Heat

Heat transfer
Solar collector

Determining the efficiency of a solar collector as a function of the throughput volume of water

Objects of the experiment

- Receiving the temperature curve as a function of time of the forced circulation
- Estimation of the efficiency

Principles

A solar collector absorbs radiation energy and heats itself and the through putting water.

The efficiency η is the ratio of the heat energy ΔQ absorbed by the water and the radiation energy ΔE:

$$\eta = \frac{\Delta Q}{\Delta E}$$

Where the radiant energy is

$$\Delta E = \Phi \cdot \Delta t$$

with Φ: radiant power.

When the collector is warmer than the environment, it gives off energy by radiation, convection and conduction of heat to the environment. Due to these losses, the efficiency decreases.

The driving force of gravity circulation for the water cycle is created by the difference of the densities of the warm water in the collector and the cold water in the reservoir. The warm water rises up and is displaced by the inflowing cold water. The starting of circulating the water or the throughput speed depends on a strong heating of the collector. Since the collector must first already assume a high temperature, the losses are large and it is given a lot of heat energy to the environment.

Therefore, a forced circulation is generated in the experiment with the help of a pump. The absorbed thermal energy of the complete system (collector, tubes and the reservoir) is distributed on the water, so that the temperature of the solar collector becomes not as high as at the gravity circulation.

In the experiment, a water pump is operated with different voltages, i.e. it is possible to work with different throughput speeds. Here, the temporal temperature characteristic of the water in the reservoir is measured.

Fig. 1: Set up

Kem 05-13

Apparatus

1 Solar collector 389 50

1 Flood light lamp 1000 W, with light shades.... 450 72

1 Water pump STE 2/50 579220
1 Variable extra-low voltage transformer S....... 521 35
1 Cable 100 cm, red/blue, pair.......................... 501 46

1 Mobile-CASSY... 524 009A
1 NiCr-Ni-Adapter S, type K............................. 524 0673
2 Temperature sensor NiCr-Ni, 1,5 mm, Type K529 676

1 Steel tape measure, 2 m............................... 311 77
1 Stoppclock 313 17

2 Stand base V-shape, 20 cm 300 02
1 Stand rod 25 cm, 12 mm Ø............................ 300 41
1 Stand rod 47 cm, 12 mm Ø............................ 30042
1 Stand rod 75 cm, 12 mm Ø............................ 30043
3 Leybold multiclamp....................................... 301 01
1 Universal clamp 0...80 mm 666 555

1 Plastik beaker 590 06
1 Silicone tubing 5 mm Ø, 1 m.......................... 604 431
1 Silicone tubing 6 mm Ø, 1 m.......................... 604 432
1 Silicone tubing 8 mm Ø, 1 m.......................... 604 434
1 Connector, straight, 6/8 mm Ø....................... 665 226

Setup

a) Water cycle

Set up the experiment as shown in Fig. 1. Use appropriate silicone tubings and connectors for the connection of the tubings with the nozzles.

- Connect the water pump so, that it pumps the water from the bottom through the solar collector, i.e. connect the output pump nozzle with the nozzle of the input chamber.
- Fix a temperature sensor directly at the output chamber of the solar collector with the help of the rubber stopper with 1.5-mm bore.
  This temperature measurement point is also used to prevent overheating of the solar collector. The water temperature must not exceed 60 °C
- Connect the nozzle of the output chamber with the input nozzle of the reservoir.
- Connect the output nozzle of the reservoir with the input of the water pump.
- Fill 1000 ml water into the reservoir.
- Lift the reservoir so that the water flows through the water pump into the solar collector and flows back into the reservoir at its input. All tubings must always remain without folding so that the water can flow without disturbance.
- Hang the reservoir on to the intended support rod.
- Switch on the power supply and run water pump with about 6 V observing the polarity.
- Make sure that the tubing system is now free of bubbles.

b) Measuring of temperatur

- Hold the second temperature sensor with the help of the universal clamp into the water of the reservoir.
- Connect the temperature sensors to the NiCr-Ni-adapter and the Mobile-CASSY.

c) Illumination

- Set up the flood light lamp on a stand base approximately 50 cm in front of the solar collector.
- Switch on the flood light lamp and align it so that the actual solar collector is illuminated. If necessary adjust the light shades slightly, so that the plastic housing is not illuminated.
- Switch off the flood light lamp and let cool down the solar collector.

Carrying out the experiment

a) Preparation

- Measure the temperature at switched water cycle and wait until the temperatures do not change anymore.

a) Measurement

- Reduce the voltage at the water pump so (to about 2.5 V), that only a small throughput speed is reached, i.e. only a small flow of water into the reservoir can be observed.
- Write down the temperature in the reservoir and observe the temperature in the output chamber.
- Simultaneous switch on the flood light lamp and start the stoppclock. Take a measuring value every minute.

Safety note

The water temperature must not exceed 60 ° C !

- Stop the measurement after 10 minutes.

Note: For longer measuring times note the maximum allowed temperature.

- Replace water to cold water. Make sure that the same amount of water is taken. The experiments should be started with the same initial temperature as possible.
- Adjust voltage (to about 4 V) at the water pump, so that a medium water flow into the reservoir can be observed
- Repeat the experiment.
- Repeat the experiment with a higher voltage (app. 7 V), i.e. with a large throughput speed.

Measuring examples

Table 1: Temperature characteristic of water in the reservoir

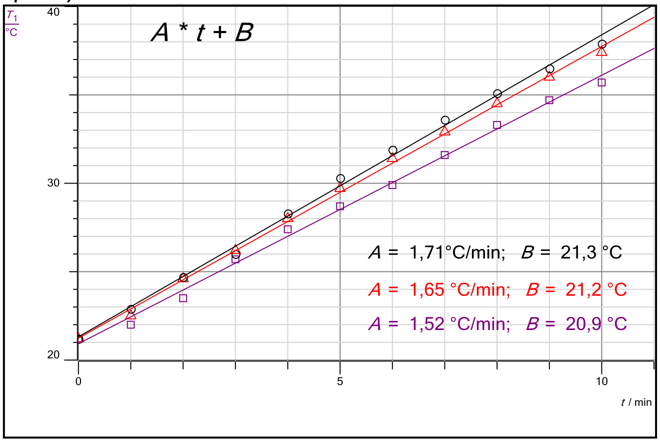
	throughput speed		
	small	medium	large
time	temperature		
$\frac{t}{\text{min}}$	$\frac{T_1}{°C}$	$\frac{T_2}{°C}$	$\frac{T_3}{°C}$
0	21.2	21.2	21.2
1	22.0	22.5	22.9
2	23.5	24.6	24.7
3	25.7	26.2	26.6
4	27.4	28.0	28,3
5	28.7	29.7	30.3
6	29.9	31.4	31.9
7	31.6	32.9	33.6
8	33.3	34.5	35.1
9	34.7	36.0	36.5
10	35.7	37.4	37.9

Table 2: Difference of temperatures between the output chamber of the solar collector and the reservoir

throughput speed		
small	medium	large
difference of temperatures		
$\frac{\Delta T_1}{°C}$	$\frac{\Delta T_2}{°C}$	$\frac{\Delta T_3}{°C}$
app. 6	app. 3	app. 1

Evaluation

Diagram: Temperature as function of the time
(Squares: small, triangles medium, circles: large throughput speed)



The diagram clearly shows that the temperature increase in the investigated time period can be considered linear.

With increasing throughput speed the temperature increases faster, i.e. there is more radiant energy taken up from the water. Thus, the ratio of energy (heat energy of the water) to the supplied radiant energy is larger.

Directly at the output of the solar collector the temperature is higher at lower throughput speed, see table 2. Due to the higher temperature of the solar collector more heat energy is lost.

As a rough estimate of the efficiency of the whole experimental setup, the electric power of the lamp is used:

The lamp is operated with an electrical power of 1000 W. One part of this power leads to heating of the lamp. Another part of the radiation doesn't light the solar collector and one part is reflected. Thus, the radiant power onto the solar collector is significantly less than 1000 W.

The absorbed heat energy Q of the water can be calculated by the mass m and the specific heat capacity c of the water:

$$\frac{Q}{t} = c \cdot m \cdot \frac{\Delta T}{t}$$

Another part of the absorbed radiant energy leads to heating of the system.

Example with the value of small throughput speed:

$$4.2 \frac{\text{kJ}}{\text{kg K}} \cdot 1 \text{ kg} \cdot 1.52 \frac{\text{K}}{\text{min}} \approx 100 \frac{\text{J}}{\text{s}} = 100 \text{ W}$$

The efficiency of the whole system is therefore in the order of 0.1 at small throughput speed and 0.12 at large throughput speed.

The real efficiency (ratio of usable energy and the real incoming radiant energy) is much bigger than this order. For real solar collector systems value of up to 80 % are given.