Design, Fabrication and Performance Analysis of A Solar Water Heater

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***Abstract*—** *This research is on solar water heater. An active solar heating system requires an external source of drive such as pump or electric motor. The main source of energy for this system is solar energy from the sun. It is cost free to heat the water and transfer heat to the fluid in the collector. The collector surface area is less than 1m^2 and sourced locally. At moderate weather condition the collector temperature might be as high as 76^{0}C at ambient temperature of 25^{0}C. Improvement in thermal efficiency of the system based on the techniques to improve upon convective heat transfer. This is achieved by Insertion of twisted aluminum tapes and its geometry on the periphery of the fluid tube aided the effectiveness of heat transfer. The overall thermal efficiency of the system was 26.34%.*

***Keywords*— *Solar water heater; Active solar heating system; Solar energy; Thermal efficiency*.**

I. INTRODUCTION

Heating of water represents a high percentage of energy consumption in homes and businesses. Solar energy has been able to supplement 30% of energy requirement for process water heating in our industries or domestic applications (Ertekin, 2006). To a large extent water heating using solar energy substantially displaced the use of convectional fossil fuels. This has been able to mitigate emission of green house gases and other pollutants; with the associated environmental issues.

A closed loop solar water heating system uses a heat transfer fluid to collect heat and a heat exchanger to transfer heat to domestic water supply. The set back of closed loop system is excessive heat loss during heat exchange process. Sitzmannx recommended the use of such system and provided basic information to manufacture and use closed loop system (Nahar, 2002).

A solar water heating system can be characterized as active or passive. An active system uses electric pump to circulate the fluid through the collector. A passive system moves the supply water or heat transfer fluid through the system without any pump but relies on thermo syphoning to circulate water. A solar flat plate collector of fixed orientation was fabricated and connected to the heat exchanger located inside the storage tank drum. The collector is a low temperature operating system at approximately 100^{0}C.

II. LITERATURE REVIEW

Israel, Cyprus and Greece are the leading nations in the use of solar water heating systems with over 30-40% of the homes enjoying from this facility (Bukola, 2006). Levi Yisser built the first prototype Israeli solar water heater and in 1952 launched the Neryah company, Israel is the first commercial manufacturer of solar water heating system (Nahar, 2002). The energy crisis of 1970 to 1980 made Israel Knesset to pass a bill requiring the installation of solar water heater in all new homes except high tower with insufficient roof area.

First flat plate solar collectors for solar water heating were used in Florida and Southern Carolina in the 1920s. There was surge of interest in solar water heating in the North after 1960, but more especially after 1973 oil crisis (Huang, 2010). In 2005, Spain became the first country in the world to require installation of photovoltaic electricity generation in new buildings. It is the second nation after Israel to demand the installation of solar water heating system in 2006 (Bello, 2009).

During the first half of 20th century fundamental research by Albert Einstein and Robert Milliken threw more light on photovoltaic effect. In 1954, the photovoltaic theories were applied to develop photovoltaic cell to convert 40% of the incident solar radiation to electrical energy. During the later part of the 20th century, interest increased tremendously in the use of solar energy.

Hence the road to develop models and devices to extract power from solar irradiation is really a long and twisted road. In the context of solar water heating systems, the physical devices might be active or passive systems.

III. MATERIALS AND METHODS

3.1 A Basic Components of Solar Water Heating System:

3.1.1 A Solar Collector:

This is the key component of the solar water heating system. The system performance thermally and economically depends on the design and selection of the right type of solar collector. The collector collects solar radiation from the sun and use the heat energy to heat up the process fluid. A typical flat plate collector consists of an absorber, transparent cover sheets, and an insulated box. The absorber is a sheet of metal with high thermal conductivity with tubes or ducts either internal or attached. The absorber surface is painted or coated to maximize radiant energy absorption and also to minimize radiant emission. The collector is placed in an insulate box, which is a structural component to provide sealing and minimize heat loss from the back and sides of the collector. See appendix I

3.1.2 Storage Tank:

The storage tank is the horizontal type. The tank capacity is 10 liters. Exchange of heat between the working fluid and the process water or cold water occurred in the storage tank. The tank is insulated to reduce heat loss during cloudy day and night time. See Appendix II

3.1.3 Cold Water Storage Tank:

A cold water storage tank of 10litres capacity was used in the study. The tank was connected to city water supply. The material of the tank is Polyvinyl Chloride (PVC).

3.1.4 Piping System:

The inlet pipe was made of galvanized iron whose diameter is 3.2 cm. It supplied water to the storage tank from cold water storage tank. The outlet pipe material is galvanized iron of diameter 2.16 cm. It is insulated with glass wool. It connects the storage tank and solar collector and draws out heated water from the storage tank.

3.1.5 Selection of Working Fluid:

Working fluid selection was based on the following criteria :

i. Low boiling point
ii. High specific heat
iii. High latent heat
iv. Non-corrosiveness for most of the fabricated materials
v. Easy availability in the market and inexpensive
vi. Excellent stability in the working range
vii. Low freezing temperature
viii. Should not form scales in the tubes
ix. High thermal conductivity

On a general note, water is used as working fluid in solar flat plate collector. Ethylene glycol could also be used as working fluid.

3.2 Efficiency Calculation

The efficiency of flat plate solar collector with any working fluid is the ratio of the heat gained by water to the actual solar energy received by the flat plate collector. The overall efficiency of the system is expressed as:

$$\eta_{overall} = \frac{mC_p\Delta T}{qAt} \quad (1)$$

Where,

m—weight of water in (kg)

C_p—specific heat capacity of water (J/kgK)

ΔT—temperature difference (outlet temperature-inlet temperature) (K)

q—solar insolation (Watts/m^2/hr)

A—surface area of the collector (m^2)

t—time (s)

The declination is the angular position of the sun at noon with respect to the plane of the equator. The value in degree is expressed by Equation (2).

$$\delta = 23.45\left[\frac{2\pi}{(284+n)365}\right]^2 \quad (2)$$

Where,

n—the day of the year (n=1for January 1, n=2 for February 1, etc

Declination varies between -23.45^0 on December 21 and +23.45^0 on June 21.

Solar Hour Angle and Sunset Time Angle:

At 7 am the solar hour angle is -75^0 and at 7 pm the solar hour angle is 75^0. The solar angle and sunset is is expressed as:

$$Cos(N_s) = tan(\psi)\tan(\beta) \quad (3)$$

N_s—the solar hour angle at sunset

ψ—the latitude of the site

IV. EXPERIMENTAL RESULTS AND COMPUTATIONAL ANALYSIS

The experimental data average over a period of six months is as in Table 1.

TABLE 1
EXPERIMENTAL DATA FROM THE SOLAR WATER HEATER.

Time (s)	Atm Temp T_a(^{0}C)	Inlet Temp T_1(^{0}C)	Outlet Temp T_2(^{0}C)	Temp Difference (ΔT) (^{0}C)	Solar Irradiation (W/m^2/hour)	Relative Humidity (%)
11:00 AM to 11:30 AM	25.1	30.9	57.3	26.4	745.9	26.6
12:00 PM noon to 12:45 PM	25.3	33.5	69	35.5	756.1	25.3
1:00 PM to 2:00 PM	25.2	34	76.1	42.1	795	25

Maximum temperature attained=76.1^{0}C

Maximum solar irradiation, R=795W/m^2/hr

Solar radiation received by the earth in 7 hours in terms of energy, R=795×7=5565Whr/m^2=5565$\times 3600 = 20034000 Ws/m^2$

Flat plate collector area, A=0.81m2

Ambiient temperature, Ta=250C

Attainable maximum temperature, T_2=76.10C

Mass of water in the storage tank, m=20kg

Specific heat capacity of water, C_p=4.182kJ/kgK

To determine collector performance efficiency, apply Equation (1).

$$\eta_{overall} = \frac{mC_p\Delta T}{qAt} = \frac{20\times4182\times(76.1-25)}{20034000\times0.81} = 26.34\%$$

V. DISCUSSION OF RESULTS

Digital thermometer was used for temperature measurement. Humidity meter was employed to determine the relative humidity of the environment in the morning time. Solar meter was used to measure solar radiation from the sun. Average highest collector attainable temperature at the outlet was 76.1^0C. The ambient temperature was 25^0C Solar radiation from the sun varies with respect to time and clear sunny day. At fully sunny day solar radiation was more and higher temperature was achieved.

VI. CONCLUSION

In this research solar energy was used to heat water using the energy from the sun. The flat plate collector was fabricated in the Mechanical Engineering workshop of the University. The following parameters were measured : solar radiation, collector's inlet and outlet temperatures, humidity of the environment and ambient temperature. Average maximum attainable temperature at the collector outlet point was 76.1^0C at ambient temperature of 25^0C.

Summarily passive solar heating should be suitable for the domestic sector and industrial establishments. It is also believed that solar water heaters as a source of renewable energy will have positive impact in reducing electrical energy consumption. It will also mitigate the generation of green house gases. It is established that this renewable energy source is abundantly available in Nigeria with estimated annual solar irradiation of 1900 to 2200kWh/m^2. Such high level of available solar energy could effectively be capitalized upon to generate electrical energy and energy for solar thermal applications in order to meet up with energy demand of Nigeria.

REFERENCES

[1] Bello, S. R. and Odey, S. O. (2009), "Development of Hot Water Solar, Oven for Low Temperature Thermal Processes", Leonardo Electronic Journal of Practices and Technologies, Vol. 14, pp. 3563-3568.

[2] Bukola, O. B. (2006), "Flow Design and Collector Performance of a Natural Circulation Solar Water Heater", Journal of Engineering and Applied Sciences, Vol. 1, pp. 7-13.

[3] Ertekin, C., Kulcu, R. and Evrendilek, F. (2008), "Techno-Economic Analysis of Solar Water Heating System in Turkey", Sensors, Vol. 8, pp. 791-802.

[4] Huang, J. et al (2010), "Experimental Investigation On Thermal Performance of Thermosyphon Flat-Plate Solar Water Heater With A Mantle Heat Exchanger", Energy, Vol.35, pp. 3563-3568.

[5] Nahar, N. M. (2002), "Capital Cost and Economic Viability of Thermosyponic Solar Water Heaters Manufactured from Alternative Materials in India", Renewable Energy, Vol. 26, pp. 623-663.

APPENDICES

APPENDIX I

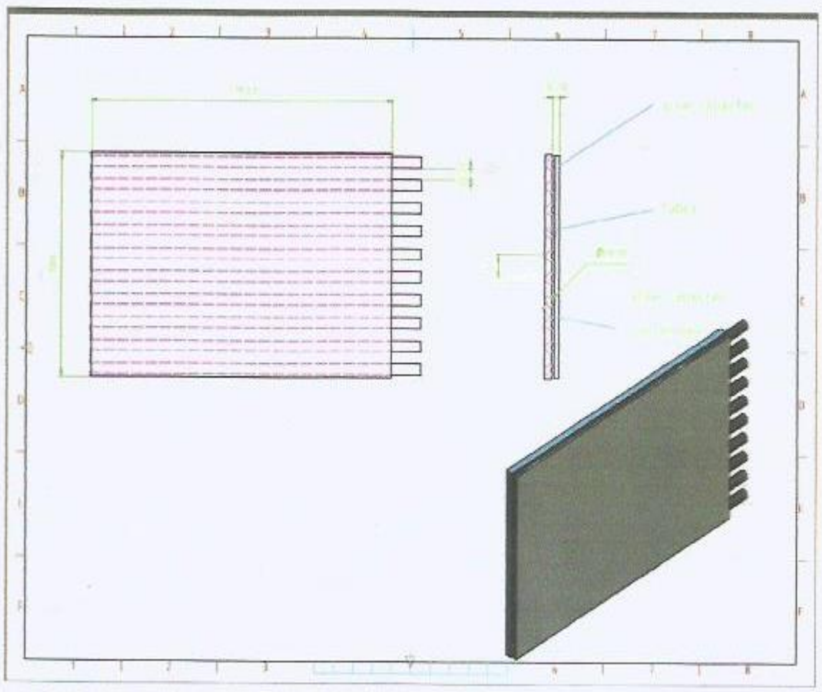

FIG 3.1 SOLAR WATER COLLECTOR

APPENDIX II

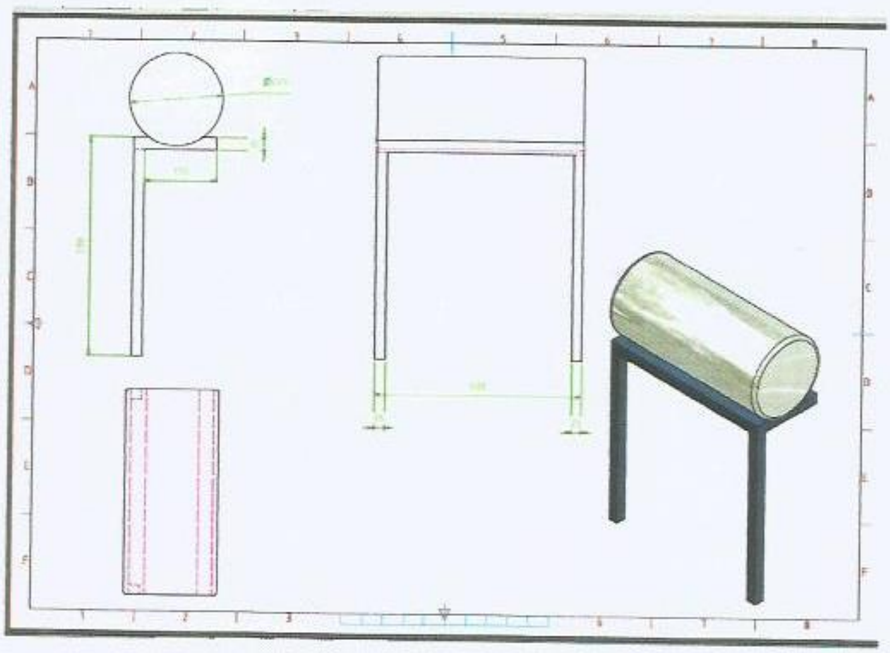

Fig 3.2 the Storage Tank

APPENDIX III

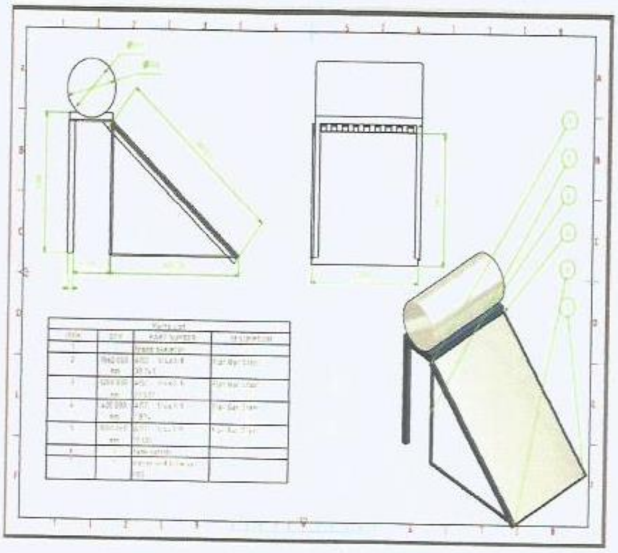

Fig.3.2 Assembly Diagram of the Solar Water Heater

APPENDIX IV

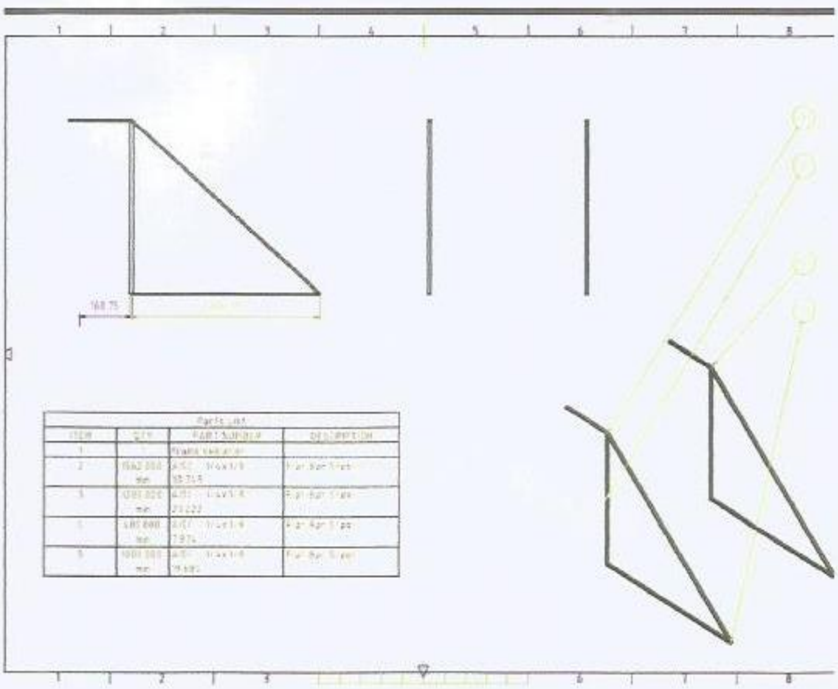

Fig3.4FRAMEWORK OF THE SYSTEM