

DESIGN OF HANDMADE SOLAR BOILER AND EFFECT OF THERMAL INSULATIONS IN HEAT CONSERVATION

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Abstract. This paper report the results of an experiment on a handmade solar boiler focusing on the effect of thermal insulations for better heat conservation and better efficiency of the device by using a concave downward dish covered by aluminum sheets, the dish used to reflect the solar radiation to the water tank. The boiler body is a box mad of polystyrene foam boards with length, width and height of 45cm, 43cm and 28.5cm respectively. The purpose of this research was to reach the 60°C water temperature, but handmade boiler reached a temperature about 10°C more than the target.

Key words: solar boiler, thermal insulation, heat conservation.

1. Introduction

The idea of using solar energy collectors to harness the sun's power is recorded from the prehistoric times when at 212 BC the Greek scientist/physician Archimedes devised a method to burn the Roman fleet. Archimedes reputedly set the attacking Roman fleet afire by means of concave metallic mirror in the form of hundreds of polished shields; all reflecting on the same ship.

The most widely-used solar thermal applications is the solar water heating (SWH) system [8]. In the nineteenth century, heating was a big problem. People generally used a cook stove for this purpose. They were using wood or heavy hods of coal lifted, then the fuel had to be kindled and the fire periodically stocked. In cities, the wealthier heated their water with gas manufactured from coal. To circumvent these problems, many handy farmers or prospectors or other outdoors men devised a much safer, easier, and cheaper way to heat water – placing into the sun a metal water tank painted black to absorb as much solar energy as possible. These were the first solar water heaters on record. The downside was that even on clear, hot days it usually took from morning to early afternoon for the water to get hot. And as soon as the sun went down, the tanks rapidly lost their heat because they had no protection from the low air temperature in the night.

Nowadays many kinds of insulations are in researchers' service to save the collected solar energy in a better manner. Thermal insulators have been used in heat storage systems to prevent temperature gradient thereby minimizing heat losses to the surroundings [4]. The thermal insulation is provided by embedding insulation materials at least on the roof areas and the vertical walls of the system [5]. New heat insulation material has been widely used in aerospace, energy, chemical and metallurgical industries, an important development trend is the research and development of composite function of heat insulation materials with low thermal conductivity [2].

In order to obtain the high strength and low thermal conductivity of composite insulation materials, The species and the composition of material need to change [3].

Because of the global concern about reducing carbon emissions, different policies could be applied to reduce carbon emissions, such as enhancing renewable energy deployment and encouraging technological innovations [6].

According to the Renewable Energy Policy Network (2010), approximately 70 million houses use SWH systems worldwide [9]. Many countries started to use facilities which uses renewable energy, but this technology is young and novel in Afghanistan, that need research investigation.

The solar energy has a very insignificant usage in heating water. The regional distribution of residential water heating fuel type in USA in as follows, 54% of the residential water heated by natural gas. 39% or the water heated by electricity, 6% of the demanded hot water heated by other sources of energy, but only 1% of the water heated by using the solar energy [1]. In America, with power accounting for 40% of CO₂ emissions, the U.S. faces challenges in producing electricity cleanly [7]. The usage of renewable energy is felt to be increased, because the organic sources of energy will be finished and now it is the main cause of the air pollution.

The appropriate design of SWH systems is important to assure good performance and maximize the economic benefits of these systems. These design methods can be broadly classified into two categories, namely, correlation-based methods and simulation-based methods [10].

2. Methodology

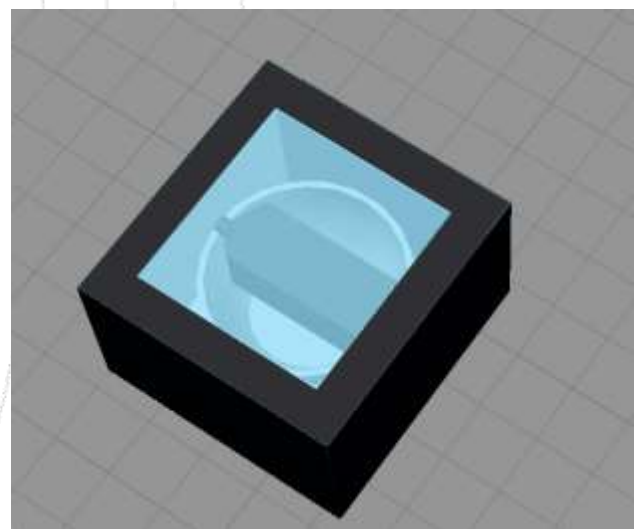
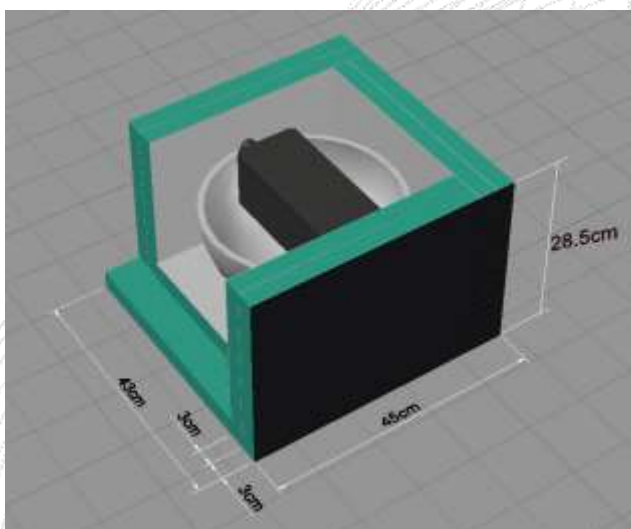
2.1 Synopsis of boiler information

Figures 1 (a) and 1(b) show the 3D views, and dimensions of the boiler, and figure 2 show the material used, wall section and detailed dimensions of walls and floor. To prevent the heat loss in three possible ways by radiation, convection, and conduction, we insulated the box as following techniques. The device is a box shaped boiler made of polystyrene foam boards of 3cm thickness, which polystyrene foam boards prevent the heat loss by conduction. Also the boiler walls and floor was insolated by aluminum foil to prevent heat loss by radiation, and to keep at minimum the heat loss by convection the box was air tighten as much as possible. A 2 letter capacity PET bottle was used as a water tank for the boiler, the bottle was painted black for better absorption of the solar heat.

a) Box dimensions

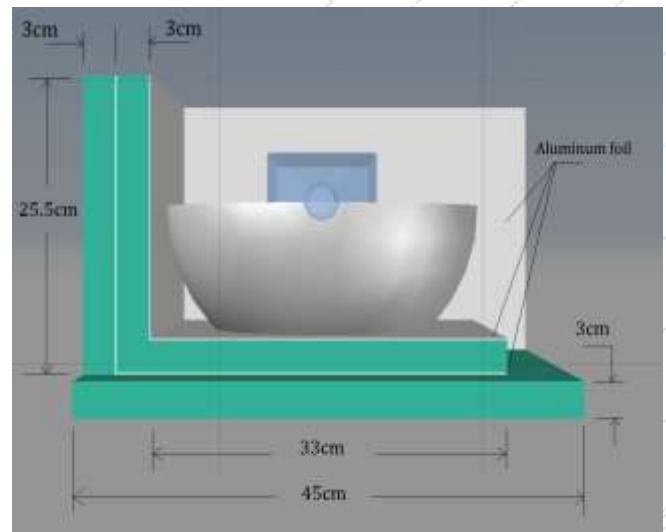
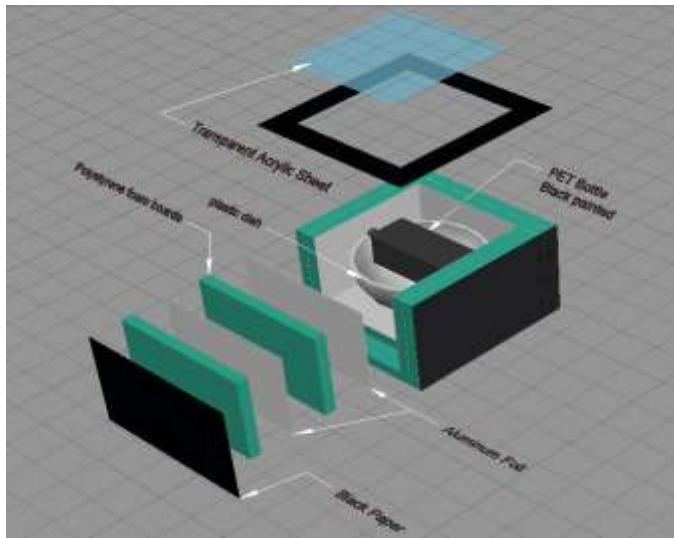
b) 3D view of Boiler

Figure 1 a) Shows the dimensions of the boiler and b) Shows the 3D view of the boiler



To increase the efficiency of the device, a concave down aluminum covered plastic dish was used to reflect the solar radiation to the back side of the PET bottle.

Also to absorb more heat by device it was covered by a black paper. The top surface of the boiler was covered by a transparent acrylic sheet to pass the solar radiation and also keep the box airtight.



a) Material used in boiler

b) Detailed dimensions

Figure 2 a) show the material used in solar boiler, and b) show the detailed dimensions of walls and floor of the box shaped handmade solar boiler.

After completing design and building of the solar boiler, two days experiment has been done and temperature data was recorded accurately for further studying on the efficiency of the device. To give more strength to the research the temperature of the water inside the bottle also calculated by formulas and finally the results was compared.

2.2. Formulas used for calculations

In existence of deferent insulations used in the handmade solar boiler still there are some heat losses in the system.

As per energy conservation law the amount of energy entered to a boiler is equal to the amount of energy stored in device plus heat loss form the system. The Energy balance equation of a solar boiler is as follows:

(Input Heat) = (storage Heat) + (heat loss from device)

$$\tau_{tp} \alpha_{bf} A_{bf} (1 + \rho_{al}) I = \frac{c_{pw} M_w d\theta_w}{dt} + \sum_{i=1}^6 A_i K_i (\theta_w - \theta_{oa})$$

$$\tau_{tp} \alpha_{bf} A_{bf} (1 + \rho_{al}) I = \frac{C_{pw} M_w (\theta_w - 1\theta_w)}{\Delta t} + (A_{tp} K_{tp} + A_{ins} K_{ins}) (\theta_w - \theta_{oa})$$

The parts of formula explained as below:

α_{bf} : Solar absorptivity (0.99), I : solar radiation incoming into the transparent sheet (W/m²)

C_{pw} : Specific heat capacity of water (j/ (kg°C) (4186), M_w : Mass of the water within the bottle (kg) (2)

, θ_w : Water temperature (°C), $-1\theta_w$: Water temperature, Δt : earlier temperature, t : time (s)

θ_{oa} : Outside air temperature (°C), A_i : Area of wall, K_i : thermal transmittance of wall i

A_{tp}, K_{tp} : Area or thermal transmittance of transparent part, $A_{ins}K_{ins}$: Area or thermal transmittance of transparent of thermal insulation board, τ_{bf} : solar permeability of transparent sheet (0.99)

ρ_{al} : Reflectivity of aluminium cover (0.3), A_{bf} : Area of bottle face (m²)

Calculation of water temperature by formulas:

$$\tau_{tp}\alpha_{bf}A_{bf}(1 + \rho_{al})I = \frac{c_{pw}M_w(\theta_w - \theta_{oa})}{\Delta t} + (A_{tp}K_{tp} + A_{ins}K_{ins})(\theta_w - \theta_{oa})$$

(Ka)

(kb)

(kc)

(kd)

$$\left[\frac{c_{pw}M_w}{\Delta t} + (A_{tp}K_{tp} + A_{ins}K_{ins}) \right] \cdot \theta_w = [\tau_{tp}\alpha_{bf}A_{bf}(1 + \rho_{al})I + \left[\frac{c_{pw}M_w}{\Delta t} \right] \cdot -1\theta_w + (A_{tp}K_{tp} + A_{ins}K_{ins}) \cdot \theta_{oa}}$$

$$k_a\theta_w = k_b(1 + \rho_{al})I + k_c \cdot -1\theta_w + k_d\theta_{oa} = \theta_w = \frac{k_b}{k_a}(1 + \rho_{al})I + \frac{k_c}{k_a} \cdot -1\theta_w + \frac{k_d}{k_a} \cdot \theta_{oa}$$

(1)

Thermal transmittance coefficient of insulation sides and back (2)

Thermal transmittance coefficient of transparent sheet (3)

$$K_{ins} = \frac{1}{\frac{1}{\alpha_i} + \frac{d_{ins}}{\lambda_{ins}} + \frac{1}{\alpha_o}} \quad (2)$$

$$K_{tp} = \frac{1}{\frac{1}{\alpha_i} + \frac{d_{tp}}{\lambda_{tp}} + r_a + \frac{1}{\alpha_o}} \quad (3)$$

d_{ins} : Thickness of polystyrene foam (m) (0.06), λ_{ins} : Thermal conductivity of polystyrene foam(w/m.°C)(0.037)

d_{tp} : Thickness of transparent sheet (m) (0.0001), λ_{tp} : Thermal conductivity of transparent sheet(w/m.°C)(0.19)

α_o : Exterior surface coefficient of heat transfer (w/m.°C) (11) (Close as tightly as factory product)

α_i : Interior surface coefficient of heat transfer (w/m.°C) (11)

r_a : Thermal resistance of closed air gap (m.°C/w) (0.09) (Close as tightly as handcraft double wall)

The temperature of the water inside the bottle can be calculated from equation (1) and the thermal transmittance coefficient of box walls and transparent sheet was calculated by equation (2) and equation (3) respectively.

2.3 Thermometers and Data Logger arrangement

In this study a correlation method was used. By using Excel program for calculation of the formulas and experiment on boiler under the direct sunlight, the correlation of the two ways of calculation has been compared together. To calculate and record the temperature inside the bottle, outside of the bottle and air temperature outside of the box, three thermometers used and connected to the data logger to record the temperature data during the experiment. The data logger recorded the temperature in a minute base.

3. Results and discussion

Two days of experiment has been don on the solar boiler after it was completed and assembled together and the tilt angle for solar boiler was 30 degrees. The thermal sensors such as thermocouple, pyrometer and data logger was connected to the surface of the bottle, back of the bottle, inside the water, surface of the boiler, and back of the boiler and the data was recorded in each minute.

Also the water temperature was calculated from equation 1 and finally the results was plotted in excel program and graphs was compared together.

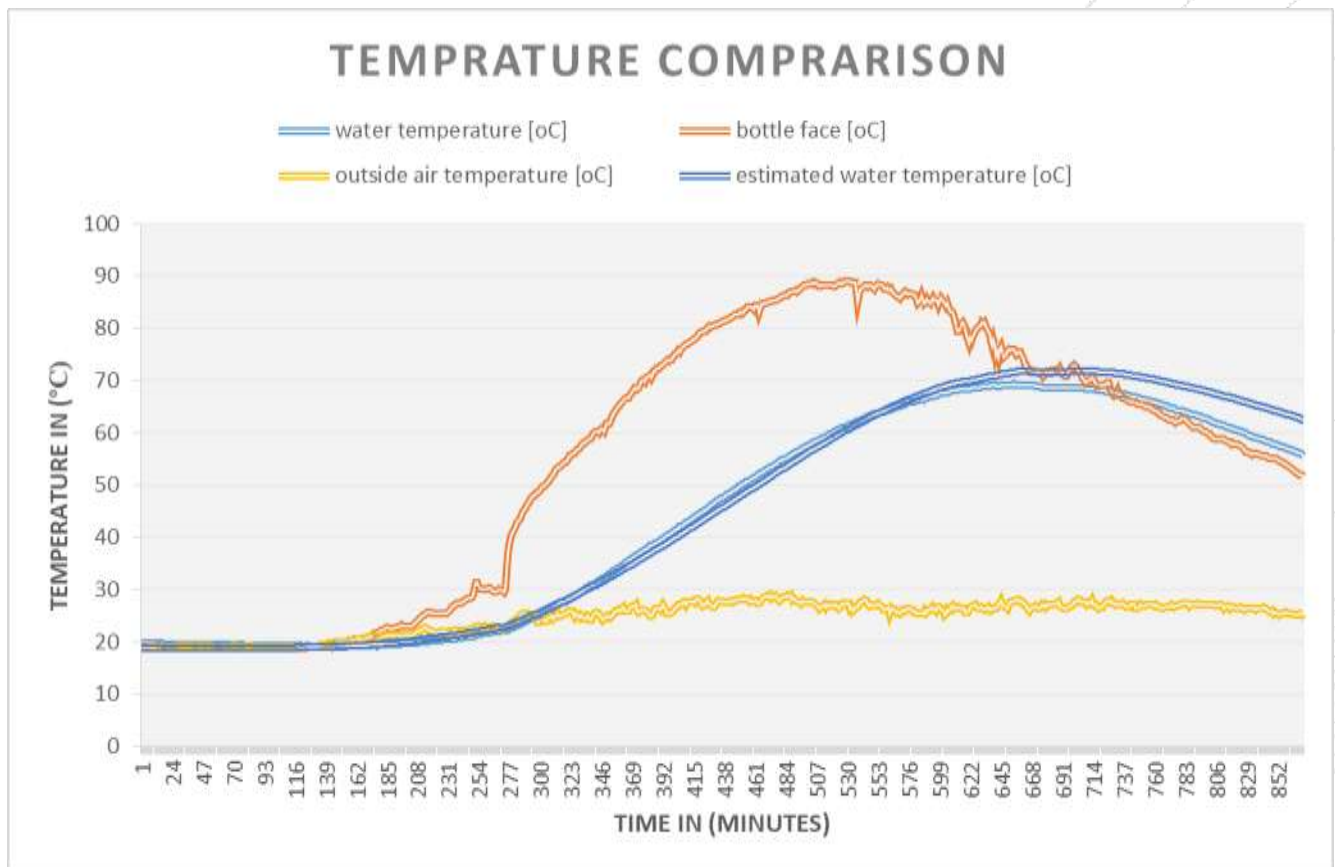


Figure 3 show the comparison of estimated water temperature and experiment based water temperature together.

The data has been recorded from 3:00 am till 17:00 pm in each minute. The water temperature has been derived both from the practical experiment and from the equation (1) and the result has been drawn in the Fig.3.

As it's visible in the Fig.3, the water temperature recorded during the experiment is about 69.3°C approximately 70°C, and the highest temperature value which has derived from the formula is 71.86 °C approximately 72°C at 13:53 pm. The difference between the experimental value and estimated value from the formula is not so much high, therefore it shows that the formula have enough accuracy and also make sure that expected temperature of the water by using thermal insulations in such manner is realistic and trustworthy.

4. Conclusion

From the experiment data and calculated data it can be concluded that the best boiler is that one which can conserve heat energy and site recorded data be very close to the data calculated by the formula. The different layers of the insolation prevented the heat transfer and energy loss of the boiler very well. Different experiment has been done in designing the solar boiler, but after when the results collected from the experiments, the solar boiler which has the concave down dish inside had the best result in comparison to other solar boilers. This boiler rise up the water temperature by about 10°C degree more than ordinary solar boiler. Also it was cleared that the formula for estimation of water temperature have a satisfactory and reliable value, so it is possible to calculate the expected water temperature without doing experiment.

In addition, the concave down dish used in the handmade solar boiler increased the efficiency of the boiler by glinting the solar radiation to the opposite side of the water tank.

References

1. K. Hudon, T. Merrigan, J. Burch and J. Maguire Low-Cost Solar Water Heating Research and Development Roadmap, National Renewable Energy Laboratory of the U.S. Department of Energy, August 2012.
2. Yu Yanjun, The research and development of heat insulation materials with low thermal-conductivity in high temperature, SHANDONG POLYTECHNIC, Jinan 250104, China, MEBE 2015.
3. Xia Shuqin Tang Zhuxing etc. Preparation of inorganic composite insulating material outsourcing exhaust pipe sleeve. Modern technical ceramics. 1997.1
4. Gesa, F. Newton¹, Atser A. Roy² & Aondoakaa, I. Solomon³, Investigation of the Thermal Insulation Properties..., American Journal of Engineering Research. 2014.
5. Novo A. V, Bayon J.R, Castro-Fresno D and Rodriguez-Hernandez J. ., Review of Seasonal heat Storage in Large Basin: Water Tanks and Gravel Water Pits. Applied Energy, 87: 390, 397. 2010.
6. Sh. Abolhosseini, Al. Heshmati, J. Altmann, A Review of Renewable Energy Supply and Energy Efficiency Technologies, The Institute for the Study of Labor (IZA), 2014.
7. Energy Efficiency and Renewable Energy: Harnessing the Power of the Consumer. Bloomberg and ABB, 2011.
8. M.R. Islam.; K. Sumathy; S.U. Khan, Solar water heating systems and their market trends. Renew. Sustain. Energy Rev. 2013, 17, 1–25.
9. Renewable Energy Policy Network. Renewable Energy 2010: Key Facts and Figures for Decision Makers. Global Status Report. Available online: <http://www.ren21.net/gsr> (accessed on 10 July 2015).
10. G.N. Kulkarni, S.B. Kedare, S. Bandyopadhyay, Determination of design space and optimization of solar water heating systems. Sol. Energy 2007, 81, 958–968.