The Thermal Conductivity of Common Tubing Materials Applied in a Solar Water Heater Collector

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The resurgence of solar heating to reduce home energy consumption has home owners constructing their own collectors. In examining the available drawings there is a variety of tubing materials used in the construction solar water heaters. This research has examined the identified six common tubing materials used in the construction of solar water heaters. Of the six materials two are metallic and four are plastic based. The thermal conductivity factors indicate that the metallic materials will outperform the plastic materials. A test collector was constructed employing the six tubing materials for the implicit purpose of comparing their ability to conduct heat in comparison to the thermal conductivity rates. Data was collected at the top of the hour every hour throughout the day in which the temperature reached a sufficient level for recording. The tests of the differing tubing materials have indicated that there is statistically no difference between the materials. This lack of difference indicates that one material should not be chosen over another in terms of its ability to transfer heat to the liquid within the tubing.

Key Words: Solar, Collector, Tubing, Thermal, Materials

Introduction

With the increasing energy costs (EIA, 2009), there is a revitalization for renewable energies to reduce the domestic energy costs (Recovery, 2009). One of the options includes the use of solar hot water collectors for generating domestic hot water and residential heating systems. The current cost factors places a restraint on the purchase and installation of current systems is a prohibitive factor for most residential home owners. Home owners are examining other avenues to enter the solar market. With interest in constructing solar collectors verses purchasing a factory built model, differing tubing materials are being employed to reduce the initial cost. Solar water heater plans available in various books and on internet for constructing solar collectors for the homeowner to construct. These plans recommend using locally available common water pipes (Markell & Hudson, 1985).

The majority of the commercially available solar water heaters are constructed using copper tubing for the transferring heat to the fluid flowing within and for the collector plate. The expense of copper is making the current models extremely expensive (Plante, 1983). Currently copper is the standard tubing material used in solar water heaters. The need to find other materials that conduct heat as well as copper, but at a lesser cost, have directed designers to explore different methods for construction. The analyses of common water pipes commercially available are tested to differentiate between the tubing materials by examining the thermal conductivity of the tubing materials for use in the construction of solar hot water heaters. In examining books and the internet for plans six common tubing materials are currently employed; copper, PVC, CPVC, PEX, PE and steel piping (Markell & Hudson, 1985) (Campbell, et al, 1978).

Thermal Conductivity

The thermal conductivity of tubing materials describes the amount of energy required to increase the temperature of the liquid inside the tubing to the same temperature on the exterior of the tubing. Simply stated, thermal conductivity is the rate at which heat is transferred through a material. Different materials contain differing thermal conductivity rates, based upon their molecular structure. The heat flow through the tubing material increases or decreases in heat by the amount of energy presents (Hewitt, 2006).

The thermal conductivity of the selected materials and the calculated heat transfer per unit of time is presented in Table 1. The ratings provided indicate the materials ability to transfer heat. The higher the rating of the material indicates the greater the ability of the material to transfer heat. This transfer rate is influenced by the thickness of the materials. All units are presented in SI units. The SI unit W/mK indicates the amount of energy in Watts or one joule per second taking into consideration the thickness of the material in meters and the temperature in Kelvin's (Manufactures Monthly, 2009).

Table 1

Thermal Conductivity of Tubing Materials

Piping	Material	W/mK
Steel	Carbon Steel	54
Copper	Copper	401
PEX	Cross-linked High-density Polyethylene	0.51
CPVC	Chlorinated Polyvinyl Chloride	0.14
PE	Polyethylene	0.38
PVC	Polyvinyl Chloride	0.19

(Manufactures Monthly, 2009) (Thermal Conductivity of Some Common Materials, 2005) (EMCO Industrial Plastics, 2009)

Fourier's law examines the heat transfer through a solid material. This transfer is relative to outside area and thickness of the walls of the tubing. This is assuming that the heat transfer is at right angle to the path of the flow of heat and the taking into consideration the differences in temperatures on the outside of the tubing and the inside of the tubing (Serway & Faughn, 2003). As these temperatures are constantly changing throughout the day it is difficult to employ Fourier's law directly to this research beyond a hypothetical examination. Differing tubing materials and their varying thermal conductivity factors are affected differently throughout the day within a solar collector. The constantly changing temperatures in the collector would have the calculations frequently changing throughout the day from the differing climate conditions.

Fourier's Law is presented as:

$q = k A dT / s$

where:

q = heat transferred per unit time (W, Btu/hr)
A = heat transfer area (m^2, ft^2)
k = thermal conductivity of the material (W/m.K or W/m ^oC, Btu/(hr ^oF ft^2/ft))
dT = temperature difference across the material (K or ^oC, ^oF)
s = material thickness (m, ft)
(Serway & Faughn, 2003)

The transfer and absorption of heat is an important factor in the efficiency of solar water collectors. The greater the heat transfer the greater the amount of solar heat is captured for use. The flow rate of the fluid within the collector creates a differing heat transfer for differing systems. In an open system a slower rate allows for a higher transfer. In contrast to closed system where the same fluids are re-circulated a higher flow rate will not have the same affect upon the amount of heat transfer.

Problem Statement

Numerous types of piping materials are available in today's market. There are six types of piping materials that are commonly used in residential structures and readily available to the consumer. These six piping materials are; copper, steel, PVC, CPVC, PE, and PEX. This study is designed to examine which piping material would provide safe and reliable tubing materials for inclusion in residential solar water heaters. When the differing tubing materials are used in a solar collector is there a variation between the thermal conductivity of the materials? If so, which type of piping material provides the highest rate of thermal conductivity and in turn the highest level of heat retention? It is assumed that the manufacture of the various piping materials is made to a consistent quality. This consistency implies that the selection of materials used in the experimental collector is equal to other materials available for purchasing. The expected results will show that the metal piping materials will conduct heat better than the plastics and that the copper pipe will outperform all the materials as this is most commonly used tubing material.

Methodology

This study examines the various piping materials for their use in the construction of a solar water heater in terms of their ability to transfer heat. The thermal conductivity of the piping materials is given in terms of their material makeup and the associated conditions. The piping materials thermal conductivity is given in terms of normal use. The testing apparatus described below is used to scientifically test the differing piping materials. The examination of the piping materials is conducted by examining the published data and the data collected from an experimental solar water heater.

Thermal Conductivity Testing Apparatus

The test collector is designed to establish which common piping material conducts heat with the greatest efficiency as shown in Figure 1. The variables measured were the temperatures for a statistical comparison to determine, if any, differences between the differing materials. The application of the six piping materials in a solar collector is investigated using an experimental collector designing and constructed to test the materials under actual conditions. The analysis of the differences between the solar thermal conductivity of the common available types of pipes is conducted using a model solar collector. The collector was devised using common materials. In the construction of the collector from left to right the piping materials are; PEX, copper, CPVC, black steel pipe, PVC and PE (black plastic roll pipe). For consistency in construction each pipe is capped on the lower end using PVC and CPVC caps, per the appropriated pipe size.

The proper angle is 10 degrees more than the latitude where it is located. The collector is set up at a 45 degree angle (the collector was setup at latitude $35^0$20'46.11"). For the optimum collection to the sun the collector is directed due south after the correction for magnetic angle.

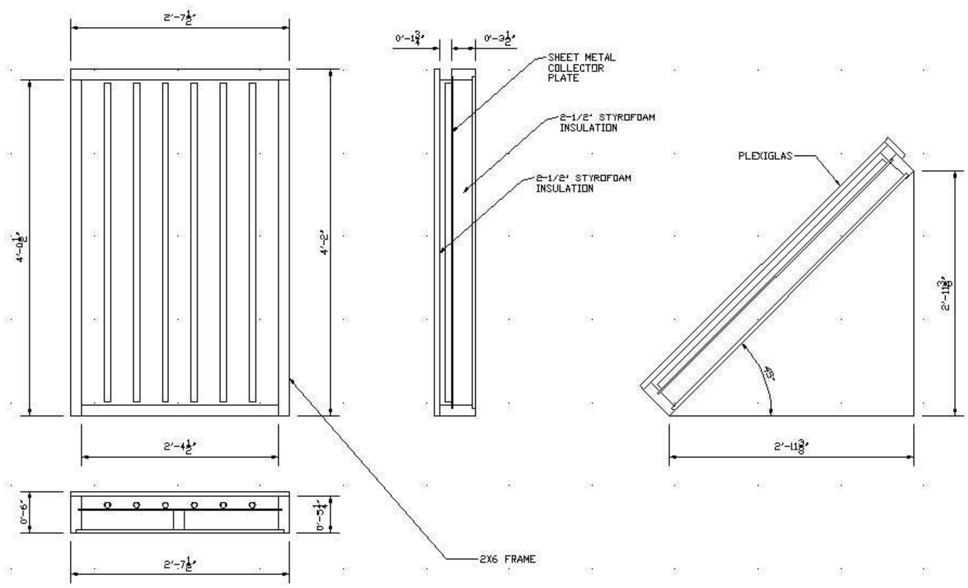

Figure 1: Experimental Frame Plans

The collector was equipped with a standard thermometer (Taylor Bi-Therm Pocket Thermometer 1" dial and a 5" slim stem, rated 50 to 550 degrees Celsius) at the top suspended to measure the collector temperature. To have access to the pipes within the collector, the insulated top of the collector is removable. With the thermometer readings start at 50 degrees Celsius, readings are taken at the top of each hour starting when the temperature went above the 50 degree Celsius reading. Each of the tubes was filled the previous night with tap water to maintain an equal temperature reading by providing time for the water to acclimatize. Along with each of the water temperature and collector readings the ambient air temperature readings were taken and visual notes on weather conditions and the location of the sun.

The collected data was analyzed using a selected statistical process for the difference in temperature throughout the day using a one-sample T-Test. Each of the daily temperatures is analyzed for a difference between the differing types of tubing materials per hourly temperature readings. The significance probability level is set at 0.05. Using the T-Test it is assumed that the data is normally distributed. The differences between the differing results are compared and discussed. The analysis was performed using SPSS.

The studies were conducted over several days during August and early September of 2009. Four day long tests were conducted to collect data and to record observations. The tests were conducted near the town of Sylva, NC. The test site was located at 35^{0}20'46.11"N by 83^{0}16'24.71"W at an elevation of 2569 feet above sea level. Sylva, NC is located 45 miles west/Southwest of Asheville, NC.

Results

As stated, the capability of piping materials to absorb and transfer collected solar heat to the liquids flowing within the pipes is critical to the absorbers efficiency. The investigation to determine which piping materials consisted of building an experimental collector and documenting the differing temperatures on the hour. The descriptive statistics indicated an average temperature of 122.84 degrees Celsius and an average time of the day of 15:30. The results were analyzed using a T-Test. Presented in the four data sets in Tables 2 through 5 are the results of the T-Tests for each of the data sets. All temperatures were taken in degrees Celsius.

The temperatures that were analyzed used the average temperature throughout the day. This provided a basis for the statistical analysis to determine if there was a statistical difference between the thermal conductivity of the pipe. The results of the average daily temperatures are provided in Tables 2 through 5.

Table 2

12 August 09 Data

One Sample Test						
Test Value = 0						
					95% Confidence Interval of the Difference	
	T	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Lower**	**Upper**
Copper	12.417	8	.000	123.88889	100.8819	146.8958
PEX	11.243	8	.000	122.11111	97.0661	147.1561
CPVC	12.842	8	.000	124.11111	101.8249	146.3973
Steel	12.998	8	.000	124.11111	102.0916	146.1306
PVC	12.418	8	.000	123.55556	100.6107	146.5004
PE	12.355	8	.000	123.00000	100.0427	145.9573

Table 3

23 August 09 Data

One Sample Test						
Test Value = 0						
					95% Confidence Interval of the Difference	
	T	Df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Copper	9.729	7	.000	119.25000	90.2661	148.2339
PEX	9.571	7	.000	118.50000	89.2239	147.7761
CPVC	10.295	7	.000	119.37500	91.9553	146.7947
Steel	10.264	7	.000	119.12500	91.6817	146.5683
PVC	10.349	7	.000	120.75000	93.1604	148.3396
PE	8.809	7	.000	113.12500	82.7593	143.4907

Table 4

30 August 09 Data

One Sample Test						
Test Value = 0						
					95% Confidence Interval of the Difference	
	T	Df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Copper	9.729	7	.000	119.25000	90.2661	148.2339
PEX	9.571	7	.000	118.50000	89.2239	147.7761
CPVC	10.295	7	.000	119.37500	91.9553	146.7947
Steel	10.264	7	.000	119.12500	91.6817	146.5683
PVC	10.349	7	.000	120.75000	93.1604	148.3396
PE	9.614	7	.000	115.62500	87.1865	144.0635

Table 5

12 September 09 Data

One Sample Test						
Test Value = 0						
					95% Confidence Interval of the Difference	
	T	Df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Copper	10.605	8	.000	131.00000	102.5152	159.4848
PEX	10.620	8	.000	130.33333	102.0332	158.6335
CPVC	10.204	8	.000	130.00000	100.6217	159.3783
Steel	10.475	8	.000	128.33333	100.0828	156.5838
PVC	10.764	8	.000	130.33333	102.4115	158.2551
PE	10.757	8	.000	128.88889	101.2584	156.5194

Given the test sample sizes, the results of the T-Test provide figures that are very similar from test to test. The test scores show very little difference as well as the mean difference and the lower and upper differences in the T-Test. These differences are consistent between each of the tests.

Discussion

The comparison of the six piping materials will assist in the selection of which tubing will conduct heat with the highest efficiency. The average temperature of 122.84 degrees Celsius is well above the average boiling point of water. Using the thermal conductivity factors (Table 1) of the materials to determine the efficiency of the piping materials it is evident that copper pipe will supply the highest efficiency at 401 W/mK and that CPVC pipe is the least efficient at 0.14 W/mK. The examination of the disparity between the two factors would indicate that conclusively copper would outperform CPVC in a solar water heater.

In each statistical measurement of the collected data, the degrees of freedom, the T-Test results and the significance level (P-values) (as presented in Tables 2 through 5) are within the prescribed ranges to determine that there is statically no difference between the various temperatures. The statistical results contradict the material properties. The assumed difference between the tubing materials occurs when the heating of the collector equalizes the temperature within the pipe materials when they are in applied subjected to the intense heat in a solar collector.

Conclusion

Contrary to the differences in the thermal conductivity factors for the selected materials, in a test collector the six materials of the tubing performed in a manner that statistically there is no difference. From the thermal conductivity and dispersion of heat to the collector fluid, any of these materials could be selected for use in a solar water heater. The selection of the materials on this one factor does not conclusively determine the proper material for a particular use. This experiment has proven that when differing piping materials are used they will perform in a similar manner. A balance will occur when there is a constant heat and that the tubing walls are too thin to make a difference. Placing the different tubing materials into a solar collector and subjecting them to intense temperatures creates conditions that they transmit heat and radiate heat equally. There are no visual changes in the piping materials from the intense heat generated in the collector. The lifespan of the materials is not determined within the confines of this research.

The results of this research will assist in the design of future water heater collectors both for the individual and the corporation. The cost implication for both entities is an important consideration. Lower construction costs will entice a larger following to explore solar water heating. Future designs can include a wider range of tubing materials with confidence that there is no reduction in efficiency. The ultimate emphasis is to create a solar collector that is affordable and easy to maintain for most homeowners. In addition the application of differing materials for use in disaster stricken areas to provide inexpensive water heating capabilities to those who have had their lives interrupted. The construction of solar panels will greatly depend upon the person's construction abilities. The results of the research is to provide data that will aid in the decision making process in the construction be it by an individual or a manufacture. The next step is to examine the different tubing materials to determine their life cycle in a collector along with a comparison to the cost in purchasing and manufacturing the panels.

Future Research

In future tests taking temperatures at shorter intervals would produce dataset with greater accuracy. Shorter time intervals of measurement were not practical due to the design of the test collector. In the current experiments, to measure the temperatures of the water in the tubing the top of the collector had to be removed. The top is insulated to prevent the escape of heat. By frequently removing the top the collector, the collector would gain the maximum heat level with the heat constantly being released. In a perfect test an electronic thermometer is placed in each of the tubes and tied into a computer program that would provide a continual flow of data for comparison. Future research will explore the melting points of the various tubing materials and their life cycle in the extreme temperatures of a solar collector.

References

Campbell, S., Taff, D., & Vogel, R. (1978). *Build Your Own Solar Water Heater.* Charlottte, Vermont, USA: Garden Way Publishing.

EIA. (2009, September 9). *EIA - Short-Term Energy Outlook*. [WWW document]. URL http://www.eia.doe.gov/steo

EMCO Industrial Plastics. (2009). [WWW document]. URL http://www.emcoplastics.com/index.cfm?fuseaction=product.display&product_ID=41&ParentCat=7

Hewitt, P. G. (2006). *Conceptual Physics.* Boston, MA, USA: Pearson.

Manufactures Monthly. (2009, September). [WWW document]. URL http://www.manmonthly.com.au/Article/Understanding-Polyethylene/136748.aspx

Markell, L. G., & Hudson, J. (1985). *Solar Technology.* Reston, Virginia, USA: Ruston Publishing Company, Inc.; A Prentice-Hall Company.

Plante, R. H. (1983). *Solar Domestic Hot Water, A Practical Guide to Installation and Understanding.* New York, New York, USA: John Wiley & Sons.

Recovery, N. (2009, June 6). *NC Office of Economic Recovery and Investment.* [WWW document]. URL http://www.ncrecovery.gov/News/PressReleaseDetail.aspx?newsItemID=45

Serway, R. A., & Faughn, J. S. (2003). *College Physics.* Pacific Grove, CA, USA: Thomson-Brooks/Cole Publishing.

Thermal Conductivity of Some Common Materials. (2005). [WWW document]. URL www.engineeringtoolbox.com/thermal-conductivity-d_429.html