SOLAR COLLECTOR TESTING

1. CONSTRUCTION AND PRINCIPLE OF OPERATION

A solar collector is used to convert solar energy into heat. We divide collectors into gas and liquid collectors (these are agents which absorb heat and transfer it to the heating water). The most common solar collectors are liquid collectors, including flat plate collectors.

A flat plate collector (Fig. 1.) consists of:

- a transparent cover (a condition for the "greenhouse effect");
- Absorber (usually a metal plate with an emissivity close to unity, i.e. e=1, which absorbs radiation very well);
- the heat exchanger (ensures the transfer of heat from the absorber to the working medium);
- thermal insulation (ensures elimination of heat loss from the collector to the environment).

A simplified schematic of a flat plate solar collector is shown in Figure 1.

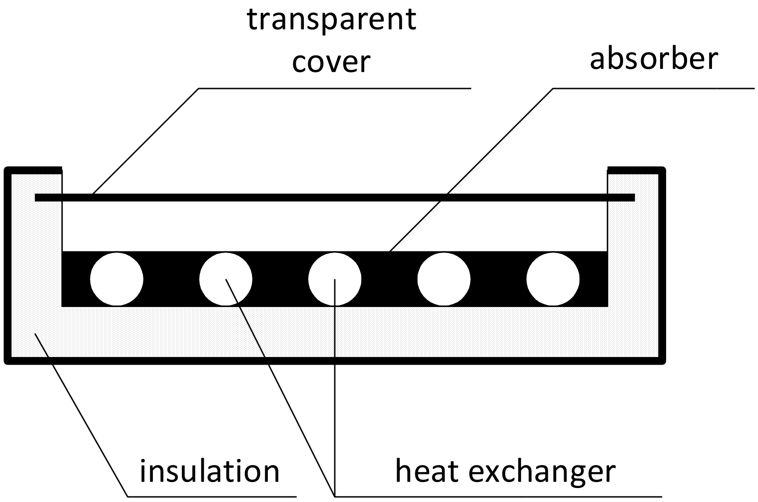
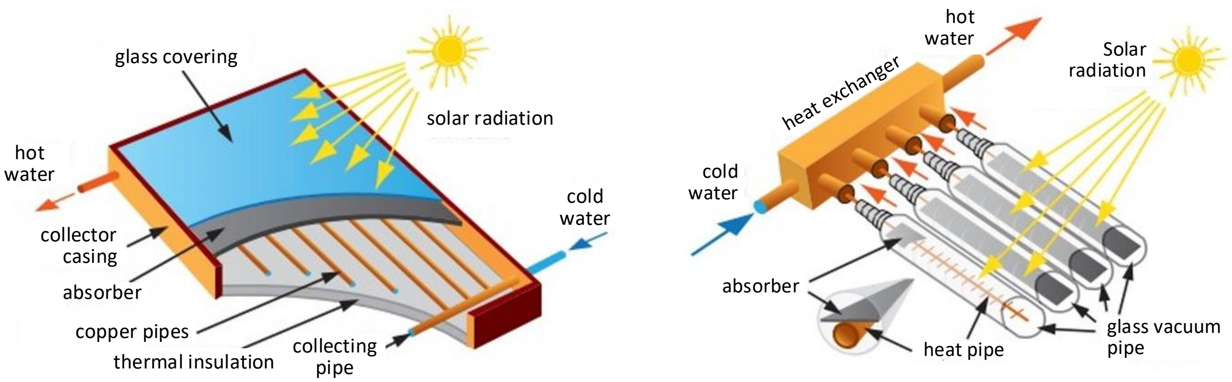


Fig.1. A simplified schematic of a flat plate solar collector

Greenhouse effect - a phenomenon occurring inside a greenhouse in which solar radiation - mainly from the visible spectrum - passes through the glass roof and walls of the greenhouse and is absorbed by the floor, ground and other objects, which then give off energy in the form of infrared radiation. As infrared radiation does not penetrate the glass, the temperature inside the greenhouse rises [1-4].

The greenhouse effect as an atmospheric phenomenon - a similar phenomenon to the one described above, but this time it is the earth's atmosphere that plays the same role as the transparent roof and walls of the greenhouse. In this case, the Earth's surface absorbs most of the sun's radiation, giving it back as infrared radiation. This radiation is absorbed by CO2, H20, ozone in the atmosphere, as well as by clouds, and then re-radiated back towards the Earth. This process prevents a rapid drop in temperature at night after a hot day, particularly when the H2O content of the atmosphere is high [1-4].

A solar collector is most commonly used to heat water flowing through it, using the radiant energy absorbed on the surface of the absorber. When determining the thermal efficiency of a solar collector or system, it is important to realise that this depends not only on its design, but also on the weather situation, the angle of the device in relation to the sun, as well as other operating conditions of the collector, such as the temperature of the absorber. Examples of typical solar collector designs: plate and so-called vacuum is shown in Figure 2



a)

b)

Fig. 2. Typical structures of solar collectors: a) plate, b) the so-called vacuum

2. TEST STAND AND RELATIONSHIPS FOR DETERMINING THE EFFICIENCY OF A PLATE SOLAR COLLECTOR

The test stand for testing the plate solar collector from Phywe (Germany), shown in Figure 3 [1,2], consists of:

Fig. 3 Main components of a flat plate solar collector test stand [1, 2]

1 - solar collector:

2 - thermoelectric thermometers ,

3 - circulating pump with rotameter,

4 - power supply: 0÷12 V DC,

5 - heat exchanger,

6 - fan with heater,

7 - halogen lamp: 1000 W,

8 - glass jar: tall, 2 litres, placed in a container with walls made of insulating material (polystyrene)

The aim of the laboratory exercise is to determine the thermal efficiency of a solar collector in various operating conditions.

The glass cover of the collector absorbs and reflects the energy of the incident radiation only to a small extent (due to the low absorption and reflection coefficients of the cover material). The part of the energy that passes through and falls on the collector absorber is mostly absorbed by it, can be expressed as [1-4]:

$$\dot{q}_a \ = \propto * \ \tau * \dot{q}_l \tag{1}$$

where: $\dot{q}_a$ - density of the radiant energy flux converted into heat on the absorber, [W/m^2]

$\dot{q}_l$- density of the radiation energy flux incident on the collector, [W/m^2];

α -absorption coefficient of the absorber;

τ -transmission coefficient of the glass cover.

Radiant energy converted into heat cannot be fully used as useful energy. Some of it is lost due to radiation, conduction and convective losses. The remaining part of the energy causes an increase in the temperature of the absorber, i.e. this part of the energy is stored in the collector. Therefore, the density of the useful energy flux is equal to [1-4]:

$$\dot{q}_N = \dot{q}_a - q_l - \dot{q}_s \tag{2}$$

where: $\dot{q}_l$ - energy flow density of absorber losses, W/m^2;

$\dot{q}_s$ – density of the energy flux stored by the absorber, W/m^2

Under experimental conditions

$$\dot{q}_s = 0 \tag{3}$$

because the temperature difference is measured under steady-state conditions with a practically almost constant water temperature at the collector inlet over time.

The heat losses $\dot{q}_l$ of the absorber are greater the higher its temperature. Heat loss by conduction is mainly determined by the quality of insulation of the rear surface of the collector. On its front side, there are heat losses due to radiation and convection. The total collector losses can be described by the relationship [1-4]:

$$\dot{q}_l = \ k * (\vartheta_A - \vartheta_U) \tag{4}$$

where: k - heat transfer coefficient from the collector to the surrounding air, W/m^{2}K;

ϑ_A - absorber temperature, °C;

ϑ_U- ambient temperature, °C.

The efficiency of a solar collector is the ratio of useful energy to the energy falling on the collector, i.e. [1-4]:

$$\eta = \frac{\dot{q}_N}{\dot{q}_l} = \alpha * \tau - \frac{k * (\vartheta_A - \vartheta_U)}{q_l} \tag{5}$$

The absorber temperature ϑ_A is not known, but the inlet water temperature ϑ_e and outflow ϑ_a are known (from measurement). Equation (5) does not allow direct calculation of the collector efficiency because the heat flux density q̇ N is not known. Therefore, introducing the absorber efficiency factor f, we have [1+4]:

$$\eta = f * \left[\alpha * \tau - \frac{k * (\vartheta_W - \vartheta_U)}{\dot{q}_l}\right] \tag{6}$$

where: ϑ_W average water temperature in the collector:

$$\vartheta_W = \frac{(\vartheta_e + \vartheta_a)}{2} \tag{7}$$

The useful power P_N is determined under conditions determined from the water mass flow rate $\dot{m}$ through the collector and the difference in water temperature at the outlet and inlet. The water flow rate is changed by changing the pump supply voltage on the DC power supply board. In bench tests, the mass flow rate is usually set to 100 g/min:

$$P_N = \dot{m} * c * (\vartheta_a - \vartheta_e) \tag{8}$$

where: $\dot{m}$ - mass flow rate of water through the collector, kg/s

c = 4180 J/(kg*K) - specific heat of water [1].

The collector efficiency is calculated from the equation [1-4]:

$$\eta = \frac{P_N}{\dot{q}_l * A} \tag{9}$$

3. DETERMINATION OF THE THERMAL EFFICIENCY OF A SOLAR COLLECTOR

The stand was additionally equipped with a digital temperature meter and resistance sensors which replaced glass laboratory thermometers. The water temperature in the ultrathermostat chamber is measured in its central part using an immersed mercury thermometer. The water temperature at the inlet and outlet from the solar collector is measured using resistance thermometers. Temperature values or the value of the inlet and outlet temperature difference are displayed on the front panel of the digital temperature meter with a resolution of 0.1^{O}C.

A view of the laboratory stand for testing a flat solar collector used in the exercise is shown in Figure 3.

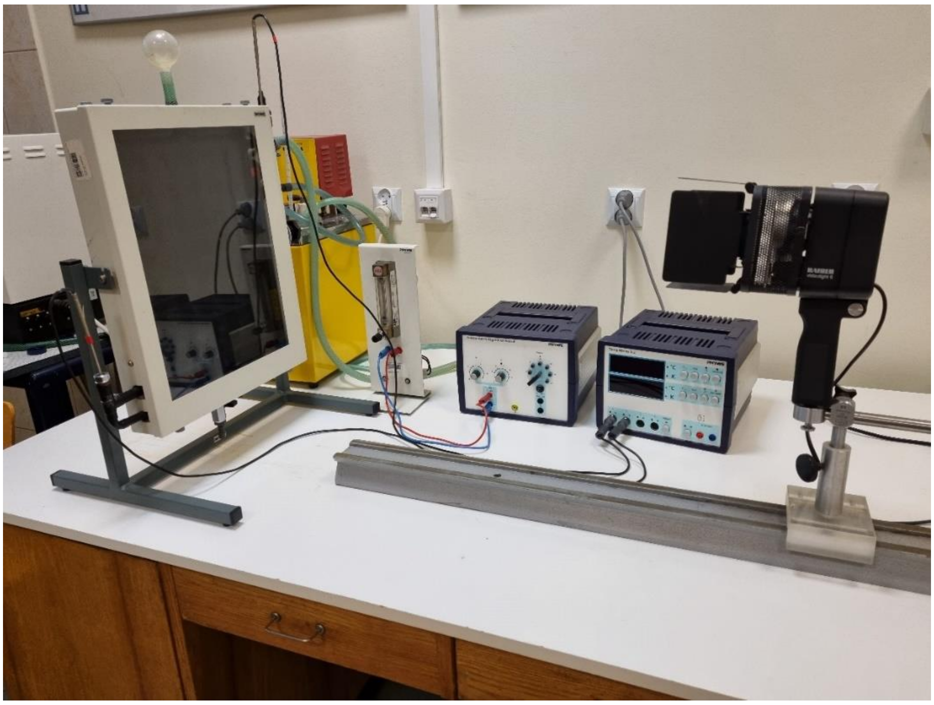


Fig. 3 View of laboratory test stand for flat plate solar collector

The heat exchanger was placed in the ultrathermostat chamber, which allowed for modification and differentiation of the measurement procedure during the exercise.

When testing the thermal efficiency of a solar collector, the following conditions must be met:

- the solar collector is illuminated with a halogen lamp of known light intensity;
- the energy absorbed by the collector will be calculated from the known mass flow rate and the known water temperature difference at the inlet and outlet from the absorber,
- water from the collector outlet flows through the coil (heat exchanger) and is again fed to the collector inlet, creating a closed circuit,
- the coil is placed in an external tank filled with water and maintained at a constant temperature. Thanks to this, the water temperature at the absorber inlet is kept almost constant,
- the measurement will be carried out with various configurations of collector elements: with or without a transparent cover and for different absorber temperature values;
- during the experiment, a halogen lamp and a stream of cold air can repeatably simulate the conditions of heat transfer to the environment - simulation of weather conditions,
- in all measurement cycles, the collector and the halogen lamp are optimally positioned relative to each other,
- the average temperature of the absorber can be approximated by the temperature of its tank in the selected place.

<u>Test program variants</u>:

A. Determination of the thermal efficiency of a solar collector when irradiating the collector with a halogen lamp in two different variants of its construction:

A1 - absorber with glass cover installed (complete collector);

A2 - absorber without cover (maximum absorbed energy).

In both cases, the water temperature at the inlet to the absorber should be approximately 20°C.

B. Determination of the thermal efficiency of the solar collector when illuminating the collector with a halogen lamp and additionally blowing cold air onto the collector, in two different variants of its construction:

B1 - absorber with glass cover installed (complete collector);

B2 - absorber without cover (maximum absorbed energy).

In both cases, the water temperature at the inlet to the absorber should be approximately 20°C. The angle of incidence of the inflated air should be approximately 60 degrees.

Measurement process

Before starting measurements, check the water circulation system in the solar collector in the following order:

- checking the connection of the heat exchanger (coil) with the inlet of the "pump system with rotameter" (lower connector);
- checking the connection of the pump outlet (upper connector) with the solar collector (inlet);
- checking the connection of the solar collector outlet with the heat exchanger,
- checking the attachment of the resistance thermometer sensors in their measuring sockets (no water leakage);
- checking the water level in the glass expansion tank above the solar collector

Connect a DC power supply to the pump (voltage regulation range from 3 to 6V)

Set the light beam covers in the vertical and horizontal positions appropriately. Set the head of the lamp at the distance given by the lecturer. At a distance of 70 cm from the front of the lamp, the light intensity is approximately 1000 W/m2. For a different value of the distance between the collector and the lamp, the new value of light intensity should be calculated accordingly.

We start the measurement cycle by measuring and recording (in a prepared table) the initial values of the water temperature in the inlet and outlet to the collector and in the ultrathermostat chamber.

We turn on the ultrathermostat and the temperature meter. We turn on the pump power and regulate the water flow on the flow meter to the value given by the Lecturer. We turn on the halogen lamp and at the same time start measuring time. After the designated time step for the next measurement, we measure the temperatures and record them in the table. The temperature measurement cycle takes approximately 20 – 25 minutes to stabilize the temperature values at the inlet and outlet of the collector.

After completing the measurement cycle, turn off the halogen lamp using the switch on the back wall of the casing.

ATTENTION!!! Do not immediately disconnect the lamp from the mains by pulling the plug from the socket (the fan continues to run and cool the lamp).

The measurement results are recorded in table 1.

t	$\dot{m}$	ϑ_e	ϑ_a	Δ ϑ=ϑ_a-ϑ_e	ϑ_U	η_i	P_i
min	cm^3/min	^oC	^oC	^oC	^oC	%	W
0							
1							
2							
…							
25							

Report

Using the relationships given above, calculate the radiation power reaching the collector from the lamp, the instantaneous radiation power in the collector, and provide the instantaneous and maximum efficiency achieved by the collector in cases where the absorber was covered with a cover and without a cover. In the calculations, assume that the light intensity on the collector surface is $\dot{q}_l = 1000\ W/m^2$ `[1] when the distance to the lamp front is 70 cm. Assume that the absorber area is $A = 0{,}12\ m^2$ [1] [1] and the transmission coefficient of the glass cover is τ= 88%.

The report should include the results of measurements and calculations in the form of a table.

Present the results of measurements and calculations graphically in the form of charts

- changes in water temperature at the connections (inlet and outlet) during measurements
- changes in the value of the temperature difference ΔT during measurements.
- changes in instantaneous power during measurements,
- changes in instantaneous efficiency during measurements,

Include conclusions regarding the results obtained in the report.

Literature:

[1] Phywe: Solar Ray Collector, LEP 3.6.01-00

[2] Phywe, Physics: Catalogue 3.22, page 171-222

[3] Terpiłowski J.: Kolektor słoneczny, 2009, Instrukcja Laboratorium Termodynamiki WAT (not published)

[4] B. J. Brinkworth: Energia stołeczna w służbie człowieka, biblioteka problemów, t.254, Warszawa 1979, PWN