ANALYSIS OF AN ACTIVE AND PASSIVE SOLAR WATER HEATING SYSTEM

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ABSTRACT

An active solar water heating system requires an external source such as pump or motor. It uses sun's energy which is free of cost to heat water and transfer heat to the fluid in collector. In this study less than 1 m^2 area of solar collector was fabricated by using indigenous materials. The temperature in moderate weather by this collector was observed as 76°C with inlet temperature of 25°C. This collector can be used for many applications. It was also observed that the designed solar water heater in this study was quite suitable for domestic sector. The overall efficiency of this system was found as 26.28% as compared to 23% (with tracking system) and 19% (with non-tracking system) observed by other researchers [1]. In this study a passive solar water heating system was also fabricated, by using indigenous and locally available materials. The maximum temperature achieved by this system in moderate weather was 90.5°C with the inlet temperature of 28.1°C. The overall efficiency of this system was found as 31.07% as compared to 19% which is higher than the system studied by other researchers

Keywords: Solar collector, heating system, indigenous material, weather applications, domestic sector, efficiency.

1-Introduction

The geographical location, topography and climate conditions of Pakistan make it an ideal candidate for exploiting solar energy. On average, almost all parts of the country

have more than 300 sunshine days a year. Pakistan ranks amongst the richest of the world in terms of solar energy potential giving an annual irradiance of 1900-2200kWh/m².The available solar radiation make the climatic conditions of Pakistan highly favorable for solar energy applications such as photovoltaic, solar water heating, solar desalination and solar crop drying.[2]

Using the sun's energy to heat water is not a new idea. More than one hundred years ago, black painted water tanks were used as simple solar heaters in number of countries. Harnessing the sun as a clean and renewable source of energy has proven to be a challenge over the centuries and in modern times has fallen off in favor of other technologies which are easier to commercialize and capitalize on.

The sun is an energy source available to everyone, an energy source that can be used simply, and inexpensively to reduce developing and undeveloped countries dependence on imported fuels. The sun gives us energy in two forms; light and heat. For many years, people have been using the sun's energy to make their homes brighter and warmer. Today we use special equipment and specially designed homes to capture energy for lighting and heating. Solar energy is inexhaustible and available in all the countries of world [3].

Solar energy can be used either directly or indirectly. In direct system solar energy can directly be converted into electricity by the use of photovoltaic cell. Solar energy can also be used indirectly for heating purpose by using solar collectors. Solar water heating is a very simple and efficient way to grab energy from the sun and use it. Solar water heating makes use of sun's energy to heat water for household and industrial use as well.

Due to energy crisis, there has been effort to develop new energy sources as a way to solve energy problems and at of there solar energy has received special attention. Solar energy can be converted into thermal energy with the help of solar collectors and receivers known as solar thermal devices. Solar thermal devices are used in solar water heaters, air heaters, solar cookers and solar dryers for domestic and industrial applications.

Some of the main benefits of active solar are;

- It can be used on your existing home regardless of its orientation or design.
- It produces more solar thermal energy for your home than passive solar energy.
- The heat energy produced can easily be used throughout your home.
- It reduces your electricity requirements.

2. DESCRIPTION

Solar water heaters also called solar domestic hot water systems can be a cost-effective way to generate hot water for your home. They can be used in any climate, and the fuel they use sunshine is free. There are two types of solar water heating systems [4,5]

1- Active solar water heating system

2- Passive solar water heating system

An active system is one where the exchange fluid is actively pumped from the storage tank through the collectors and back into the tank. An electronic controller, a small pump, valves and other components are needed for proper operation and future ability to service. The system works as; first the fluid is pumped up into the rooftop collectors where it is heated. It is then sent through heat exchanger typically attached to or near storage tank.There are two types of active solar water heating systems, indirect systems and direct systems;

- **Indirect systems** use a heat transfer fluid which is usually a water-antifreeze mixture. After the heat-transfer fluid is heated in the solar collectors, it is pumped to a storage tank where a heat-exchanger transfers the heat from the fluid to the household water. This type of system is also known as a **"closed-loop" system**.
- **Direct systems** heat the actual household water in the solar collectors. Once heated, the water is pumped to a storage tank and then piped to faucets for use in your home. Since this system uses regular household water in the collectors, it should only be used in areas that do not experience freezing conditions. This type of system is also known as an **"open-loop" system** [4]

Passive solar technologies are means of using sunlight for useful energy without use of active mechanical systems as in active solar water heater. Passive solar heating relies on gravity or natural convection to circulate heated household water through the system without any pumps. Passive systems are not efficient as active system but less expensive than active systems.
Solar collector used for water heating applications:

2.1-Flat-plate collector

Flat-plate collectors are the most common collectors for water heating (liquid type) and for space heating installations (air types). In simple words a flat-plate collector is an insulated metal box with either glass or plastic cover, which is called glazing as shown in Fig.1. It is very easy to explain the working phenomenon of flat-plate collector. The sunlight passes through the glazing and strikes the absorber plate. The absorber plate then starts to heat up concentrating solar radiation into heat energy. The heat is then transferred to liquid passing through the flow tubes [4,6].
Most solar collectors are boxes, frames, or rooms that contain these parts:
(1) Clear covers that let in solar energy;
(2) Dark surfaces inside, called absorber plates, that soaks up heat;
(3) Insulation materials to prevent heat from escaping; and
(4) Vents or pipes that carry the heated air or liquid from inside the collector to where it can be used.

Covers

Many clear materials can be used as covers for solar collectors, but glass is the most common material. Glass can be made quickly and easily. The special glass used in solar collectors resists breaking and scratching. When sunlight passes through glass and hits a

surface inside a solar collector, it changes into heat. Although glass allows sunlight to pass through, it also traps the heat produced inside the collector.

Absorbers

The heat produced inside a solar collector is soaked up by metal sheets or containers filled with water, rocks, or bricks that have been painted black or another dark color. These dark-colored objects that soak up heat are called absorbers. Without absorbers, solar heating systems would not produce enough heat to warm rooms inside your house.

Insulation

Heat always tries to move from a hotter object to a colder one. Insulation is what prevents or slows down the movement of heat. Because insulation prevents the heat inside a solar collector from moving to the outside where the temperature is lower, it is an important part of any solar collector.

Vents and Pipes

When a solar collector is working properly, the heat that it produces moves from the collector to an area where that heat can be used. If the collector's job is to heat air, then vents, ducts (air tubes),and fans carry the heated air from the collector to an other part of the house. If the collector's job is to heat water, then pipes, tubes, and pumps move water from the collector to water heating or space heating equipment.

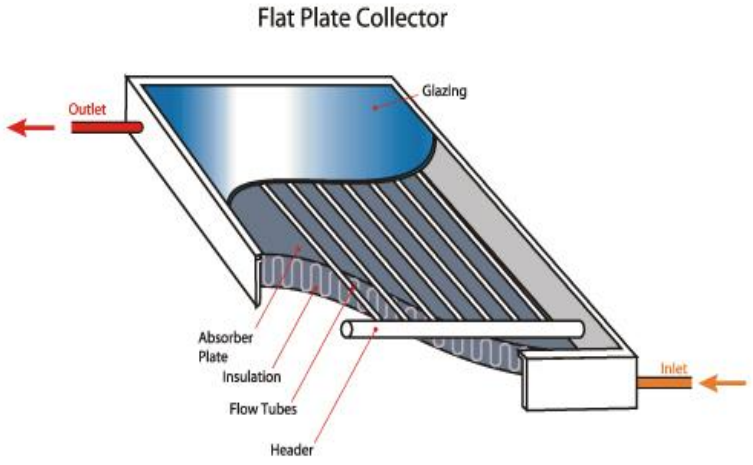

Figure 1. The Flat Plate Collector

3. MAIN COMPONENTS OF ACTIVE SOLAR WATER HEATING SYSTEM

It generally consists of following components;

1- A solar collector
2- A storage tank
3- Heat exchanger fluid in indirect systems
4- Pump

If we want to utilize solar energy for heating purpose it requires solar collector to generate heat. Solar collectors are the hearts of most solar systems. A solar collector designed to collect heat by absorbing sunlight. Solar collectors are able to harvest the suns energy in the form of heat.

A solar water tank is an insulated water storage tank. Cold water that is used to go directly to conventional water heater enters the solar tank and solar-heated water exits.

Heat exchangers are used in regions that experience temperatures less than freezing. Heat exchangers themselves are built into a closed loop system and transfer the heat gathered in the collector to the house's hot water supply. They enable the transfer of heat from one fluid to another without the two mixing. The main advantage of using heat exchanger is to protect the system against freezing, and as one option to supplement another source of water heating.

Pumps are used in active systems, but are not required in batch or thermo-siphon systems. They circulate water or antifreeze between the solar collector and the storage tank. The pump used in this study is shown in Fig.2

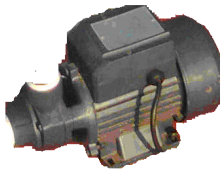

Figure 2. Pump

4-MATERIALS FOR FABRICATION OF AN ACTIVE SOLAR WATER HEATER

Following materials have been used for fabrication of active solar water heating system.

1. **Copper tubes**, these tubes used for making the manifold of riser and header pipes for water carriage in the collector. The copper tube of dia (0.0127m and 0.0254m) was used respectively.
2. **Aluminum foil**, it was used for making the absorber plate and as insulating material from the outside of collector.
3. **Glass wool**, the glass wool was used for insulating collector back surface and storage tank.
4. **Wood**, wood was used for making the collector box and stool for tanks.
5. **Poly glass** was used for glazing of collector usually of thickness of 4mm & 5mm.
6. **Silicon paste** was used for sealing the collector with glazing to avoid any leakage.
7. **Iron Angles** were used for making stand frame for solar collector.
8. **Pump**, Centrifugal type pump have been used for circulating the water in the collector.
9. **Iron sheet**, was used for fabricating the storage tank.

10. **Copper rods**, was used for welding of copper tubes.
11. **Valves** were used for proper flow control.
12. **Air vent**, was used for proper ventilation.
13. **Red and light blue paint**, were used for painting the supporting stand and storage tank.

The whole system was fabricated in mechanical engineering workshop of QUEST Nawabshah.

4.1-Fabrication of the Active Solar Water Heater

First of all a wooden box as shown in Fig.3 was made for collector it is the most important part.

Figure 3. Wooden Box used in the study

Wooden box was insulated with glass wool and after that it was insulated with aluminum foil. Solar radiation falling on the absorber plate was heating the metal plate and some of heat was transferred to water flowing through tubes.

The copper tubes were joined by welding. Copper rod was used for welding the rods. The arrangement of copper tubes as a carrier of fluid is shown in Fig.4

Figure 4. Copper tube Structure of Flat Plate Collector

Double glazing was used as to protect the loss of heat. The thickness of inner glass was kept 3mm and outer glass was 5mm. Double glazing is better than single glazing because of more heat is lost by single glazing. Double glazing results more absorption of heat at the inner side. Glass is effective in reducing radiated heat loss because it is opaque to the longer wavelength infra-red radiation and re-emitted by the hot absorber plate. The collector with frame is shown in Fig.5. In this way the collector was fabricated.

Figure 5. Collector with frame

A tank was used in active solar water heating system called hot water storage tank (shown in Fig.6) to store hot water.

Figure 6.Solar storage tank

After completing the fabrication of collector and tanks assembly of different components was done and the pump was fitted to circulate the water towards the collector. Following figure 7 shows the fitting of pump.

Figure 7. Fitting of pump

In this way whole system was completed and installed after that the performance of the system was analyzed.

5. EXPERIMENTAL SET- UP

Water gets heated in the risers of the flat-plate collector and its density will decrease the lighter density water move up and stored in the hot water storage tank. Higher density water from the bottom of tank again enters the flat-plate collector gets heated and move

up and again store in solar storage tank and vice-versa. Hot water can be drawn from the solar storage tank for further application [7,8,9].

6. RESULTS& DISCUSSIONS

The temperature of inlet and outlet water was measured by using digital thermo meter. Solar radiation and relative humidity was measured by using solari meter and humidity meter respectively. The procedure used for measurement is shown in Fig.8, however the data collected after interval half an hour is shown in Table 1.

Figure 8. While getting results

Table 1. The collected data of various parameters

Time	**Atm.T^{o}C**	**Inlet T_1^{o}C**	**OutletT2 ^{o}C**	**Diff: ΔT ^{o}C**	**H. Avg.%RH**	**S.Rad w/m^2**
11:00 am to 11:30 am	32.6	30.9	57.3	26.4	26.4	745.9
12:00 noon to 12:45 pm	33.5	33.5	63.9	30.4	30.4	756.1
01:00 pm to 02:00 pm	33.7	34	76.1	42.1	42.1	795

This can be seen from figure 9 that temperature is increased with the increase of solar radiation, which is obvious. Maximum temperature was attend as 76.1^{0}C

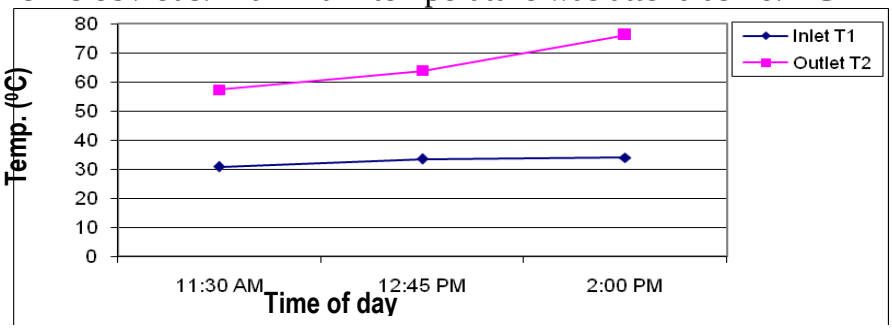

Figure 9.The Comparison of temperature and time

7. EXPERIMENTAL ANALYSIS OF FLAT- PLATE COLLECTOR

Average solar radiation received by earth in terms of energy R = 795W/m^2/hour]
Solar radiation received by earth in 7 hours in terms of energy R = 795×7W/m^2/day

$R = 5565Wh/m^2$
$R = 5565\times3600WSec/m^2$
$R = 20034000WSec/m^2$
Area of flat-plate collector = $0.82m^2$
T_1= temperature of water at inlet in ^0C
T_2 = temperature of water at outlet in ^0C
M = mass of water taken in storage tank 20Kg
Specific heat of water = 4.182KJ/KgK
To determine efficiency we know that
η= output of the collector/input radiation
$\eta=m\times Cp\times (t_2-t_1)/R\times A$…… (1)
So therefore,
$Q = m\times Cp\times (t_2-t_1)$
$Q = 20\times4.182\times (76-25)$
$Q = 4264620Joules$
And $R\times A$
$R_1 = R\times A$
$R_1= 20034000\times0.81$
$R_1 = 16227540Joules$
Putting all values in equation no 01
η= 4264620/16227540
η= 26.28%

8. DISCUSSION

First of all inlet and temperature of hot water in storage tank were tabulated on hourly basis with the help of digital thermometer. Humidity was measured with help of humidity meter. At morning time the humidity was 26.6%. Solar radiation was measured with the use of solari meter. Solar radiation varies with respect to time and clear sunny days. When there was full sunny day solar radiation was more and more temperature was achieved. Atmospheric temperature was also noted. It was observed that outlet temperature of water was attained up to 76.1^0C as compared to the inlet water temperature of 25^0C.

9. CONCLUSION

In this study solar energy was used to heat water through sun's energy. Flat plate collector was fabricated in Mechanical Engineering Workshop. Collector absorbs the heat from sun and rises the temperature of collector.
If there will be more solar radiation than more will be temperature of water. Different readings have been taken and noted. Following parameters have been measured;

- Solar radiation.

- Temperature (inlet and outlet)
- Humidity.
- Atmospheric temperature

Maximum temperature that has been measured was up to76.1^0C depending upon the weather condition, as compared to water inlet temperature of 25^0C. It was concluded that active solar water heating is suitable for domestic sector and hoped that solar water heater as a source of renewable energy will have positive impact in reducing electrical energy consumption. It was also concluded that the renewable source which is abundantly available in Pakistan is solar energy-showing an annual irradiance of around 1900-2200kWh/m^2. Such high level of available solar energy can be effectively capitalized both for electric and solar thermal applications in order to fulfill the energy deficit in Pakistan.

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