Low-Cost Solar Water Heater

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***Abstract*— This paper presents an overview of the use of solar energy for domestic water heating purposes. In addition, the results of a preliminary research to develop a low cost system for heating water using solar energy, a green energy source is also included. For the system presented herewith, the absorption of sunrays radiated heat is by means of a thermal collector. The heating and recirculation process are automatically controlled using sensors, actuators, and a Programmable Logic Controller (PLC). The results obtained indicates that the system presented have the potential to supply enough hot water to meet the requirements for domestic consumption.**

Keywords-component; Green Energy, Solar, Thermal Radiation, Water Heater

I. Introduction

As household-income rises in countries such as China, Thailand and Malaysia, domestic energy consumption also increases. The use of air-conditioning, hot water heater etc causes an ever increasing use of energy. In most countries, the main energy source used is from traditional non renewable energy sources such as coal, oil and gas.

The world's oil and gas supply is now depleting at a very fast rate causing oil's prices to increase tremendously especially in the last few decades. In addition, the use of fossil fuels have created serious environmental problems and pollution, which is now and will in the future lead to undesirable consequences such as the depletion of the ozone atmospheric layer, water, and air pollution; and global warming.

These problems have promoted numerous attempts and research that will lead to the utilization of alternative green sustainable energy sources. These sources such as wind energy, solar heat, energy from sea waves etc, exist in adequate quantities, and are environmentally safe. The main objective of these attempts is to replace the total dependence on fossil fuels energy such as coal, oil, liquefied petroleum and gas. The fossil fuels energy is currently the main energy source on our planet.

Approximately 70% of the world's electricity [1] and 99.97% of the Middle East countries' electricity [2] is generated by the combustion of fossil fuels, which is a very expensive method for electricity generation. The cost of power generated forced power companies to raise the unit cost per consumed kilowatts and as a consequence families are now facing higher electricity bill.

Fitzmorris [3] found that 90% of water heated in US households from 1985 to 2007 uses natural gas and electricity. Figure 1 shows the use of fuel in the United States for domestic water heating market. As depicted, it can be seen that gas and electricity market share have been growing. Others however are decreasing including the use of solar energy.

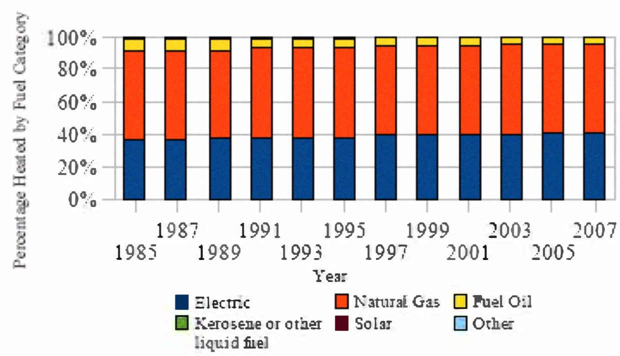

Figure 1. US Domestic Water Heating by Fuel Category [3]

The reason solar water heating for domestic use in the US has been losing market share from 1985 to 2000 is due to price. In most cases, it cost more to install a solar heating system compared to piping for gas, electric water heater in US homes. Thus, house builders will usually go for the cheaper option which is to install gas piping or electricity in order to minimize construction cost. The solar water heating system used in the past was also expensive and over sized [3]

A. Solar Energy

Solar energy is a sustainable, green energy generously provided for free from the sun. Technology that utilizes solar energy includes solar energy lighting (PV), solar water heater, solar stoves and solar dryers. In areas where there is a lack of electricity, small scale solar photovoltaic technologies are used for power generation and road lighting [4].

Heating water by sun is one of the best applicable and cheapest methods. In communities throughout the developing world, poor families struggle to meet their hot water needs. In many countries, demand for fuel wood is one of the principal contributors to deforestation [6]. Others rely on electricity or liquid fuels such as propane to heat their water. These fuel options are unsustainable as they are costly to households and contribute to the buildup of greenhouse gases in the atmosphere.

Many communities face limited access to fuel and/or electricity, limiting their ability to access hot water for domestic uses. Access to a low cost solar water heater would provide numerous benefits to households in developing communities. Many households could reduce their fuel costs by eliminating or reducing their need for wood, gas, or electricity to heat water. Substituting traditional fuel sources with solar energy would reduce carbon emissions.

In many homes in countries such as Malaysia, Yemen, Thailand and China, water heating is required for domestic use such as for bathing, clothes and dish washing. Heating water is an energy intensive requirement. Thus using solar energy to heat water will reduce reliance on the use of electricity and gas to heat water for domestic use.

Access to a cheap and easy water heating device using free solar energy would be beneficial to countries with low house hold income. Such devices would be very efficient in countries near the equator which will have access to solar energy throughout the year. There are also health benefits associated when water is heated using solar energy as the user would be less exposed to toxins and pollutants released from using traditional burning fuels.

B. *Solar Water Heaters*

Utilization of solar energy for domestic use has been of interest since the 18th century. In the 1790s, Horace de Saussure observed that boiling temperatures can be obtained under glass covering a box. It is from this initial observation that concepts for current solar water heaters evolved from [5].

There are two main types of solar water heater systems: passive and active. Active systems integrate pumps and rotary elements, which will add to its construction cost. 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. Therefore, passive systems are more appropriate for low-income families [7].

An example of a researcher involved in solar water heaters is Al-Madani [8], who in 2002 investigated the performance of a batch solar water heater in Bahrain. The heater consists of an evacuated cylindrical glass tube. Water goes through copper coils, which act as collectors at the glass tube. The testing of prototypes resulted in a maximum temperature difference between the inlet and outlet of the cylindrical batch system of 27.8°C and 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 [8].

Similarly in 2006, Y. Tripanagnostopoulos experimented on the optimization of an integrated tank-collector batch solar water heater that contained two cylindrical tanks and a compound parabolic concentrator made of aluminum Mylar glazed with an iron oxide and black matte absorbing surface. Tripanagnostopoulos found that this system had high thermal losses and suggest the usage of a selective absorber such as double-glazing and transparent insulating material. It can be concluded that this system was more complicated to be built. Nevertheless, the segregation of the water mass from the non-uniform distribution of solar energy can result in better performance and significant water stratification [9].

In 1988, F.O. Akuffo in Ghana studied a simpler batch solar water heater. The integrated storage-collector unit was a rectangular galvanized steel box with a total storage capacity of 90L. "Angle iron" was used to support the edges and prevent buckling and jute fiber was used as insulator. The design reached a maximum temperature of 45°C by 4:30pm and provided 30°C water at 5:30am the next day. Daily ambient peak temperatures exceeded 37°C. Akuffo and Jackson recommend the transferring of the heated water to a better-insulated storage tank to reduce overnight heat loss [10].

II. BACKGROUND AND OBJECTIVES

It was observed that the water utility PVC pipes on the house roofs in Yemen can absorb the radiated heat from the sun. The water in the pipes was heated to a temperature up to the range of 35^0C to 50^0C. As water within this range is very suitable for typical domestic use such as bathing, and kitchen utensil and clothes cleaning, a project was then initiated to develop a low-cost solar water heating system that utilize the thermodynamic process using a sustainable green energy source to heat water for domestic consumption [5].

The goal of the project presented herewith is to develop a method to utilize the heat from the sun to heat enough water for domestic consumption. The final product would be an affordable solar water heater for low and medium income households in third world countries. It is hoped that the system will enable the reduction of electricity power consumption of electrical water heaters. The system can be sold commercially in the Middle East, Africa and countries with sunshine for most part of the year.

A. *Methods and Material*

The prototype system is called the Green Water Heater (GWH). The separated-tank solar water heater was chosen since it can keep the water hot during night and easier to be built than other systems. The design is depicted in Figure 2 and the system layout in Figure 3.

The Green Water Heater uses a very low cost pump for water recirculation. For this prototype, the control system utilizes a PLC unit with temperature sensors, level switches, and light indicators to control the heating process to achieve better heating and hot water storage efficiency.

The main components of the GWH are:

1) Thermal collector that consists of bended copper pipes with a diameter of 7.5 mm in equal spacing, decreasing sequences square shapes inside a wood box with a fiber glass top of 35cm width and 75cm height. The pipes' set is separated from the wood by aluminium sheet 1 mm layer and insulating material known as Rockwool blanket. Figure 4 shows the construction of the thermal collector.

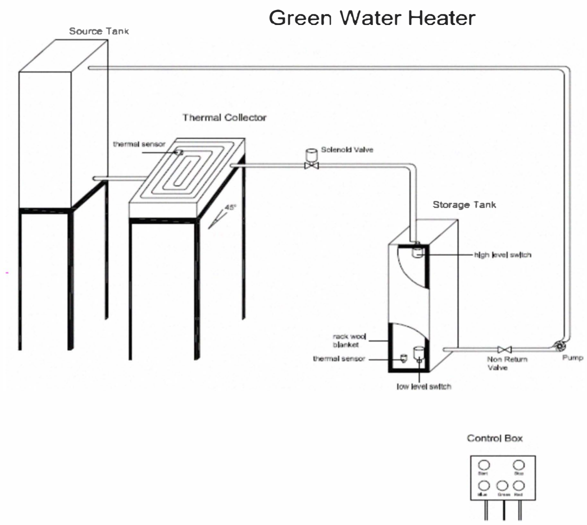

Figure 2. Green Water Heater –Schematic Diagram

2) Source tank is built from a fiber glass with the dimensions of 38cm width, 38cm depth, and 81cm height. It has an outlet and inlet ports.

3) The thermal storage tank's inner layer was welded of stainless steel 2 mm sheets with the dimensions of 31cm width, 31cm depth, and 78cm height. The outer shell was made of fiber glass. The two layers were separated from each other by a layer of Rockwool insulator with 4cm thickness.

III. THE GWH SYSTEM OPERATION

The system operation flowchart is depicted in Figure 5. The system starts working when the start button is pushed. The thermal sensor starts to detect the temperature at the thermal collector. When the temperature has reached above 65^{0}C the solenoid opens to drain the hot water to the thermal storage. The solenoid valve will be closed when the hot water is replaced with cold water which needs to be heated. The thermal storage tank will be filled by hot water until the high level switch is activated, which will then shut down the solenoid valve and a blue lamp will switched on to indicate that the tank is full.

When the temperature of water inside the storage tank falls below 25^{0}C (detected by the sensor in the tank) the pump will start pumping the cooled water for re-circulating and a green lamp will switch on.

During the recirculation, the cold water is at the bottom and the hot water is at the top of the tank. If the temperature sensor detect that water being pumped has a temperature of more than 25^{0}C, the system would shut down the pump. If all the water in the storage tank is cold, the pump would keep on re-circulating the water until the low level switch is activated, then the pump will shut off.

When the storage tank starts to fill with hot water again, and the low level switch will be deactivated and would trigger a timer that holds the pump off to enable the temperature sensor to detect and keep monitoring the water temperature for a short period.

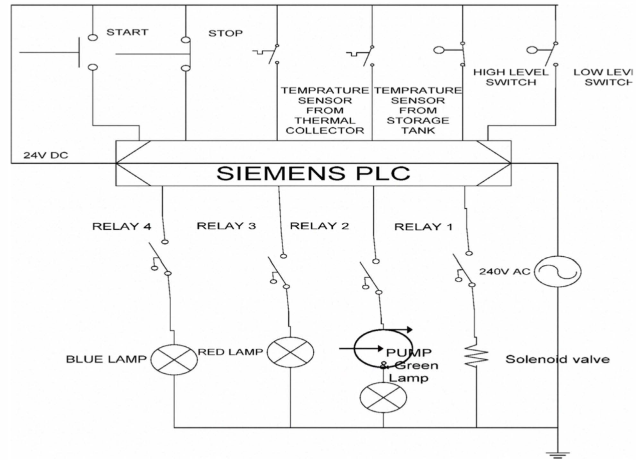

Figure 3. Green Water Heater System Layout

Figure 4. Construction of the Thermal collector

A. GWH Prototype Performance

The prototype was fully tested in the laboratory both by software and hardwire simulation. The PLC was programmed and simulated using the LOGO! software from Siemens Company. The simulation was also performed for analog inputs. All sensors were tested and calibrated to ensure a linear measured temperature Vs voltage output could be obtained.

Subsequently, a field test of the GWH prototype to enable an evaluation of the green water heater (GWH) performance was carried out. The objective of the test was to obtain an overall evaluation of the system ability and efficiency to heat water. Figure 5 shows the prototype at the test site. Data was collected five times a day. The water temperature and voltage output from the temperature sensors were measured in the early morning at 7.00 am, then 10am, 1.00 pm, 4,00 pm and late evening at 7.00 pm..

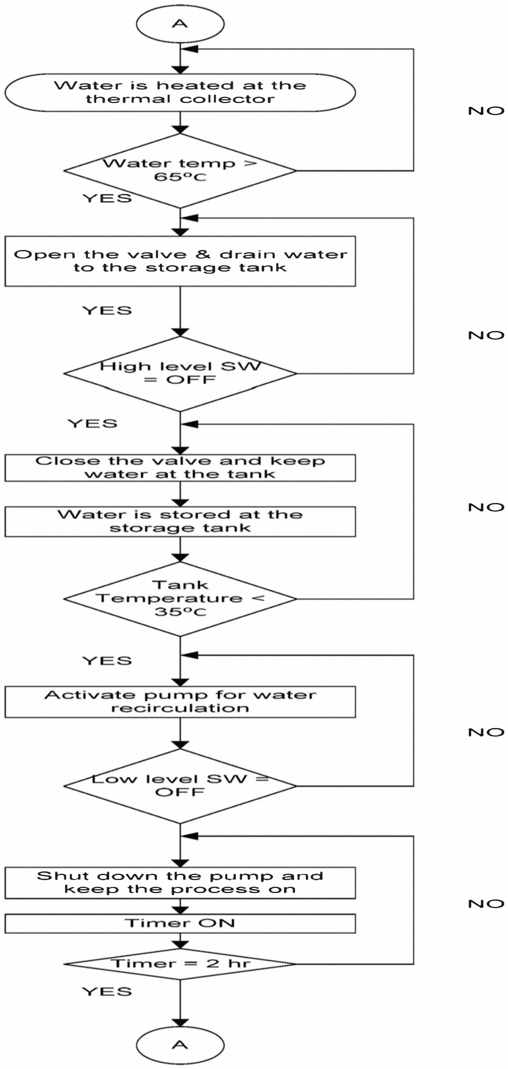

Figure 5. GWH Operations Flowchart.

Figure 6. GWH prototype at test site.

IV. RESULTS AND DISSCUSION

The results from the test are tabulated in Table 1 and Table 2, where the temperature of both the thermal collector and thermal storage tank were measured at different periods of the day together together with the respective output voltage from the sensors. During the test all light indicators were monitored. Where, the red light indicates that the thermal storage tank is empty; the blue light indicates that the storage tank is full, and the green light indicates that the pump is pumping water for the recirculation process.

TABLE I. THERMAL COLLECTOR TEMPERATURE MEASUREMENT

Time	Temperature in °C	Output voltage in volts
7:00 am	32	1.70
10:00 am	78	3.70
1:00 pm	82	4.50
4:00pm	80	3.82
7:00 pm	40	1.78

TABLE II. THERMAL STORAGE TANK TEMPERATURE MEASUREMENT

Time	Temperature in °C	Output voltage in volts
7:00 am	Empty	-------
10:00 am	Being filled	------
1:00 pm	50	1.98
4:00pm	48	1.85
7:00 pm	45	1.80

The above results were measured on April, 11th, 2010 on a normal sunny day with short period when the sunny day was interrupted by clouds but with no rain. At the early morning of the day the red light was working indicating that the thermal storage tank was empty, however, the light shut off at noon time indicating that the tank already contained some hot water.

The results obtained from the field tests indicated that the system is working and could provide hot water in the required range in both the thermal collector and thermal storage tank. The maximum water temperature in the thermal collector was 82^0C which is more than the expected temperature of 65^0C. The maximum water's temperature measured from the storage tank is 50^0C which indicated that the rock-wool is quite a good insulator material.

However, the field test highlighted a problem with the prototype thermal collector. Due to the small diameter of the copper pipes used (7 mm) and improper bending of the copper pipes (manually done), only a small volume of water could flow out of the thermal collector when the valve is open. This very low flow rate caused the water collection into the storage tank to be very slow. Larger diameter pipes and a pipe bending machine will be used for the second prototype. Figure 6 shows the outflow of heated water from the thermal collector. Figure 7 shows the bended pipes in the thermal collector.

Figure 7. Output flow rate from the thermal collector.

Figure 8. Bended pipes of the thermal collector.

V. CONCLUSION

Results from the preliminary research indicate that the GWB can be used to harness solar energy to heat up water for domestic purposes.

A field test in areas without much cloud and, higher sun radiation intensity and longer daylight should provide better performance results. There is thus a great potential to further develop the GWB for use in countries such as Yemen and the Middle East.

VI. FUTURE DEVELOPMENT

The system will be further developed by using a low cost simple controller chip rather than the PLC used. Other materials and different diameter piping will be tested in the thermal collector to identify the best heat absorption material. For areas where there is no electricity available, the system can be designed to be totally independent by generating its own power by introducing photovoltaic solar panels which will operate the solenoid valve, pump, and the controller.

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