Solar Water Heater Research Project:

Collector Facing Horizontal Angle Orientation

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ENVS 102- Environmental Science Lab

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**Introduction**

**Objective**

Our initial goal for this research project was to design and build a passive thermosyphon solar water heating system capable of reaching an optimal temperature of 100°F (38°C) – 110°F (43°C). Additionally, the system was designed to support a semester-long study on the optimal position of the collector relative to the sun, along a horizontal angle (or azimuth), capable of producing the above-stated temperatures.

**Background Research**

The overall process of this research project required a fairly extensive amount of background research, mainly to uncover and utilize the past findings of others. The background research revealed articles discussing the step-by-step process of how to construct several types of passive solar water heaters and a thorough review of relevant terminology. This served as a great starting point for understanding some of the components of designing any type of passive system. There were discussions of the methods of insulating systems, orientation of the systems relative to the sun, as well as the important design elements needed for an efficient collector and storage tank to achieve optimal insolation. The background research revealed in-depth discussions on several variations of solar heating systems and clear explanations on some underlying principles of how these systems work including the associated properties of water and thermodynamics. Basically, this was a review of the physics at work in a thermosyphon system. There were also specific reviews of flat-plate collector designs (the type used here) including the dimensions of the many parts included in such a system. There were also discussions of both open and closed loop systems practical for installation in a home.
Perhaps most helpful though, were the excellent diagrams presented throughout much of the research. Among the individual sources that proved most useful were the websites for the U.S. Department of Energy, Energy Efficiency and Renewable Energy and the past student reports (available on Dr. Floyd’s webpage) on similar research. A bibliography of the research team’s resources used for this project is located at the end of this report.

**Hypothesis**

While the research team understands that past research clearly supports a generalized south-facing collector orientation, our hopes were to reveal a more specific optimal range of horizontal angles from which a flat-plate collector is most effective in capturing solar energy. While a true south-facing (0°) collector may yield the highest levels of insolation, the research team believed there to be an optimal range of south-facing angles (-15° to +15°) that would allow the collector to capture the same amount of radiation from the sun as if it were oriented in a true south-facing (0°) direction. For the purposes of this experiment, true south will be given the value 0° (where east would be -90° and west +90°).

**Results**

**Research Design Process**

As is reflected in the weekly data graphs (see pages 9-13 and the Appendix), the dependent variable is the temperature of the water in both the storage tank and the collector output pipe. The independent variable is the orientation of the collector (expressed in horizontal angle measurement relative to the sun). In order to establish our point of reference from which to measure the angle along the horizon, the team used a magnetic compass to determine the direction of magnetic south. However, because we
used true south as our point of reference and because the magnetic North Pole and the geographic North Pole do not coincide, we also utilized a declination calculation$^1$ and a sun path chart (see Fig. 1)$^2$ to accurately orient our collector. After determining the latitude (39.27825 N) and the longitude (76.740124 W) for the 21228 zip code (Catonsville, MD), it was determined that the declination (the angle between magnetic north and true north) was 11° 0’ W. $^3$ After determining true south, using a protractor we marked-off lines of reference on the workbench to denote horizontal angles every 15° from -60° to +60°. These lines served as the basis for our weekly horizontal angle changes.

Fig. 1

The research data collection took place over a period of 7 weeks, from Tuesday March 11, 2008 through Tuesday, April 29, 2008. However, the data results reflected in our final graphs and calculations are based only upon the data collected only from week 2 through week 7 (where weeks 2 & 3 are combined as they reflect measurements from the same horizontal angle and week 1 is counted only as preliminary data from no specific horizontal angle).
In order to accurately test our hypothesis, we took measures to try and produce reliable and valid results. In part, this required controlling for as many variables as possible. Our experimentation took place within the setting of a climate-controlled greenhouse. From this setting, there was no need to control for factors regarding the weather immediately surrounding our solar heating system. However, the weather outside of the greenhouse is a variable that we attempted to control for in our final results. We were able to control for varying degrees of sun exposure (i.e. limited amount of exposure on overcast days versus full exposure on sunny days) by taking averages from our weekly data. For example, the data from the two sunniest days (presumably the two highest temperatures) of a given week were averaged and this average was used to represent the week’s average maximum storage tank water temperature.

Additionally, during the course of the project the sun’s path continually increased in altitude, appearing to rise higher in the sky as the summer solstice was approaching (see Fig. 1). While we did not physically attempt to control for this factor by making adjustments to the vertical angle orientation of the collector to offset the sun’s change in position, we took this into consideration when evaluating our data. It should be noted that the vertical position (or latitude) of the collector remained at one constant angle throughout the duration of the experiment, at about a 50° angle from the workbench.

**System Design and Construction**

The materials used in the construction of our passive solar water heater, their costs, and each item’s specific qualities and dimensions are listed in Fig. 2. Our system design was based upon the following factors: the team’s individual research on the web
and scientific databases, past student reports on similar projects, class discussions, and the availability and cost of materials.

(1) 18” X 24” X .093” Plexiglas $ 7.18
(1) 24” X 6” X ½” piece lumber $ 2.95
(2) 24” X 4” X ½” piece lumber $ 5.62
(1) 10’ X ½” M-grade copper tubing $10.59
(3) ½” copper tee fitting $ 2.32
(4) ½” copper elbow fitting $ 1.91
(2) ½” X 3/8” copper female adapter $ 6.78
(2) 3/8” X 3/8” brass hose barb adapter $ 5.26
(1) duct tape $ 4.53
(1) plumbing tape $ 1.05
(1) 1.3 gallon (4.9 liter) plastic container w/lid $ 5.82
(1) can matte finish black spray paint $ 5.00
(1) box 1 ¼” finishing nails $ 2.65
(2) 3/8” plastic hose barb nipple w/gasket N.A.
(2) 3/8” inside diameter vinyl plastic tubing piece N.A.
**Total Cost** $61.66

**Fig. 2 Building Materials**

The flat-plate collector dimensions were designed relative to the size of the water storage tank by using a 1 sq. foot collector facing per 1-gallon tank ratio, as this was revealed as optimal in our research. The storage tank capacity was approximately 1.3 gallons (or 3.75 liters) of water, but we kept it filled with approximately 3.5 liters (or 0.35 cc) of water. It was important to use a square-sided storage tank so that the fittings installed on its side would fit flush without any leaks. Also, a tight fitting lid for the storage tank was necessary, not only to prevent loss of water through evaporation, but also to prevent unwanted heat loss through the top of an open container. The final dimensions of the collector measured L24” X W7” X D4”. However, it is important to note the Plexiglas facing measured at L24” X W6” or 1 square foot. This was an unconventional part of our design, while still in keeping with the desired 1 square foot
measurement. Our original intention for elongating the collector was to maximize the horizontal space within our limited workbench area, as we would be rotating the collector each week. We chose to utilize copper tubing to construct the collector manifold (see Fig. 3) because of its superior heat transfer abilities when compared with vinyl tubing, as was also revealed in our research. However, vinyl tubing was used to connect the storage tank to the collector to and from both the intake and outtake.

![Collector manifold prior to assembly. Shown with straight pipe, tees & elbows.](image)

**Fig. 3** Collector manifold prior to assembly. Shown with straight pipe, tees & elbows.

After its assembly, the collector manifold was painted black in an effort to collect the most amount of the sun’s energy. We found it sufficient to attach the Plexiglas facing with duct tape instead of risking breakage by attaching it with nails or screws. Finally, it is important to note that there was no insulation used on this solar water heater. This decision was based upon the objective of reaching a maximum temperature, without concern for actually sustaining a maximum temperature. **Figures 4 & 5** show the completed system at work in the greenhouse, facing a +60º angle along the horizon.
Weekly Data Graphs and Lab Notes

Week 1 Tuesday, March 11-Tuesday, March 18:

After the construction and assembly of our solar water heating system was complete, we decided to set it up within the greenhouse and begin collecting data with LoggerPro. The purpose of this preliminary data collection was to be sure the system was working without leaks or any other unforeseen problems with design, construction, assembly and/or initial placement. The system was oriented without regard to specific horizontal or vertical angle. LoggerPro was set to collect temperature data continuously.
for 168 hours at a rate of 4 samples per hour. The data software monitored two distinct area’s temperatures with probes located in: 1) the water in the storage tank and 2) the water in the collector output pipe.

After the first week of continuous data collection we noticed no leakage of water. The storage tank reached a maximum temperature (on Monday, March 17, 2008) of 31.01º C (87.82º F) and the collector output pipe reached a maximum (same day) of 27.12º C (80.82º F). A graph of week 1 data can be found in the Appendix.

Weeks 2 & 3 Tuesday, March 18-Tuesday, April 01:

![Graph of 2008 Mar 19 to Apr 01: 0 Degrees](image)

Beginning at week 2, we set up a system from which we could make weekly adjustments to the horizontal angle placement of the collector. The collector was positioned at a horizontal angle of 0º (true south) and a vertical angle of approximately 50º from upright. The LoggerPro was set to collect for 350 hours at 4 samples per hour. During these two weeks of testing, the storage tank reached a maximum temperature (on Wednesday, March 26, 2008) of 26.91º C (80.44º F). Since our hypothesis predicted that,
at this angle (0º or true south), our tank would reach its highest temperature, the group was surprised to have not reached a higher maximum temperature.

**Week 4 Tuesday, April 01-Tuesday April 08:**

This week, the horizontal angle of the collector was adjusted to +15º. The group determined that we would be more likely to find a position of optimal sunlight collection if we continued movement westward along the horizon. The vertical angle was kept constant, at approximately 50º. LoggerPro was set to collect continuously for 168 hours at a rate of 4 samples per hour. The storage tank reached a maximum temperature (on Saturday, April 05, 2008) of 30.61º C (87.10º F). With this new information, the group decided to continue collector movement for next week westward along the horizon.
This week, the horizontal angle of the collector was adjusted to +30º. The vertical angle was kept constant at 50º. The LoggerPro was set to collect continuously for 168 hours at a rate of 4 samples per hour. The storage tank reached a maximum temperature (on Thursday, April 10, 2008) of 34.71º C (94.48º F). Again, in order to locate an optimal angle for maximum insolation, the group decided to continue movement of the collector toward a more westward-facing orientation for next week.

Additionally, it was noticed that while constructing the collector we failed to remove the thin plastic protective covering from the Plexiglas collector facing. Although Dr. Floyd did not foresee this as a problem for solar collection, the group disassembled the collector and removed the protective covering anyway. Also, it should be mentioned that from the first week of data collection, the water in the covered storage tank remained at a constant level, with no need for refilling. However, the group has needed to monitor weekly, the position of the temperature probe in this tank because the connecting cord
(from probe to computer) was stretched to its maximum length and had a tendency to almost lift the probe tip out of the water surface. Luckily, the probe has remained in the tank water at all times, but its placement has varied from the tip being \( \frac{1}{2} \) inch submerged to about 2 inches submerged.

**Week 6 Tuesday, April 15-Tuesday, April 22:**

This week, the horizontal angle of the collector was adjusted to +45º as we have yet to ascertain any optimal range. The vertical angle was kept constant at 50º. The LoggerPro was set to collect continuously for 168 hours at a rate of 4 samples per hour. The storage tank reached a maximum temperature (on Friday, April 18, 2008) of 35.39º C (95.70º F). In keeping with the trend of the past several weeks of data, this week’s maximum storage tank water temperature is the highest recorded thus far. The group will
make calculations in order to account for the ever increasing outside air temperature and determine if the water’s temperature is a function of the outside air temperature.

**Week 7 Tuesday, April 22-Tuesday, April 29:**

![Graph showing temperature data for Apr 22 to Apr 29: +60 degrees](image)

This week, the horizontal angle of the collector was adjusted to +60º as we have yet to ascertain any optimal range. The vertical angle was kept constant at 50º. The LoggerPro was set to collect continuously for 168 hours at a rate of 4 samples per hour.

The storage tank reached a maximum temperature (on Saturday, April 26, 2008) of 35.56°C (96.01°F). This week’s maximum water temperature is the highest overall temperature that the water in the storage tank had reached for the duration of the experiment. Based solely upon maximum storage tank water temperature, this may mean we will not locate any optimal range of horizontal angle orientation.
Discussion

In order to more clearly and comprehensively evaluate the week-to-week data, several data tables and graphs of the combined weekly data have been constructed. Such graphs allowed the research team to draw conclusions about the data and notice any trends that may have occurred. In addition, these graphs helped us to evaluate whether or not our research hypothesis is, in fact, supported. Interestingly, some final graphs seem to support our hypothesis while others can be seen as refuting the hypothesis.

Final Graphs

As the research progressed, it appeared that a clear trend was developing while evaluating the maximum temperatures achieved from week to week, as seen in the following chart entitled Maximum Temperature. Contrary to our hypothesis, with the

![Maximum Temperature Chart]

Contrary to our hypothesis, with the
collector facing 0° (or true south), the graph reveals that the water in the storage tank reached a high temperature of approximately 26.91°C, compared with a high temperature of approximately 35.55°C with the collector facing +60° horizontal angle. This evidence alone does not support our hypothesis that an optimal range of collector insolation should exist at south-facing horizontal angles and these angles would be within the range of -15° to +15°. According to the graph directly above, no optimal was yet discovered and furthermore, a southwest-facing collector had provided the highest temperatures, thus, the most insolation, or exposure to the sun’s rays.

However, several factors may have played a role in receiving this data. This may have been a result of the protruding southeast wall of the greenhouse blocking some of the early afternoon sun and preventing an accurate reading of the highest possible level of sun exposure available to the collector at a true south-facing angle (or 0°). At the same time, the vertical angle at which the collector was held constant (approx. 50°) may have played a prominent role. It is possible that when the collector was oriented in a more southwest-facing horizontal angle, the collector was at an optimal vertical angle for the maximum collection of solar energy and perhaps the opposite was true when the collector was more south-facing.

Also of interest, and perhaps most closely in support of our hypothesis, is the final graph illustrating the relationship between outside air temperature and storage tank water temperature entitled Outside Tmax per Storage Tank Tmax (seen on page 16). In this graph, the relationship was meant to show if the temperature of the water within the storage tank was a function of the temperature of the outside air. The maximum water temperature at a specified horizontal angle was compared with the maximum outside air
temperature occurring on that same day (for further data, see Appendix for the graph illustrating *Outside Tmax and Storage Tank Tmax*).

By the significant variances in ratio, it can be said that the temperature of the water within the storage tank is not a function of the temperature of the outside air, which also supports the fact that the water temperature increases are a result of a properly functioning thermosyphoning solar water heater. Perhaps of equal importance, this graph seems to support our hypothesis that an optimal range of collector insolation should exist at south-facing horizontal angles within the range of -15° to +15°. Note the highest data point (1.837°C) exists at a horizontal angle of +15°.

The data tables for the graphs discussed above, as well as further research with additional graphs and tables, can be found in the Appendix.
Mechanisms and Design

There are other factors regarding the mechanisms of operation and system design that are important to discuss. First, the collector design held some interesting and unintended consequential effects. As was discussed in the above section entitled System Design and Construction and as seen in Fig. 4 above, the collector was an elongated version of the more conventional square-shaped collectors others chose to build. Our original intentions for this component of the design are explained above. However, what is important to consider is the possibility that this elongated collector may have allowed us to more accurately test the levels of insolation at varying angles along the horizon. That is, although the total surface area measured 1 square foot, only 6 inches (the width of the collector) of collector facing was available to capture solar energy.

In addition, the depth of our collector may have also inhibited less direct sunrays to enter the collector by effectively blocking them out. Although this was an unintended consequence of our design, and may have been a factor in the water temperature never reaching our desired goal, this may be an important element for future researchers to consider.

Although our system, thus far, was unable to reach the desired water temperature range of 38º C to 43º C, it suffered no leaks at anytime and was built quite solidly. It is possible that the number of manifold piping or its volume capacity played a role in its ability to achieve higher temperatures. Further research on these variables was conducted this semester and should be considered by others in their design as an important factor. Again, the depth of our collector may have played a role in lower than expected water temperatures as well. The four inch deep walls created a larger than necessary volume of
air within the collector that may have had an effect on its ability to produce higher
temperatures.

Lastly, although we had weekly data on the temperature of the water as it first
exited the collector from the collector output pipe, we spent little time evaluating these
numbers. We used this data only as a means to evaluate if our system was working
properly, but other data seemed to conclusively show that it was working properly.
However, it should be mentioned that the expected result was that the water in the
collector output pipe would consistently be at a higher temperature than the water in the
storage tank. In fact, the opposite was true. This may point to some design flaw, but it
would require further investigation.

Conclusion and Recommendations

Conclusion

Overall, the most important aspect of this research project involved rethinking the
relationship between humans and energy consumption. Our attempt to optimize a
component of capturing solar energy for the purpose of heating water mostly illuminated
one simple fact: the Sun’s energy, unless stored, is not consistently available 24 hours a
day, year-long at any one place on Earth. However, the “needs” of humans living within
industrialized societies currently dictates an ever-ready supply of energy with many of
these sources quickly being depleted. Thus, it is important for the scientific community to
optimize solar energy. However, perhaps it is most important for humans to rethink our
energy consumption and relative “needs” in light of what sources are truly available long-
term. At this point, conservation of energy is the most immediately effective way of
heading-off any foreseen or unforeseen problems associated with our current worldwide
energy consumption. The Appendix includes data graphs and tables measuring the amount of Btu’s and Calories our specific solar heater was able to produce. Also related, are the graphs in the Appendix illustrating the maximum change in temperature entitled $\Delta T_{\text{max}}$ and $\Delta T_{\text{max Avg}}$. While evaluating these, the bench-scale size of our system must be considered, as the numbers may appear unimpressive, but can be applied to a larger system’s water volume capacity.

**Recommendations**

In terms of technical recommendations here are a few. Get your system up and running as quickly as possible, *without* compromising quality. Our group was up and running first and still able to collect useable data for only 7 weeks. Seven weeks may seem like enough, but in fact it was not. If we were to redo this experiment several things would change. However, without the fortune of having current access to the other research groups’ most recent data and conclusions this will be a more generalized suggestion. It is probably much more important than we had anticipated to simultaneously measure and compare both the horizontal and the vertical orientation of the collector in relation to the sun. Although we attempted to keep the vertical constant and thought it possible to later account for the changing altitude of the sun’s path, we have no definitive evaluation of the effects of this variable. However, future researchers may be able to simply use data from this semester’s groups and evaluate the relationship based upon past research.

A crucial component to this project rests in the group’s ability to keep continuous, detailed and accurate lab notes. Summarizing any information at the close of the research would prove very difficult without these. Do not rely on memory alone as you will
probably only remember what you think is important at the time and dismiss some critical observation that could easily have been noted and revisited later.

Additionally, this project requires a fair amount of critical evaluation and it is much easier to do so as a group. What one researcher overlooks as valuable information, another is sure to pick up on. With that said, do not hesitate to become engaged in the thinking process of the research, as every member has much to contribute, despite their level or area of understanding.

Do yourself, and your group, a favor and research as much as possible during the first few weeks of lab. This is critical and will determine your success for the duration of the project. Also, keep in mind the immense amount of information that exists, not only on the web or in books, but also the knowledge within yourself, other group members and the instructor. The chances are, if you start asking the questions, someone will help you find the answer. However, initiative is paramount in a lab setting.
Notes


3. NOAA, Geomagnetism.


Bibliography


Appendix- A1

Week 1 Data Graph

![Graph showing temperature changes over time for Storage Tank and Collector Output Pipe from 2008 Mar11 to Mar18 with no specified angle.]

Final Data Tables

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<th>Horizontal Angle (x-axis)</th>
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Appendix-A2

Final Graphs

**Avg Max Temp (Top 2)**

- 26.88765
- 30.18211
- 32.79374
- 35.2564
- 33.98093

**Delta T Max**

- 12.17925
- 14.73219
- 18.49237
- 19.53291
- 16.51113
Appendix-A3

**Delta T Max Avg (top 2)**

- 11.95299
- 16.2371
- 13.29703
- 15.73192

**Storage Tank Tmax and Outside Tmax (reflects data from corresponding days)**

- 26.91084
- 30.61493
- 34.71464
- 35.38907
- 35.55831

- 20.556
- 16.667
- 22.778
- 26.667

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Max Temp  
Outside Temp max
Outside Tmax per Storage Tank Tmax (reflects data from corresponding days)

System Caloric Output (single day) - Delta Tmax x .35cc

Appendix-A4
Appendix-A5

System Btu Output (single day)

Horizontal Angle (0 to +60 degrees)

- 90.98
- 110.03
- 138.12
- 145.89
- 123.33

Btus