Related topics

Absorption, heat radiation, greenhouse effect, convection, conduction of heat, collector equations, efficiency, energy ceiling.

Principle and task

The solar ray collector is illuminated with a halogen lamp of known light intensity. The heat energy absorbed by the collector can be calculated from the volume flow and the difference in the water temperatures at the inlet and outlet of the absorber, if the inlet temperature stays almost constant by releasing energy to a reservoir. The efficiency of the collector is determined from this. The measurement is made with various collector arrangements and at various absorber temperatures.

Equipment

Solar ray collector	06753.00	1
Lab thermometer, -10..+100C	38056.00	2
Lab thermometer, w. stem, -10..+110C	38060.00	1
Circulating pump w. flowmeter	06754.01	1
Power supply 0-12 VDC/6 V; 12 V AC	13505.93	1
Heat exchanger	06755.00	1
Solar coll.stand, teaching aid	06757.00	1
Immersion heater, 1000 W, 220-250 V	04020.93	1
Hot-/Cold air blower, 1000 W	47540.93	1
Halogen lamp 1000 W	08125.93	1
Tripod base -PASS-	02002.55	2
Support rod -PASS-, square, l 250 mm	02025.55	2
Right angle clamp -PASS-	02040.55	2
Universal clamp	37715.00	1
Glass beaker, tall, 2000 ml	36010.00	1
Glass beaker, short, 5000 ml	36272.00	1
Safety gas tubing, DVGW, 1 m	39281.10	3
Measuring tape, l = 2 m	09936.00	1
Stopwatch, digital, 1/100 sec.	03071.01	1
Connecting cord, 750 mm, red	07362.01	1
Connecting cord, 750 mm, blue	07362.04	1

Problems

To determine the efficiency of the solar ray collector under various experimental conditions.

1. Absorption of energy from the environment (20°C) without illumination by sun or halogen lamp, water temperature at the absorber inlet $\vartheta_e \approx 5°C$.

   1.1 Absorber with insulation and glass plate (complete collector)

   1.2 Absorber alone (energy ceiling)

Fig. 1: Experimental set-up: Solar ray Collector.
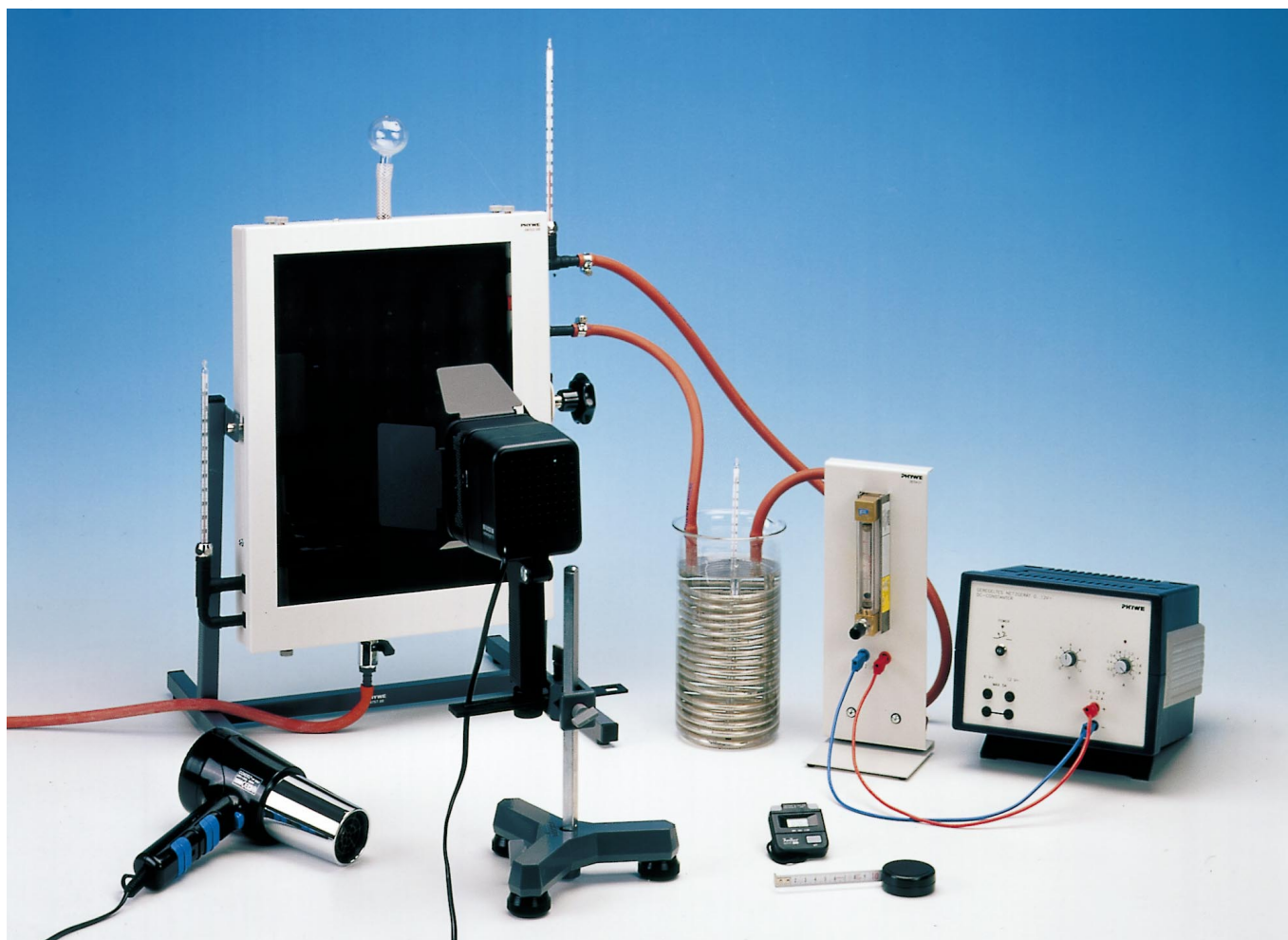
2. Illumination with halogen lamp.
   Water temperature $\vartheta_e \approx 20°C$.

   2.1 Complete collector

   2.2 Collector without glass plate

3. Illumination with halogen lamp.
   Water temperature $\vartheta_e \approx 50°C$.

   3.1 Complete collector

   3.2 Complete collector, cold jet of air impinges

   3.3 Collector without glass plate

   3.4 Collector without glass plate, cold jet of air impinges.

Set-up and procedure

The experiment is set up as in Fig. 1. The water temperature in the beaker is measured with the thermometer with immersion stem, the temperatures in the collector circuit with the other two thermometers. A check is made at the start that these two thermometers agree, any differences being taken into account in the evaluation.

To fill the solar ray collector circulation system, the heat exchanger is first connected to the pump inlet (at the bottom) by a rubber tube. A tube is also to be connected to the pump outlet (at the top) and the other side of the heat exchanger. The flowmeter valve is opened, the system is carefully filled with water (in such a way that water flows first through the heat exchanger and then through the pump) and sealed with a pinchcock.

The solar ray collector is filled via the filler connection on the underside (plug thermometers into measuring sockets!). The short connecting tube between the outlet and inlet of the absorber is removed in order to connect the pump and heat exchanger to them (see Fig. 1).

The pump requires a voltage of approx. 3…6 V DC for this experiment. The residual air is expelled from the circuit by squeezing the tubing and water is added, if necessary.

A 1000 W halogen lamp ensures uniform, reproducible illumination (zoom lever of the lamp in 'parallel' position). At a distance of 70 cm from the lamp filament the light intensity is approx. 1 kW/m^2. The heat exchanger is placed in a water reservoir (beaker). The valve on the flowmeter is to be fully opened before each separate series of measurements, so that, with maximum volume flow, the temperatures at all points of the circulation system have assumed roughly the temperature of the water reservoire.

The volume flow is set by the valve to $\dot{V} = 100$ cm^3/min in each case for recording of the series of measurements. The temperatures at the inlet and outlet of the absorber are measured, for example, every minute; they remain approximately constant after approx. 10 mm.

The duration of each series of measurements is 15min.

1. The heat exchanger is to be placed in the 2 l beaker which is filled with ice-water. Both series of measurements are recorded without illuminating the collector. In the first instance the collector is complete, for the second series of

measurements the glass plate and the rear insulation are removed.
During the series of measurements the beaker must always contain sufficient ice for the temperature at the inlet of the absorber not to exceed 5°C by a substantial amount.

2. 4.5 l of water at room temperature is poured into the 5 l beaker; the heat exchanger is put into it. The distance between the solar ray collector and the halogen lamp is 70 cm.

   Both series of measurements are recorded with illumination. In the first instance the collector is complete, for the second series of measurements the glass plate is removed, and rear insulation is left in place. Care must be taken to see that the outlet temperatures are as constant as possible (± 2 K).

3. The water in the 5 l beaker is heated to approx. 60°C with an immersion heater so that the temperatures in the collector circuit reach at least 50°C before starting the series of measurements. The distance between the solar ray collector and the halogen lamp is 70 cm.

   The hot air blower (with cold air setting) is to be set up at the side at a distance of approx. 30 cm so that the stream of air impinges on the collector at an angle of approx. 30°.

   The first two series of measurements are recorded with the collector complete, first without and then with a stream of cold air. The third and fourth series of measurements are made without the glass plate, again first without and then with a stream of cold air.

   Care is to be taken to see that the outlet temperatures are as constant as possible (± 2 K).

Theory and Evaluation

A solar ray collector is used to heat water by means of radiant energy. In order to be able to make statements concerning the efficiency of a collector or a solar installation it is essential to be aware not only of its construction but also of the weather situation, the mounting angle relative to the sun and other operating cdndit ions, such as the temperature of the absorber.

In the experiment a halogen lamp and a stream of cold air reproducibly simulate the weather. The collector is optimally aligned with the halogen lamp in each series of measurements. The mean absorber temperature can be approximately preset by means of the selected reservoir temperature.

The glass covering of the collector absorbs or reflects the incident radiant energy to a small extent. The portion passing through impinges on the absorber and is to a very large extent absorbed by it.

$$q_a = \alpha \cdot \tau \cdot q_i \qquad (1)$$

q_a = Radiant energy converted into heat in the absorber per unit time and area

q_i = Light intensity at the position of the collector

α = Absorption factor of the absorber

τ = Transmission factor of the glass covering

The radiant energy converted into heat is not all available as useful energy. Some of it is lost through heat radiation, heat

conduction or heat flow. A further portion may lead to an increase in temperature of the absorber, i.e. this portion is stored in the collector. The useful energy q_N produced per unit time and area is therefore

$$q_N = q_a - q_v - q_{sp} \qquad (2)$$

q_v = Lost energy / s m^2

q_{sp} = Stored energy/s m^2 Under the conditions in the experiment

Under the conditions in the experiment

$$q_{sp} \approx 0, \qquad (3)$$

as the temperature difference is measured in the stationary state with (almost) constant inlet temperature.

The heat losses of the absorber are greater the higher its temperature. The rear insulation determines the heat conduction losses; losses occur at the front due to radiation and convection. All the losses can be described by the following formula:

$$q_v = k \cdot (\vartheta_A - \vartheta_U) \qquad (4)$$

k = Coefficient of heat transmission

ϑ_A = Absorber temperature

ϑ_U = Ambient temperature

The efficiency of a solar ray collector states the ratio of useful energy to irradiated energy.

$$\eta = \frac{q_N}{q_i} = \alpha\tau - \frac{k \cdot (\vartheta_A - \vartheta_U)}{q_i} \qquad (5)$$

The absorber temperature is not known, the inlet and outlet temperatures ϑ_e and ϑ_a of the water are measured. Moreover, equation (5) does not take account of the heat transfer from the absorber to the water, for which an absorber efficiency factorfis. introduced:

$$\eta = f \cdot (\alpha\tau - \frac{k \cdot (\vartheta_W - \vartheta_U)}{q_i}) \qquad (6)$$

where ϑ_W is the mean water temperature.

$$\vartheta_W = \frac{\vartheta_e - \vartheta_a}{2} \qquad (7)$$

The useful power P_N can be determined in the stationary state from the volume flow of the water

$$\dot{m} = 100 \text{ g/min}$$

and the outlet and inlet temperature difference.

$$P_N = c \cdot \dot{m} (\vartheta_a - \vartheta_e) \qquad (8)$$

c = Specific thermal capacity of water.

The light intensity at the position of the collector is

$$q_i = 1 \text{ kW/m}^2,$$

the area of the absorber

$$A = 0.12 \text{ m}^2.$$

Table 1 shows the collector efficiency measured under various conditions

$$\eta = \frac{P_N}{q_i \cdot A} . \qquad (9)$$

Table 1: Water temperatures and collector efficiency under various experimental conditions, $\dot{m}$ = 100 cm^3/min, q_i = 1 kW/m^2, $A = 0 \cdot 12$ m^2.

No.	Glass plate	Light	Cold air	$\frac{\vartheta_e}{^0 C}$	$\frac{\vartheta_a - \vartheta_e}{K}$	$\frac{\eta}{\%}$
1.1	+*	–	–	≈ 5	2,5	15
1.2	–*	–	–	≈ 5	5,0	29
2.1	+	+	–	≈20	11,0	64
2.2	–	+	–	≈20	12,5	73
3.1	+	+	–	≈50	8,0	47
3.2	–	+	+	≈50	8,0	47
3.3	+	+	–	≈50	6,0	35
3.4	–	+	+	≈50	3,0	17

* This series of measurements without rear insulation

Comparison of measurements 2.1 and 3.1, or of 2.2 and 3.3, clearly shows that the losses of the collector increase as the absorber temperature increases. Conversely, if the absorber cools below the ambient temperature, energy can be taken up from the environment even without solar irradiation (measurements 1.1 and 1.2). An absorber which is not insulated is more effective in this case. Inpractice, cooling of the liquid in the absorber circuit below ambient temperature is achieved by releasing energy to a heat pump.

The measurements under 2 and 3 show the effect of the glass covering. When the collector is operated at ambient temperature, the heat losses are negligible. The transmission factor of the glass covering can be read off from the comparison of 2.1 and 2.2. Inaccordancewith equation (6):

With glass $\eta = f \cdot \alpha \cdot \tau,$

without glass $\eta = f \cdot \alpha,$

$\tau = 88\%$ approx.

Comparison of measurements 3.1 and 3.2 shows that the glass covering reduces the heat losses of the absorber: greenhouse effect! The solar radiation is for the most part allowed through by the glass plate, the heat radiation of the hot absorber is for the most part absorbed and reflected.

In the case of a collector with glass covering, the wind has no measurable effect on the efficiency, whereas the increase in temperature in the case of a collector without glass is markedly reduced (measurements 3.2 and 3.4).

Which type of glass covering is used in practice (single, double, selectively coated) depends upon the range of application of the collector, i.e. especially upon the desired absorber temperature. Double glazing reduces the heat losses at the front but also decreases the transmission of sunlight, so the expense is only worthwhile in the case of high absorber temperatures.