour and day to day in order to receive the optimum amount of radiation (Kalogirou, S.A, 2004).

.1.7 FLAT PLATE COLLECTORS

Flat plate collectors currently are currently manufactured in two different forms. Firstly collectors using liquid with no glazing are manufactured using a black absorbent polymer coating without an insulated backing. The liquid tubes are sometimes welded to the absorbing plate, or they can be manufactured as part of the plate. These tubes are then connected at both ends by large diameter header tubes. These collectors also utilize a transparent cover to reduce the convection losses from the absorber plate by trapping a layer of stagnant air between the absorber plate and the glass (Kalogirou, S.A, 2004).

1.8 PARABOLIC CONCENTRATING COLLECTORS:

Parabolic concentrators shown below in Fig. 6 are rarely used in the European climate but they are very useful for high temperature applications from 100-200°C, where the efficiency of the collector outperforms that of vacuum tube collectors. In very hot countries where solar cooling systems are used, temperatures levels of 150°C or higher are easily achievable.

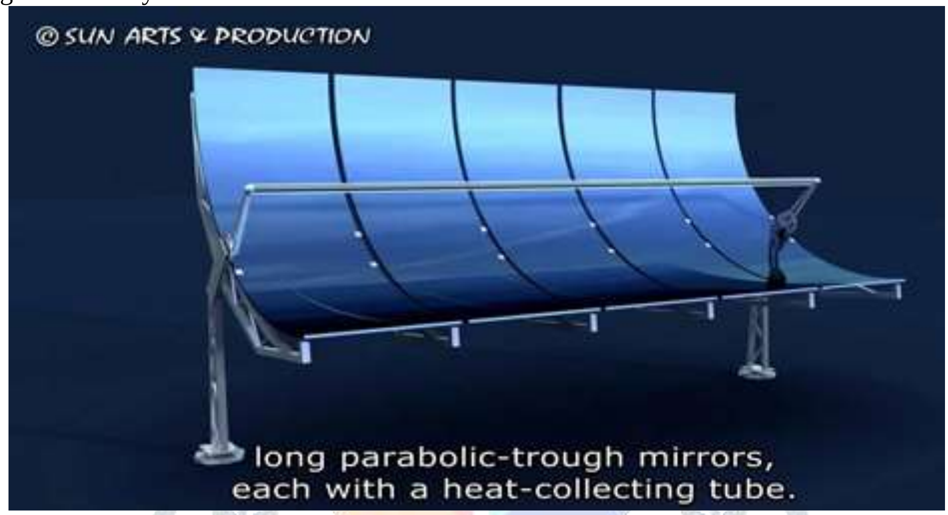

Fig. 3 Parabolic Concentrating collectors

1.9 EVACUATED TUBE COLLECTORS

Evacuated tube collectors are in most cases more efficient than most flat plate collectors, but as a result of this increased efficiency are also more costly due to their complex design. Due to the absorber being mounted in an evacuated and pressure-proof glass tube, conductive and convective losses are minimized increasing efficiency. Evacuated tubes work efficiently at low radiation levels with high absorber temperatures and can provide higher output temperatures than flat.

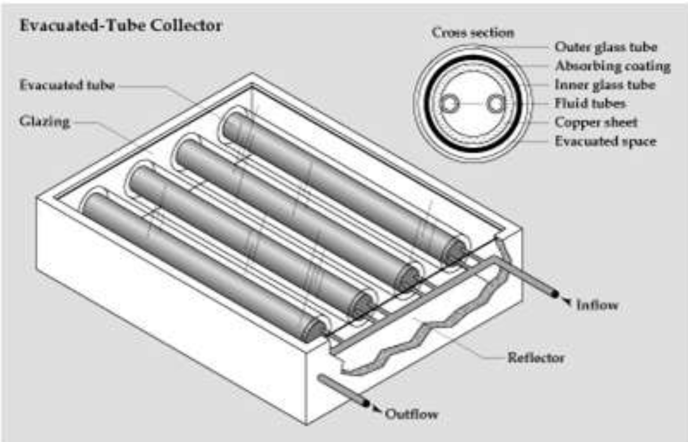

Fig.4 Evacuated tube collector

1.10 HEAT PIPE COLLECTOR

The second type of collector shown in Fig. 5 utilizes heat pipes inside vacuum sealed glass tubes with a reflector also used to further increase the ability to absorb radiation. This effect tends to give Evacuated Tube Collectors an advantage over Flat Plate Collectors in day-long performance (Kalogirou, S.A, 2004).

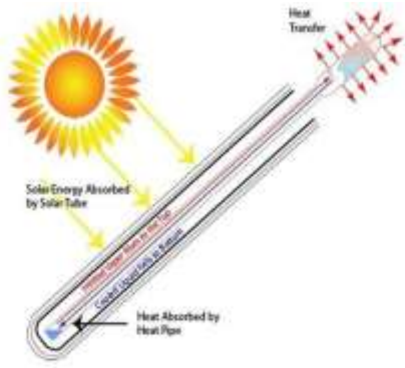

Fig.5 Heat Pipe Collectors

There are two main types of solar water heater systems: passive and active. Active systems integrate pumps and rotary elements and are therefore very expensive. Passive systems use natural water circulation, gravity, and/or pressurized water systems. Passive solar water heater systems are much less expensive than their active counterparts and are easier to maintain and repair. (Soteris A. Kalogirou, 2004) presents a survey of the various types of solar thermal collectors and applications. All the solar systems which utilize the solar energy and its application depends upon the solar collector such as flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors which are used in these system. The solar collectors are used for domestic, commercial and industrial purposes. These include solar water heating, which comprise thermosyphon, integrated collector storage, direct and indirect systems and air systems, space heating and cooling, which comprise, space heating and service hot water, air and water systems and heat pumps, refrigeration, industrial process heat, which comprise air and water systems and steam generation systems, desalination, thermal power systems, which comprise the parabolic trough, power tower and dish systems, solar furnaces, and chemistry applications.

(K. Sivakumar) represent the design of Elliptical heat pipe flat plat solar collector and tested with a collector tilt angle of 11° to the horizontal. Experimental analysis of the effect of condenser length/evaporator length (Lc/Le) ratio of the heat pipe, different cooling water mass flow rates and different inlet cooling water temperature were analyses. Five numbers of elliptical heat pipes with stainless steel wick has been fabricated and used as transport tubes in the collector. Copper tube has been used as container material with methanol as working fluid of the heat pipe. These heat pipes were fixed to the absorber plate of the solar collector and the performance of elliptical heat pipe solar collector has been studied and results were compared. It has been found from the experimental trials that the elliptical heat pipe solar collector having Lc/Le ratio of 0.1764 achieved higher instantaneous efficiency.

(B Sivaraman and N Krishna Mohan, 2005) represents experiments on the effect of L/d ratio of heat pipe on heat pipe solar collector. Two solar collectors with different L/d ratiohave been designed and fabricated. A heat pipe with stainless steel wick replaces the transport tubes of the solar collector. Copper and stainless steel were used as container and wick material and methanol was used as working fluid of heat pipe. Heat pipes are designed to have heat transport factor of around 194 W and 260 W of thermal energy. Experiments were conducted during summer season with a collector tilt angle of 13o to the horizontal. The collector with L/dratio of 52.63 was found to be more efficient than the collector with L/dratio of 58.82. This improved efficiency is due to increase in heat transport factor of heat pipe, which increase with decrease in L/dratio.

(Hussain Al-Madani, 2006) studied a batch solar water heater in Bahrain consisting of an evacuated, cylindrical glass tube. Water runs through copper coils, which act as collectors, located within the glass tube. Side-by-side testing of prototypes resulted in a maximum temperature difference between the inlet and outlet of the cylindrical batch system of 27.8°C with a maximum efficiency of 41.8%. Al- Madani determined the cost of manufacturing the cylindrical batch system to be $318, slightly less expensive than typical flat plate collectors of $358. (Dharamvir Mangal, Devander Kumar Lamba, Tarun Gupta, Kiran Jhamb, 2010) presents acknowledgement to one of the latest solar water heater which is evacuated solar water heater based on a thermo siphon principle used for heating water for domestic purposes in household by utilizing solar radiations. As the air is evacuated from the solar tube to form a vacuum, this greatly reduces conductive and convective heat loss from the interior of tube. As a result wind and cold temperature have less effect on the efficiency of evacuated solar water heater. Result of less heat loss is fast heating of water as compared to flat plate solar water heater/collector. This paper introduced the benefits of evacuated tube solar water heater. In India, it is still new model of solar water heater which can be used in our household to face the challenge of climate change, global warming, energy crisis etc. When comparing peak efficiency levels it may seem that there is little difference between flat plate and evacuated tubes, in fact flat plate may actually be higher, but this is during minimal heat loss conditions. When averaged over a year evacuated tube collector have a clear advantage.

(K. S. Ong and W. L. Tong, 2011) presents a System performance of solar water heaters depend upon collector and storage tank design and sizing and weather conditions (solar radiation intensity and ambient temperature). Short and long term performance tests were conducted on natural and force convection U- tube and heat pipe evacuated tube solar water heaters. The test procedures employed enabled comparative performances of solar water heating systems to be made even when they were tested at different times of the year. The experimental results showed that the natural convection heat pipe system was capable of heating water to 100˚C and performed best among the systems tested.

II. MATERIALS AND METHODS

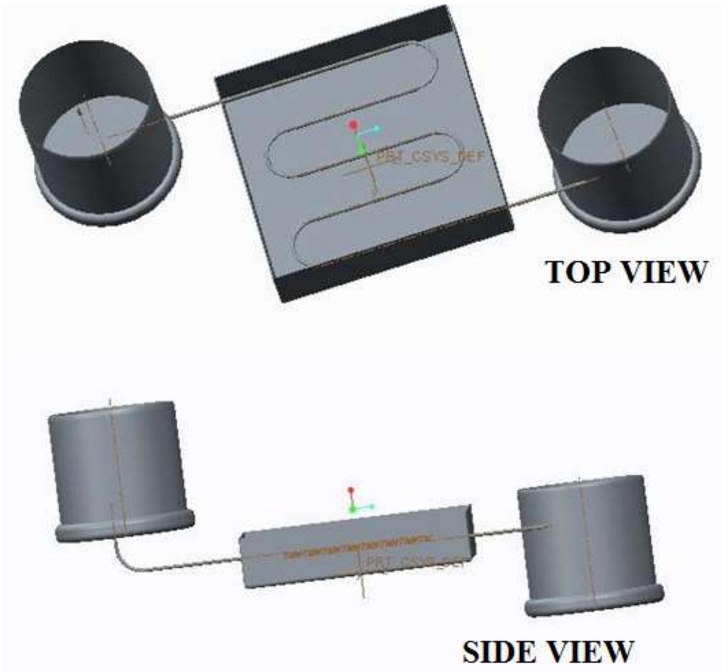

Fig.6 Top and Side views of the System (3D model)

2.1 SHEET METAL

Sheet metal is metal formed by an industrial process into thin, flat pieces. Sheet metal is one of the fundamental forms used in metal working and it can be cut and bent into a variety of shapes. Countless everyday objects are fabricated from sheet metal. Thicknesses can vary significantly; extremely thin sheets are considered foil or leaf, and pieces thicker than 6 mm (0.25 in) are considered plate.

2.2 BLACK PAINT

Black is the darkest colour, the result of the absence or complete absorption of visible light. It is an achromatic colour, literally a colour without hue, likes white (its opposite) and grey. It is often used symbolically or figuratively to represents darkness while white represents light. The black body is the perfect absorber of light, but, by a thermodynamic rule, it is also the best emitter.

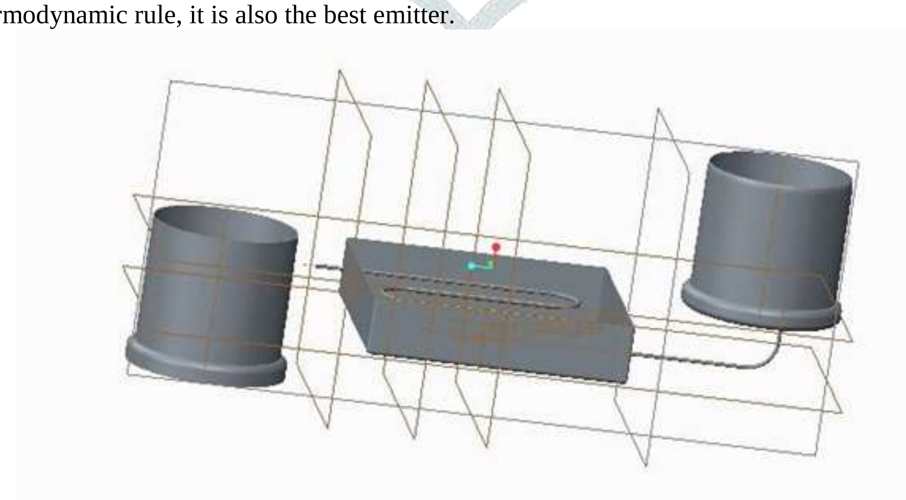

Fig.7 3D model of final view of the system

-

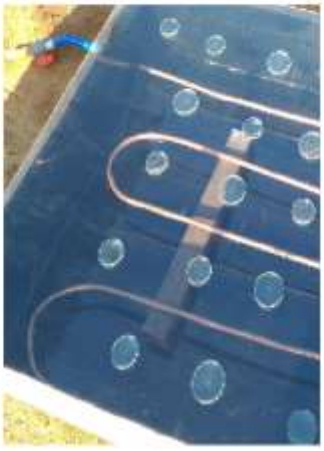

Fig.8 Copper tube and Lens arrangement

2.3 SOLAR LENS

A burning glass or burning lens is a large convex lens that can concentrate the sun's rays onto a small area, heating up the area and thus resulting in ignition of the exposed surface. Burning mirrors achieve a similar effect by using reflecting surfaces to focus the light. They were used in 18th-century chemical studies for burning materials in closed glass vessels where the products of combustion could be trapped for analysis. The burning glass was a useful contrivance in the days before electrical ignition was easily achieved. The diameters of lens are 50mm, 60mm and 75mm and it should be transparent in nature.

2.4 GLASS

Glass is a non-crystalline amorphous solid that is often transparent and has widespread practical, technological, and decorative usage in, for example, window panes, tableware, and optoelectronics. The most familiar, and historically the oldest, types of glass are "silicate glasses" based on the chemical compound silica (silicon dioxide, or quartz), the primary constituent of sand. The term glass, in popular usage, is often used to refer only to this type of material, which is familiar from use as window glass and in glass bottles. Of the many silica-based glasses that exist, ordinary glazing and container glass is formed from a specific type called soda-lime glass, composed of approximately 75% silicon dioxide(SiO_2), sodium oxide (Na_2O) from sodium carbonate (Na_2CO_3), calcium oxide, also called lime (CaO), and several minor additives.

2.5 COPPER TUBE

Heat exchangers are devices that transfer heat in order to achieve desired heating or cooling. An important design aspect of heat exchanger technology is the selection of appropriate materials to conduct and transfer heat fast and efficiently.

Fig.9 Copper tube

III. EXPERIMENTAL SETUP AND PROCEDURE

Oxy-fuel welding (commonly called oxyacetylene welding, oxy welding, or gas welding in the U.S.) and oxy-fuel cutting are processes that use fuel gases and oxygen to weld and cut metals, respectively. French engineers Edmond Fouché and Charles Picard became the first to develop oxygen-acetylene welding in 1903. Pure oxygen, instead of air, is used to increase the flame temperature to allow localized melting of the work piece material (e.g. steel) in a room environment.

IV. RESULTS AND DISCUSSION

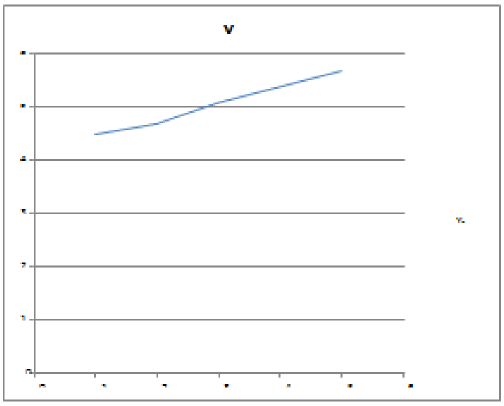

Fig.10 Temperature Vs Time with Lens

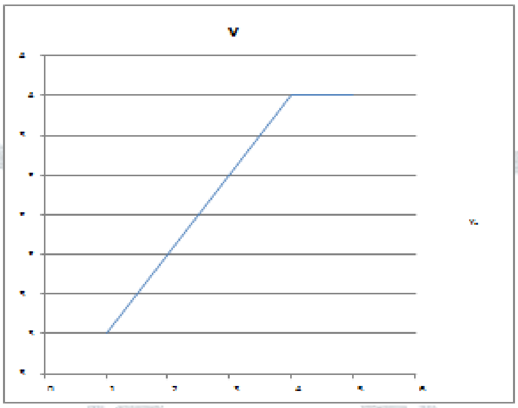

Fig.11 Temperature Vs Time for without Lens

Sheet metal cutting is a major classification for many different press working operations. Cutting operations involve the separation of the metal of the sheet in certain areas. This separation is caused by shearing forces acting on the metal through the edges of the punch and die. Press working, a term referencing sheet metal operations in general, involves the working of a sheet between two die. In press working, the upper die is called a punch. Sheet and plate generally refers to rolled metal with a high surface area to volume ratio. The difference is that sheet metal is under 1/4 inch (6mm) in thickness, while plate metal is thicker. Most of the sheet metal cutting processes discussed can be performed on both sheet and plate metal, although for many sheet metal operations difficulties will arise with increasing plate thickness. Usually "sheet" and "sheet metal" is also referencing plate.

V. CONCLUSION

Renewable energy research has become increasingly important since the signing of the Kyoto Protocol. Solar water heating (SWH) is one of the most effective technologies to convert solar energy into thermal energy and is considered to be a developed and commercialized technology. However, there exist opportunities to further improve the system performance to increase its reliability and efficiency. A concise review primarily on the design features and related technical advancements of the SWH systems in terms of both energy efficiency and cost effectiveness has been presented. Several solar water heating designs have been introduced in the market and are more commonly utilized in the tropical regions of developing countries. Recent developments in heat pipe based solar collector technology exhibit a promising design to utilize solar energy as a reliable heating source for water heating applications in solar adverse regions.

Heat pipe based solar water heating is influenced by many factors including the nature of the refrigerant, due to the environmental concerns. Without lens the performance will be lower. With lens the efficiency is high compared to conventional method explained experimentally and proved.

References

[1] Acknowledgement of Evacuated Tube Solar Water Heater Over Flat Plate Solar Water
[2] Al-Madani, Hussain (2006). ―The performance of a cylindrical solar water heater.‖ Renewable Energy Vol. 31, pp 1751-1763.
[3] Bennet T. (2007). ―Solar thermal water heating, a simplified modeling approach‖.
[4] Charles Smith (1995). ―History of Solar Energy Revisiting, Past Solar Power Technology Review‖.
[5] Data-Annual Report (2001). ―International Energy Agency of Solar Heating and Cooling rogramme‖.
[6] Dharamvir Mangal, Devander Kumar Lamba, Tarun Gupta, Kiran Jhamb (2010).
[7] Duffie J.A and Beckman W.A. (1991). ―Solar Engineering of Thermal Processes‖, Second Edition, Wiley-Interscience, New York.
[8] Eicker, U (2003). ―Solar Technologies for Buildings‖ West Sussex:Wiley.
[9] Harrison J, Tiedeman T (1997). ―Solar Water Heating Options in Florida‖, Florida Solar Energy Centre. Rpt: FSEC-EN-9-85.

[10] Heater‖ International Journal of Engineering (IJE), Vol. 4, pp 279-284.
[11] Jump up^ Gulland, John. "Heating water with a wood stove". woodheat.org.
[12] Wood Heat Organization Inc. Retrieved 29 March 2012.
[13] Jump up^ Israeli Section of the International Solar Energy Society, edited by Gershon Grossman, Faculty of Mechanical Energy, Techno, Haifa; Final draft.
[14] Jump up^ Lane, T. & Olson, K. (2002). "Solar hot water for cold climates: Part II – Drain back systems". Home power Magazine. 86: 62–70.
[15] .K. S. Ong, W. L. Tong, Sheriwati, K. Low (2011). ―System Performance of Heat Pipe Solar Water Heaters‖ 10th IHPS, Taipei, Taiwan, pp 261-266. Ret screen (2012).
[16] K. Sivakumar, N. Krishna Mohan and B. Sivaraman (2005) ―Performance analysis of elliptical heat pipe solar collector‖ Indian Journal of Science and Technology.
[17] Ken Butti, John Perlin (1980) ―A Golden Thread,‖ Van Nostrand Reinhold Company.
[18] Marken. C (2009). "Solar collectors: Behind the glass". HomePower. 133: 70–76.
[19] Roger Taylor (2006). ―Solar thermal technology and applications‖, NREL, pp 7.
[20] Sivaraman B and N Krishna Mohan (2005). ―Experimental analysis of heat pipe solar collector with different L/di ratio of heat pipe‖, Journal of Scientific & Industrial Research, Vol. 64, pp 698-701.
[21] SOPAC Technical Report 297 (1999). ―Energy Unit, South Pacific Applied Geosciences Commission‖.
[22] Soteris A. Kalogirou (2004). ―Solar thermal collectors and applications.‖, Progress in Energy and Combustion Science 30, pp 231–295.
[23] Dinesh Babu Munuswamy, Yuvarajan Devarajan, M. Naresh Babu, Sathiyamoorthi Ramalingam. Experimental investigation on lowering the environmental hazards and improving the performance patterns of solar flat plate collectors by employing the internal longitudinal fins and nano additives. Environmental Science and Pollution Research, (2020) DOI: https://doi.org/10.1007/s11356-020-10311-3
[24] R.Ravisankar, V.S.K. Venkatachalapathy, K. Velmurugan, N. Alagumurthi, R.Sathiyamoorthi, Comparative assessment on heat transfer characteristics of a Truck Radiator using various nano-additives, Aut Aut Research Journal, Vol, XI (X), pp. 1-14 (2020), Aut publications