Solar heating

SOCRATES MINERVA Programme 99843-CP-1-2002-1-PL

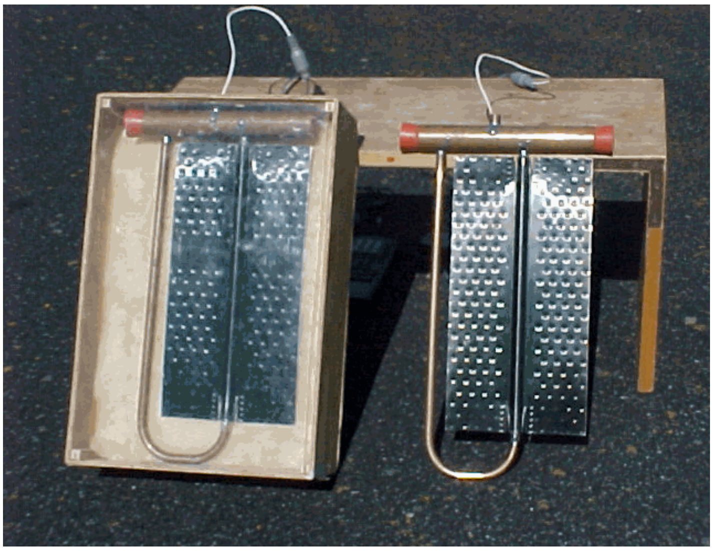
Data acquisition

Objectives:

The objective of this experiment is to explore how insulation, covers and different surface materials effect the power and efficiency of a solar panel.

Materials:

Temperature sensor, CBL, TI83/84, solar heating panel, insulation material and plastic or glass covers.



Before you start the experiment try to figure out how a temperature versus time graph will look. Sketch the graph. How hot can the panel be and what will the increase look like? Also try to think of how different experimental setups may influence the result.

If there are many groups conducting the experiment it might be interesting that different groups investigate how different arrangements influence the result of the experiment. A way is to let every group do as they think is the best and compete about the best efficiency of the panel.

Before setting up the experiment make sure that you have the programs TEMP and CLEAN in your TI-83.

Fill the solar collector with cold water. Do not forget to measure the amount of water it contains and make notes of that.

Attach the temperature probe to channel 1 of the CBL and connect it to the calculator. Put the probe in the water in the collector.

Start the program TEMP on your calculator. The calculator screen prompts for the number of samples per second. The program is written to take 99 data points, which means that an input of 1/30 gives 30 s between samples and a total experimental time of 50 minutes. Please observe that the time interval must be an integer multiple of 0.25.

After the experiment the temperature versus time graph will be shown on the calculator screen. The y-axis is the temperature in ˚C and the x-axis is the time in seconds. The temperature data are stored in list L_2 and the time data is stored in list L_1.

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Data analysis (TI83/TI84)

If you download data from the website you get two temperature graphs, one for an uninsulated collector and one for a collector that is insulated on the backside and covered with a plastic window on the side directed towards the sun. The dimension of the collector is 28 cm x 14 cm and it contains 1,4 dl of water.

Analysis 1: Discussion of the temperature curve

Study the graph and compare it to the curve you sketched before performing the experiment. If there are differences try to figure out why.

The most apparent thing of the curve is that it seems to reach a plateau where the temperature is stable. Why is it so?

Try to think of different ways to improve your collector. If time permits, try them! Also try to explain why these improvements work.

Analysis 2: The power from the collector

Use the curve to find a value for the power that the collector gives. What happens with the power as the temperature increases? If you want to compare your collector with others you have to agree on the temperature at which you should calculate the power.

To use hot water in your household it has to have a certain temperature. This is to prevent certain germs to grow in your heater. Find that temperature in a book or ask somebody who knows. What is the power of your collector at this temperature. What power is needed to be able to provide the hot water needed for your family?

People that uses solar heating normally do not heat the water all the way using the sun. Find out how a large-scale solar heating system works.

Analysis 3: The efficiency of the collector

On a bright day the sun shines with a power of approximately 1000 W per square meter. Use this value to calculate the efficiency of your solar heat collector.

When you have finished your work, **but not before**, you can compare your conclusions with this completed analysis.

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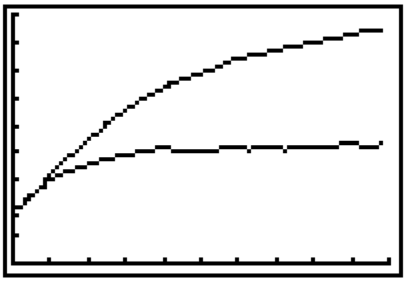
Completed analysis (TI83/TI84)

After performing the experiment you get a graph over temperature as a function of time. If you download data from the website you get two temperature curves. One for an uninsulated collector and one for a collector that is insulated on the backside and covered with a plastic window on side exposed to the sun.



Analysis 1: The temperature curves

As is seen from the graphs the temperatures do not increase linearly, but rather exponentially towards a maximum value. This is because the collector not only absorbs energy but also radiates heat. The emission is proportional to the absolute temperature to the power of 4. This means that the hotter the collector gets the more energy is radiated from it. At a certain temperature the energy lost by radiation is equal to the energy received from the sun. An equilibrium is reached and the temperature will not increase anymore.

To improve the efficiency of the collector it is important to try to minimize the energy losses. As is seen in the two graphs the insulated and covered collector reaches a much higher temperature before equilibrium. The reason for this is:

Insulating the backside: By insulating the backside the collector is prevented from radiating heat from half of its surface. Thus the energy losses is cut to the half.

Covering the front: Covering the front with glass or plastic results in an effect similar to the green-house-effect. The glass allows the shorter wavelengths of high-energy radiation from the sun to pass through, but it absorbs the longer wavelengths that are emitted from the collector, thus cutting energy losses even more.

Increasing the amount of cooling-water: If the amount of cooling-water is increased the temperature of the collector will not be as high and the losses are smaller. The drawback with increased cooling is that the temperature of the water from the collector will be lower and that might be a problem in some applications.

Changes of the surface of the collector: That a material is black means that it does not reflect but absorbs visible radiation. There are materials that have different characteristics in different wavelengths of the electromagnetic spectrum. One way of increasing the efficiency of the collector is to use a "selective black paint, ie. a paint that is black in visible light and "white" in infrared. This "selective black" surface will absorb the sunlight but is not so good when it emits the longer wavelengths of heat radiation.

Analysis 2: The power of the collector

A steep slope of the temperature graph indicates that more energy is absorbed during a certain time interval, say 1 second, compared to a flat curve. This also means that more energy can be taken from the collector if the hot water should be used for heating purposes.
A recommended temperature of hot household water in Sweden is 70 ˚C to prevent bacteria from growing in it. This temperature is not even reached for the uninsulated collector and for the insulated one the graph is flat. At this temperature the power from the collector is not very high.

To calculate the power two points on the graph are chosen, one with a temperature slightly below 70 ˚C and one slightly above.

Choosing the points (1500; 68,69) and (1650; 71,49) the energy that is needed to increase the water temperature is

$$W = m \cdot c \cdot \Delta T = 0{,}14 \cdot 4180 \cdot (71{,}49 - 68{,}69) = 1639 \text{ J}$$

The power absorbed by the collector will then be:

$$P = \frac{\Delta W}{\Delta t} = \frac{1639 \text{ J}}{150 \text{ s}} = 11 \text{ W}.$$

The power available from the collector is the same.

In most systems the water from the collector is not used directly in the household. It is just preheated to by the collector to 50 ˚C. Us is understood from the discussion above this is because the power of the collector is so much larger as the slope of the curve is high, that is if the temperature is low. If we make the same calculation when the temperature is 50 ˚C the power from the collector will be 20 W. Check this!

If we want to compare the two collectors with each other we have to go to a even lower temperature, say 30 ˚C. At this temperature the power from the two will be:

From the insulated collector: 28 W

From the uninsulated collector: 17 W

Analysis 3: The efficiency of the collector

The efficiency tells us how much of the incoming energy is converted to useful energy. In this case it is the ratio between the energy stored in the hot water and the energy in the incoming sunlight. Given the dimensions of the collector and the intensity of the sunlight we can calculate the power that hits the collector:

$P_{in} = 1000 \text{ W/m}^2 \cdot 0.14 \text{ m} \cdot 0.28 \text{ m} = 39.2 \text{ W}$

The efficiency for the insulated collector at 70 ˚C will then be:

$$\eta = \frac{10.92 \text{ W}}{39.2 \text{ W}} = 0.28 = 28\,\%$$

This means that the collector converts 28 % of the energy in the suns radiation to useful energy.

Note that if we settle for a temperature of 30 ˚C the efficiency of the isolated collector will be as high as 71 %.