Journal of Physical Science and Innovation Volume 5, Number 1, 2013.
ISSN 2277-0119

REGULATION OF THE TEMPERATURE DISTRIBUTION IN A BATCH HEATER COLLECTOR TANK USING BAFFLES

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ABSTRACT

This study examines the problem of getting an even temperature in the tank of an integrated collector storage (ICS) heater. The naturally occurring thermosyphon current, together with baffles (or fins) on the inside of the absorber are used to bring all water layers inside the tank to an even temperature. The prototype was designed as an outdoor hand-washing cistern with no other means to push the heated water out other than gravity. The results indicate that adding baffles to the underside of the collector aided in proper mixing of water to reduce the temperature stratification and allow better heat penetration to the lower parts of the tank. The mixing action occurred with variable effectiveness at different collector inclinations. The most effective mixing was found to occur at 60^{0}-collector inclination angle. The best-achieved temperature difference between the top and bottom levels of the tank was 3^{0}C.

Keywords: Mixing Baffles, Gravity Flow, Batch Heater, Uniform Temperature

INTRODUCTION

In developing countries renewable energy and specifically, solar hot water systems, could present a sustainable solution for poor households to improve sanitation. Only if the upfront prices of these systems were competitive as compared to other devices using other fuels, for instance charcoal. Imported solar devices are rarely in the affordable price range of average households. Therefore, a need exists to encourage production of locally fabricated solar water heating systems in order to enhance penetration of solar energy use. The simple integrated collector storage (ICS) prototype device demonstrated in this study can help increase usage of renewable energy technologies for hand sanitation. It will provide a portable hot water cistern that will provide small volumes of hot water at a suitable temperature, on demand.

Solar hot water heaters use the basic theory of stratification where the design allows only slow mixing of the water between layers. As a result, the top layers are always the hottest. The hottest water is drawn off first from the highest point of the collector, either for use or for storage. It is necessary in such a case to plumb cold water into the heater bottom to push out the hot water from the top of the collector. In batch heaters, when no such arrangement is available, the water has to be drawn off using gravity. Hence the water inside the heater needs to be mixed first, otherwise only the cold water at the bottom of the collector will be drawn.

The rate of energy transfer between the absorber and the water layer beneath it depends on their temperature difference. The closer the two temperatures are, the less the energy absorbed. To increase the efficiency of heating, the hot layer contacting the absorber has to be exchanged with a cooler layer constantly. In this study, heating efficiency in the fabricated prototype heater is enhanced by keeping the water layers constantly mixing.

The study was undertaken to determine whether a set of buffers fixed to the absorber in combination with currents naturally generated in the heater because of thermosyphon flow, could be used to achieve the desired mixing. Thermosyphon flow occurs whenever a layer of water gets heated, and as a result, its density decreases. The now lighter water rises to the highest point of the tank by floating on the heavier cooler layers. This action occurs in a cycle that creates convection currents in the water. The prototype of a small Integrated Collector Storage (ICS) heater fabricated for this study is in figure 1. The photo illustrates the prototype in an actual test setup with the temperature and irradiance logging instruments connected.

Figure 1: The Test Prototype Connected to Data Logging Equipment

Eight temperature sensors (Tc 1 to Tc 8) are used. Four are equally spaced at the top of the collector 2 cm from the absorber and four equally spaced at the bottom of the tank (figure 2), they were used to monitor the temperatures at the two levels that were analyzed for temperature stratification difference.

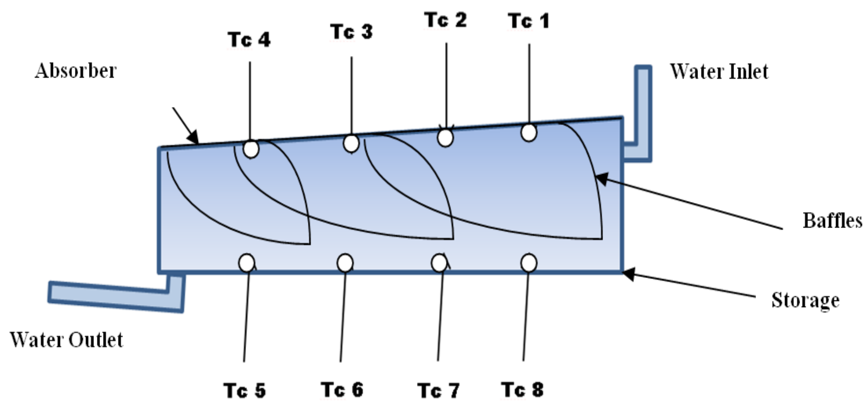

Figure 2: Thermocouple Sensor Placement in the Tank

The absorber used had a set of baffles attached to it in the pattern indicated in figure 3. The pattern was laid out in such a way as to make a channel where the thermosyphon currents flowed, causing the water to churn in horizontal and vertical directions. This water movement inside the tank mixed up the water layers to an even temperature.

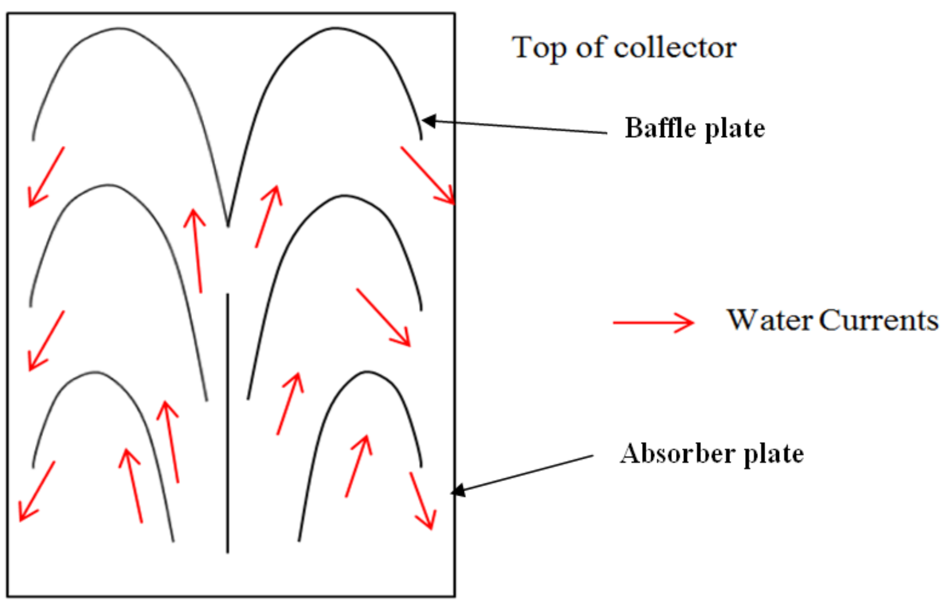

Figure 3: Layout of Baffles on Absorber with Thermosyphon Water Current Paths Shown

Baffles have been used in a previous study (Garg and Rani, 1982), but to improve on losses of heat from the heater tank. In the current study, the work of baffles employed here was mixing up the water in the collector. There is also an additional benefit of using the baffles. When some water in a batch heater is drawn off, the absorber is no longer in full contact with the water layer below it. This reduces heat energy transfer efficiency. Baffles in this study helped to continue the transfer of heat to the water even after some load has been drawn off.

Earlier studies by Muneer (1985) and Muneer *et al.,* (1984; 2006) had generally looked at design parameters and how these parameters affect the performance of the water heater. The design used in this study had a tank with a total volume of 38 liters, with an effective absorber area, A = 0.2442 m^2 tested at Latitude -1.143, and Longitude -36.969 at 1501 feet above sea level. When the collector receives insolation, the absorber plate starts to heat up. This results in the development of a varying density layer of water on the waterside of the absorber plate. The density of this layer decreases higher up the absorber plate slope. This results in a velocity layer as the density of hottest water decreases and it gets pushed up the slope to accumulate at the highest end of the tank. This accumulation will occur with a plain absorber. When thermosyphon action starts with a finned collector installed, rising fluid encounters the baffles (fins) which channel it into paths where it is forced to change direction. The deflection is away from the tank's lateral centerline and also into the depths of the tank. This causes the water to churn and mix. The stronger the thermosyphon current gets, the more effective the mixing action. The convective currents resulting from thermosyphon action get stronger with increase in insolation and an increasing angle of collector inclination.

The optimum orientation for a solar collector is to face the equator (Twidell and Weir, 2006). Duffie and Beckhman (1991), suggest the optimal angle of the collector inclination be 0.9 times the latitude of the location. A study done (Henderson *et al*., 2007) drew the result that a 5 to 10 degrees increase in the angle of inclination of the collector for particular latitude would improve the thermal performance of the heater Gupta *et al.,* (1968) found experimentally that the flow rate of a thermosyphon water heater could be increased by increasing the relative height between the collector and storage tank, but the efficiency was not increased.

A comparative study of the triangular water heater with a rectangular one (Kaushik *et al*., 1984) had results that the triangular system resulted in higher solar gain and enhanced natural convection, leading to a higher water temperature. The present article is the outcome of a research carried out for the design and fabrication of a solar hand-washing cistern using an integrated solar collector for Kenya's informal food outlets.

MATERIALS AND METHODS

To test the effectiveness of baffles in mixing the tank contents, two absorbers were fabricated. One was plain and the other was finned (baffled). The plain collector was made by cutting out of a galvanized sheet an area equivalent to the collector aperture (47 mm x 71 mm). The finished absorber had an effective absorber area of (39 mm x 66 mm). The top surface of the absorber was coated with black lacquer very thinly applied. It was then perforated to make securing holes to the tank. The baffled absorber was similarly fabricated but with baffles (fins) added on the water side in the pattern of figure 3. The tank bottom and sides were insulated using glass fiber and the top was insulated using 4 mm window glass spaced 2 cm from the absorber plate. The device was mounted on a fabricated stand that would allow inclining the collector to the desired angle. At the highest end of the absorber, a pinhole was made to purge the air gap that is likely to occur when the tank is fully loaded. The design used had a depth 3 times larger at the higher end than at the lower end of the collector, to take advantage of enhanced natural convection.

The two absorbers were tested each in its own day. The collector was tested at an inclination angle of 60^0 both times and with a glass cover fitted at a full load of water. At hourly intervals the temperature of all the 8 thermocouples were logged between 8.00 am to 12.30 pm. The mean of the four top temperatures (Tc 1-4) and mean of the four bottom temperatures (Tc 5-8) was calculated. In addition, the mean of the top and bottom temperatures (Tc 1-8) aggregated, for each position. These calculated mean values were plotted against time.

The inclination approximate angle was found experimentally by testing at 0^0, 15^0, 30^0, 45^0, 60^0 collector inclination angles. For the inclination tests, the heater was fitted with the finned collector and a glass cover and operated at a full load. The inclination angle was measured as the angle between the absorber plane and the horizontal plane. The first test done was with the collector horizontal and consequent angles were at increasing intervals of 15^0 to a maximum of 60^0. Each inclination test was performed on its own day between 8.00 am to 3.30 pm, logging temperature and insolation at intervals of 10 minutes.

The stratification in all cases was analyzed by comparing the mean of temperatures at the top (Tc 1-4) near the absorber and at the mean of temperatures at the bottom (Tc 5-8), of the collector. The overall collector temperature was the mean temperature of all the 8 sensors in the tank (Tc 1-8) averaged at each of the four positions.

RESULTS

The behavior of the collector with a plain absorber indicates that stratification temperatures difference between the mean of top four sensors (Tc 1-4), and the mean of four bottom sensors (Tc 5-8), increases with time (figure 4). When the temperature evens out after 11.00 pm, this big stratification temperature difference remains. With a finned absorber (figure 5), the stratification temperatures difference between the mean of top four sensors (Tc 1-4), and the mean of four bottom sensors (Tc 5-8) does not increase with time. It is five times smaller by 12.30 pm, compared to stratification temperatures difference between the mean of top four sensors (Tc 1-4), and the mean of four bottom sensors (Tc 5-8) for the plain absorber by 12.30 pm. From the results, the stratification temperatures difference between the top of the collector (the mean of top four sensors (Tc 1-4)), and the bottom of the collector (mean of four bottom sensors (Tc 5-8)) was 15°C, with the plain absorber (no baffles). The stratification temperatures difference was 3°C with the finned (baffled) absorber under the same conditions.

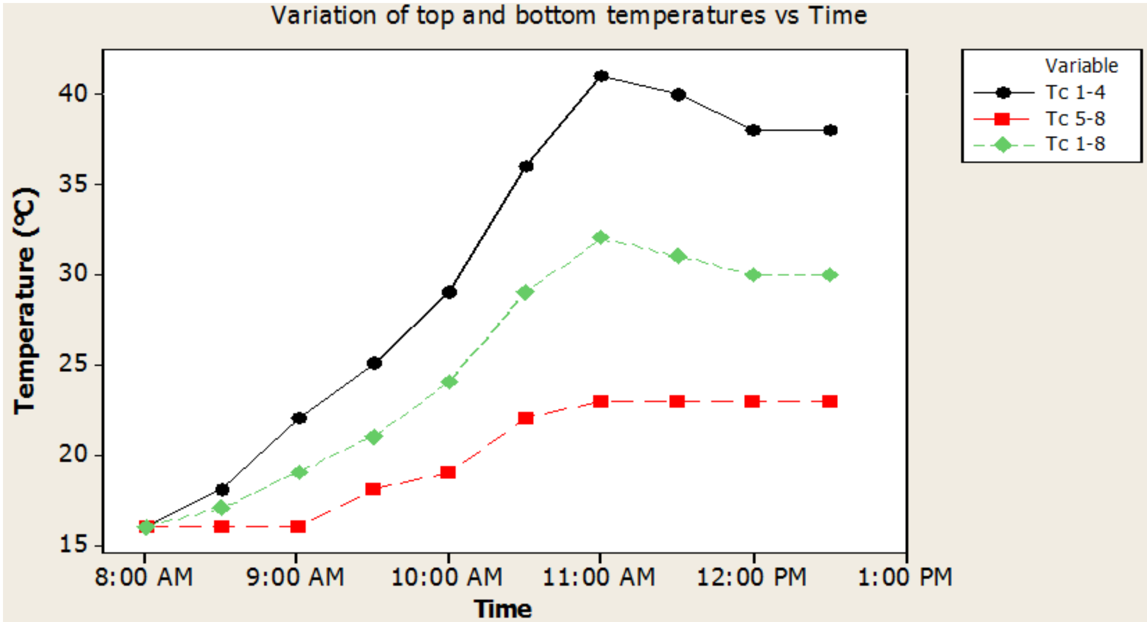

Figure 4: Variation of Temperature at the Top and Bottom of Collector Tank with a Plain Absorber

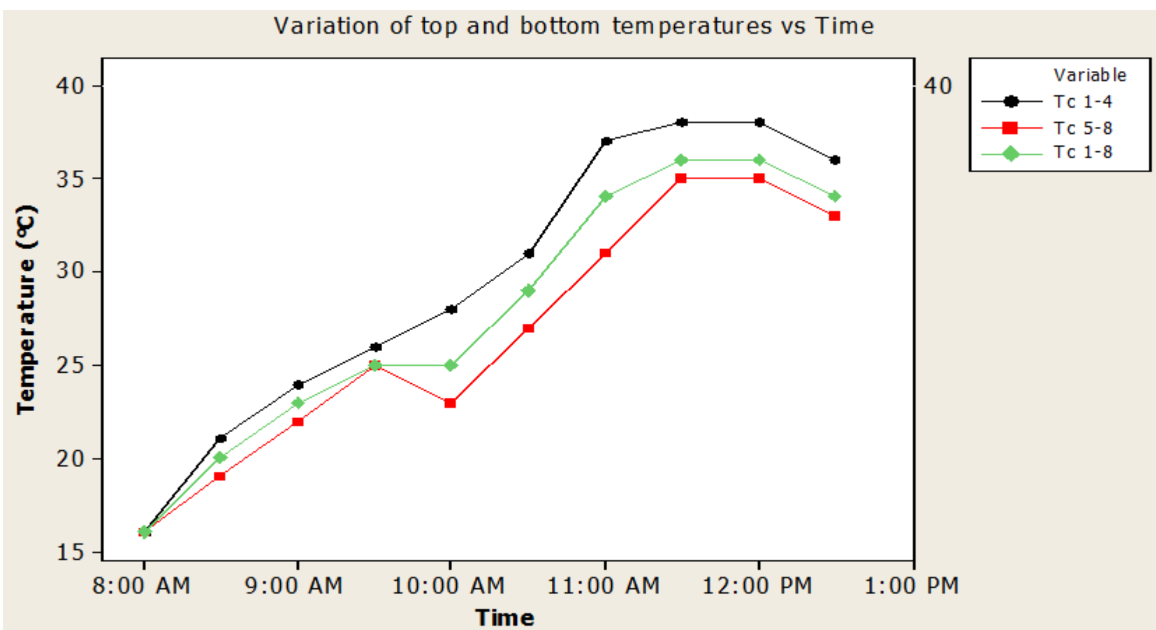

Figure 5: Variation of Temperature at the Top and Bottom of Collector Tank with a Finned Absorber

With the finned absorber and glass cover fitted, various inclinations gave improving stratification temperature differences as the collector inclination angle increased. Figure 6 shows that the highest stratification temperature difference between the mean of the four bottom temperatures (Tc 1-4) and mean of the four top temperatures (Tc 5-8) at each inclination angle. The highest stratification of 29°C occurs at 15° collector inclination and the lowest of 3°C occurs at 60° collector inclination. The stratification temperature difference starts to be noticeably improved from 30° collector inclination angle, onwards to steeper angles as illustrated in figure 6.

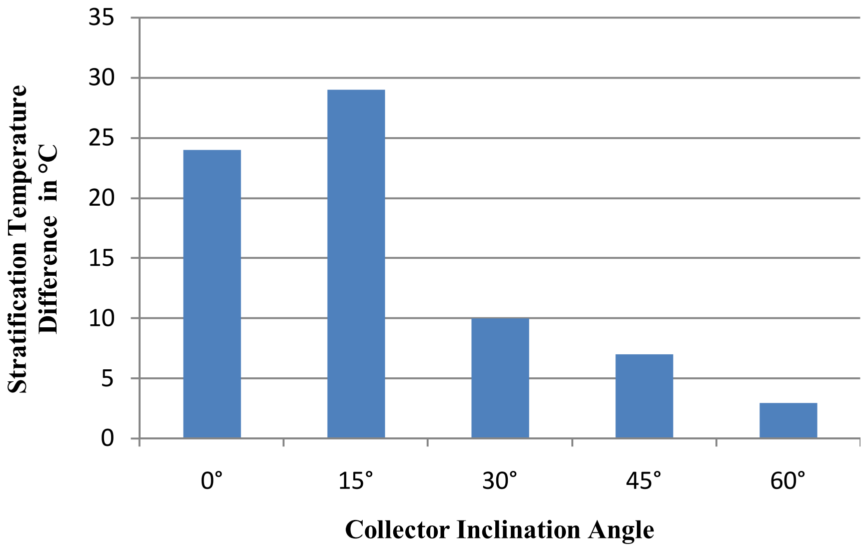

Figure 6: Variation of Stratification Temperature at the Top and Bottom of the Collector Tank at Various Collector Inclinations

DISCUSSION

Integrated Collector Storage (ICS) systems can satisfactorily cover the need of about 100-200 liters per day of hot water in the low temperature range of 40-70 °C (Rhushi Prasad P., *et al.,* 2010). This study provides a technique that allows batch heaters to be used where there is no cold water plumbing to help unload the heated batch.

The plain absorber (with no fins or baffles) is observed to have a widening difference between the mean of the four top temperatures and the mean of the bottom four temperatures with time. The reason was that as the insolation increased with time, it initiated stronger convection currents that arose from the heated water becoming lighter and floating to the top of the tank. On the other hand, the fins on the absorber in the second case prevented this pile up of hot water at the top of the collector by utilizing the currents caused by thermosyphon to churn and mix up the layers into an even temperature.

As a physical confirmation of the action of the baffles, the finned absorber had the smallest stratification temperature difference of 3^0C at the highest collector inclination. This is the steepest inclination angle in this test when thermosyphon action is expected to be strongest. On the other hand, the non-finned absorber had a stratification temperature difference of 15^0C under the same physical conditions. These results mean that steeper inclination angles produce better mixing, confirming that steeper inclination angles produce stronger thermosyphon currents. Stratification at the horizontal position is about 5^0 less than at 15^0 inclination. This is because at the horizontal position, convection currents are weaker than at 15^0 inclination, hence creating less stratification.

Thermosyphon action improves with higher angles of inclination, these convective currents would be strongest at 60^0, a reason why the temperatures are almost equal at the top and bottom of the tank at this setting. This confirms Symons and Peck (1984) that convection is affected by the angle of inclination of the plate. However with a 60^0 degree inclination, more optical losses occur due to the cosine loss occurs in the beam component as the collector is tilted from the horizontal (Rhushi *et al*., 2010). Collector inclination of 45^0 is an acceptable angle as optical losses are unlikely to prevent attaining of the target temperatures. The baffles fixed to the underside of the collector also aided in improving heat penetration to the lower parts of the tank by conduction and convection as supported by Garg *et al.* (1991) who in their study introduced an absorber plate with fins attached in an effort to improve energy transfer efficiency.

From the results, it is evident that stratification temperature difference can be controlled by selecting inclinations angles and by adding mixing baffles inside the water tank. Higher inclination angles resulted in better mixing of the water in the tank due to stronger currents. A strong thermosyphon action has proved beneficial for this mixing. From results, the best angle to use in this respect is inclination angles of 45^0 to 60^0 with a finned absorber collector and a glass cover.

CONCLUSION

The plain absorber had a large stratification temperature difference, between the top and bottom layers of the collector, which increased with time and with insolation, ending up at 15^0C by 12.30 pm. This difference between the top and bottom layers of the collector went down to 3^0C when the plain collector was substituted for the finned one in the same collector, operating under similar conditions. The naturally occurring thermosyphon currents together with baffles fixed to the inside of the absorber, can therefore be used to generate the mixing action required to bring all layers of the water inside the tank to an even temperature. A heater using this mechanism is suitable where there are no other means to push the hot water out of the heater, other than by gravity, for example in outdoor camping solar heaters.

RECOMMENDATIONS

It is recommended that similar studies should be carried out with air as the heating fluid since the result would be of interest to incubator manufacturers.

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