CYLINDRICAL SOLAR COLLECTOR WITH REFLECTOR

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Abstract. A new construction of air-heating solar collector – the cylindrical solar collector – has been worked out. Such collector can be used without or with reflectors. Measurements have been done at the Research Institute of Agricultural Machinery, Latvia University of Agriculture. Air is heated in the solar collector approximately to 40-60 ºC without reflectors and up to 90 ºC with parabolic reflectors, what results also in decreasing of the humidity of this air from 60 % (normal ambient air humidity) to 18-8 % respectively. Then such hot dry air is used for drying of agricultural products. The cylindrical form of the collector has some advantages in comparison with the traditional flat plate collector: it receives more solar energy in the morning and evening, and there is not a necessity for thermal insulation of the backside. Due to the cylindrical form of the collector, the heating power changes only slightly during the day. Since the reflector reduces the time of use of the collector to approximately 11 hours (because of covering of solar rays), it gives more improvement in the autumn and spring.

Keywords: air heating, solar radiation, cylindrical.

Introduction

Align with decrease of reserves of fossil fuel, as well as impact of use of fossil fuel on climate, in the world more attention has been paid to renewable sources of energy, including solar energy.

Also in Latvia solar energy has been used, mostly in solar collectors for hot water production [1], [2]. Another possibility of use of solar energy in Latvia is for drying of agricultural products. For this purpose mainly air heating solar collectors have been used. However, in Latvia because of its geographical and climatic conditions there are some features in comparison with traditional solar energy using countries [3; 4]. Therefore, traditional flat plate solar collectors are not efficient enough in Latvia and new constructions of solar collectors must be investigated. One of such new constructions can be a cylindrical solar collector, i.e. a solar collector with cylindrical absorber. The main advantage of such construction is a capability to receive solar energy from all sides, what means to receive also diffused radiation and from the clouds reflected one, and also better in comparison with the flat plate collector to receive energy in the morning and evening. Similar constructions of air-heating cylindrical solar collectors for drying of agricultural products already have been investigated by other authors [5; 6]. But in these investigations the cylindrical solar collector was placed vertically and the energy output and effectiveness of the collector were not investigated, only temperatures measured.

In our work a new construction of solar collector – cylindrical solar collector mounted on the axis pointed to the Polar star – has been investigated. Continuous measurements of temperature of the outflowing air allow to determine the daily course of temperature and its dependence on meteorological conditions, and to calculate the energy output and effectiveness (as defined in our previous works, eg., [7]) of the collector with or without reflectors.

In this work mainly the same collector has been investigated; use of it for hemp drying will follow later.

Materials and methods

A new construction of a solar collector – cylindrical solar collector (Fig. 1) and cylindrical solar collector with parabolic reflectors (Fig. 2) - has been investigated.

The cylindrical solar collector consists of two cylinders: the inner is black-painted metal (galvanized 0.5 mm thick steel sheet, coated with black mat silicon color), and the outer is transparent 1 mm thick PET material, coated with UV-protective film. Diameter of the inner cylinder is 0.59 m, of the outer 0.67 m, the length of both cylinders is 1.3 m. Both cylinders are mounted on one axis which has been pointed to the Polar star to ensure perpendicular striking of solar beams to the collector surface all day. The ends of the cylinders are closed with metal discs, from inside covered with 3 cm thick Rockwool heat insulation. There are openings in the discs for inflow of cold air and outflow of heated air. These openings are positioned so that inflow is from the bottom of the lower end of the cylinder and outflow is at the top of the upper end of the cylinder. Such positions allow convection-provided flow of the air without a fan. There are two openings in every end allowing using heated air both from the inner cylinder and from the space between the metallic cylinder and the transparent one, either together or separately.

Reflectors were two polished metal sheets shaped as wide parabola.

Fig. 1. **Cylindrical solar collector**

Fig. 2. **Cylindrical solar collector with reflector**

Temperatures were registered using the HOBO logger. This logger is capable to measure air temperature and relative humidity and two external temperatures using sensors connected with cables. We used two such loggers to measure the ambient air temperature and relative humidity, inflow air temperature, outflow air temperature and relative humidity and temperature inside the cylinder and in the space between the cylinder and outer transparent cover.

Measurements have been carried out from 9 of July till 8 of October. Solar energy was measured using the pyranometer CMP 6 from "Kipp&Zonen", corresponding to the 1-sth class of ISO. Global solar energy was registered after every 5 minutes. Analyzing of the solar radiation data also gives a view on nebulosity.

Air flow was measured using an anemometer (Fig. 3). Measuring has been carried out with and without forced flow. Without forced flow it is convectional flow. For full autonomy of the drying process the forced flow is ensured with a fan powered by a solar cell. The fan with 12 V direct current electrical engine was used. This voltage was ensured using 97W flexible PV module (Fig. 4).

The energy outcome Q from the solar collector has been calculated by (1):

$$Q = c \cdot m \cdot \Delta T \,, \tag{1}$$

where Q – energy outcome, J;
c – specific heat of air, J kg^{-1} K^{-1};
m – mass of heated air, kg;
ΔT – difference between inflowing and outflowing air temperatures, K.

Fig. 3. **Anemometer for flow measurements**

Fig. 4. **97 W flexible PV module**

The specific heat of air is calculated from (2)

$$c = \frac{i+2}{2} \cdot \frac{R}{\mu} \,, \tag{2}$$

where c – specific heat, J·kg^{-1}·K^{-1};
i – number of degrees of freedom;
R – universal gas constant, J·K^{-1};
μ - molecular mass, kg.

The mass of heated air by (3) can be calculated

$$m = \frac{pV\mu}{RT} \,, \tag{3}$$

where p – atmospheric pressure, Pa;
V – volume of the heated air, m^3;
T – air temperature, K;
R – universal gas constant, J·K^{-1};
μ – molecular mass, kg.

The volume of heated air can be obtained by multiplying the velocity of the air flow with the cross-sectional area of the inflow (or outflow) tube of the collector.

Calculating in a similar way the energy amount received by water vapor at such little relative humidity of air gives approximately 100 times smaller value than that of the air and therefore can be neglected.

The obtained data are compared with theoretical calculations using the methods explained in our previous works [7].

Results and discussion

As it was expected, the cylindrical solar collector receives solar energy longer during the day as the flat one. The thoretically calculated daily course of power of cylindrical (a) and flat (b) solar collectors is shown in Fig. 5.

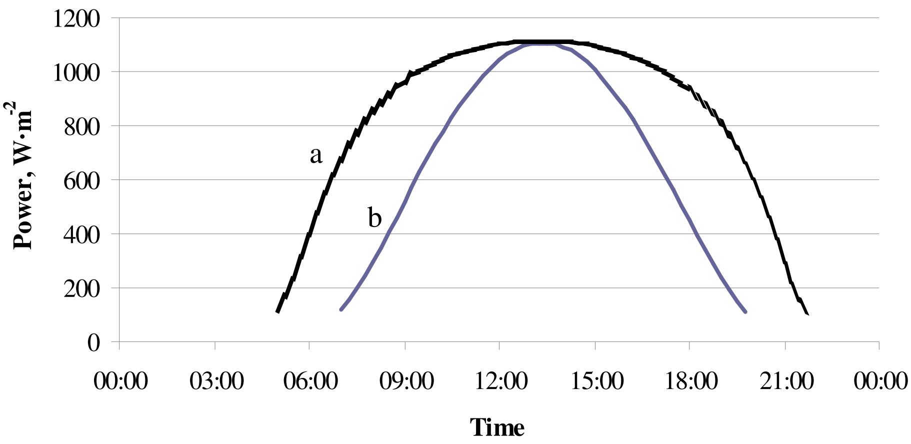

Fig. 5. **Theoretically calculated daily course of power of solar collectors:** a – cylindrical; b – flat

At midday the amount of the received energy is the same for both (with equal area), but in the morning and evening the cylindrical collector receives more energy than the flat one, and it starts to receive it earlier in the morning and ends later in the evening. Such situation has been observed also experimentally. Fig. 6 shows the daily course of temperature of the outflowing air from the cylindrical solar collector (a) in comparison with that of global solar energy (b).

Another interesting fact from this picture (Fig. 6) is that when clouds appear, solar energy among the clouds is higher than that of a clear day. It means that we receive not only direct radiation, but also reflected from clouds, which, in general, is in other direction as the direct one. Therefore, the cylindrical solar collector, which receives energy from all sides, has advantages in comparison with the flat one.

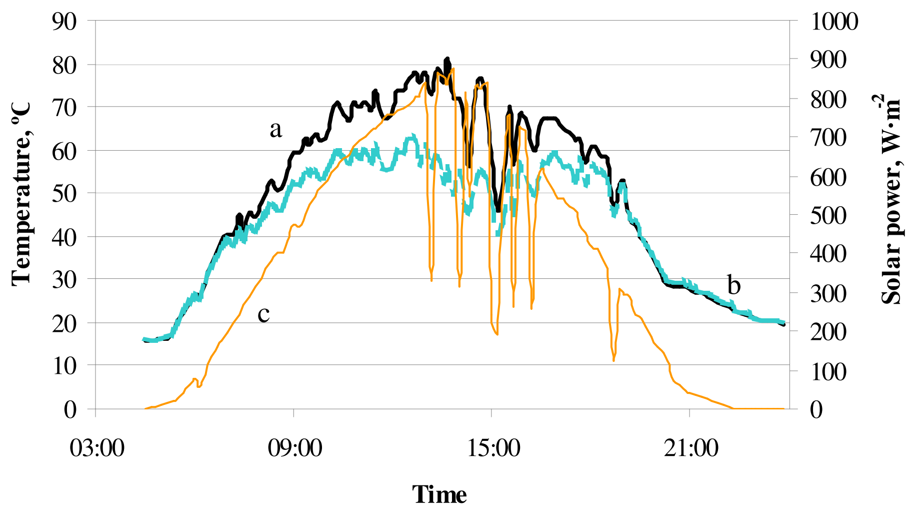

Fig. 6. **Daily course of temperature of air outflowing from cylindrical solar collector (a and b) and global solar power (c)**

From this figure it can be seen, that in the afternoon global solar energy (curve c) significantly reduces from time to time what indicates of the presence of clouds, but temperatures of the collector (both inner cylinder and middle space) decrease only slightly.

It might seem that capability to receive radiation from all sides, when really radiation comes only from one side at the time, results with large temperature difference between the sun side and the dark side, but infrared pictures show that it is not so. Investigations show that at temperature of outgoing air

80 ºC the temperature difference of several places of the collector surface does not exceed 10 ºC, such difference is too small to show in grayscale pictures.

Similar graph for a collector with parabolic reflectors is given in Fig. 7.

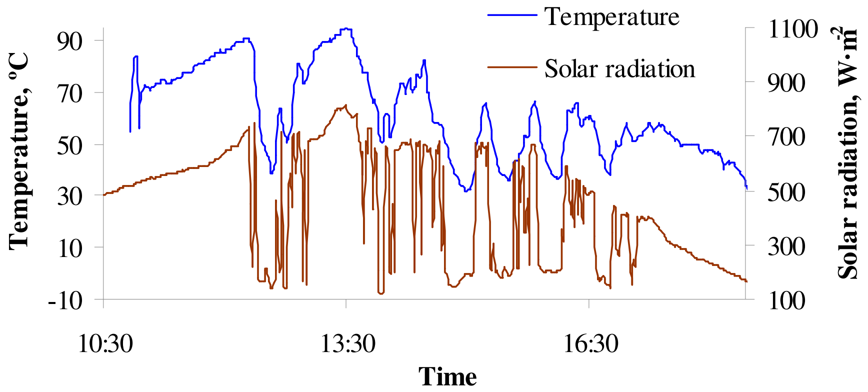

Fig. 7. **Daily course of temperature of air outflowing from cylindrical solar collector with reflectors and global solar energy**

Effectiveness of a solar collector is defined [7] as the ratio of energy output from the collector to global solar energy on horizontal surface of the same area as the collector has. It is not efficiency as usually used for characterizing solar collectors. Efficiency is the ratio of energy output to solar energy received by the collector. It does not depend on positioning of the collector, but effectiveness does. Furthermore, solar energy received of the collector is hard to evaluate. Global solar energy on the horizontal surface can be directly measured by a pyranometer, but for calculation of energy received by slope surface solar coordinates must be known as well as separately beam and diffused radiation. Effectiveness unlike efficiency can be greater than one.

The simplest way to evaluate the effectiveness of the solar collector is to plot daily sums of energy output of the collector via those of global solar energy, then to draw a linear trendline taking into account that the intercept must be zero, because when solar energy is zero then also the energy output from the collector is zero. Slope of this trendline is the effectiveness of the collector.

The plot of the daily sum of the collector output energy (for 1m^2 of surface area) via those of the global solar energy on horizontal surface 1 m^2 (Fig. 8) gives effectiveness 0.45 with the determination factor $R^2 = 0.83$.

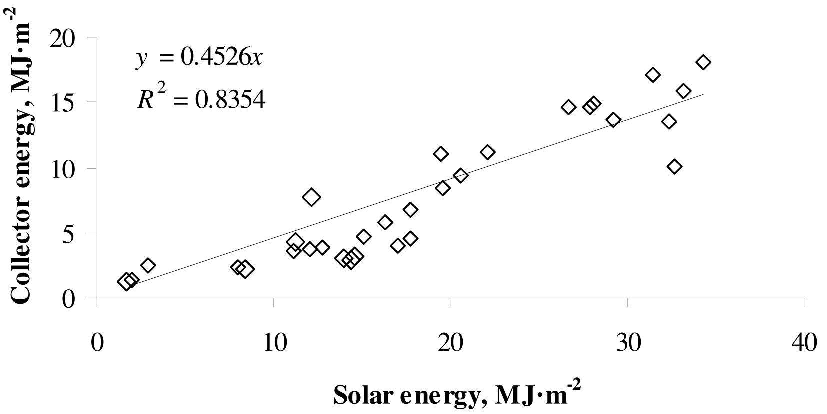

Fig. 8. **Dependence of daily sum of energy output from cylindrical solar collector on daily sum of global solar energy**

For calculating of energy outcome of the solar collector the air flow was measured. Without a fan (convection flow) it was 1±0.7 m/s. With a photovoltaic powered fan the flow was 3.9±0.5 m/s. Then calculations show the power of the collector 100-200 W at medium cloudy day without a fan and 600 – 1100 W with a fan. It means that convectional flow without a fan is not strong enough for effective use of such solar collector, but with a fan the power of the cylindrical solar collector is sufficient for drying of agricultural products.

Significant difference between collectors with and without reflectors has not been found. It may be because investigations with reflectors were carried out late in the autumn – further investigations are necessary.

Further investigations would be carried out on using of a cylindrical solar collector for hemp drying.

Conclusions

The power of the cylindrical solar collector with diameter 0.6 m and length 1.3 m is approximately 600 W in a medium cloudy day and up to 1100 W in a clear day, using solar energy (photovoltaic) powered fan. Such power is sufficient for drying of agricultural products and therefore the cylindrical solar collector can be used for this purpose in Latvia.

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