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Air Heating Solar Collector for Hemp Drying

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***Abstract* – Attempts to use solar energy for drying of hemp (and other agricultural production) have been made in this work. Air is heated in solar collector approximately to 40 – 60 degrees Celsius, which also results 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 hemp or other agricultural production.**

A new construction of air heating solar collector – a cylindrical solar collector has been worked out.

***Keywords* – Air heating, production drying, solar collector, solar energy**

I. INTRODUCTION

Along with the decrease of the reserves of fossil fuels, as well as the increasing impact of the use of fossil fuels on the climate, on the world scale more attention has been paid to renewable sources of energy, including solar energy.

In Latvia, solar energy is also used, mostly in solar collectors for hot water production [1], [2]. Another possible use of solar energy in Latvia is for drying of agricultural production. Mainly air heating solar collectors have been used for this purpose. However, due to geographical and climatic conditions in Latvia there are some specific 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 the capability to receive solar energy from all sides, which means to receive also diffused radiation and the radiation reflected from clouds, it is also better in comparison with the flat plate collector with regard to receiving energy in the morning and evening. Similar constructions of air-heating cylindrical solar collector for drying of agricultural production have already been investigated by other authors [5], [6]. But in these investigations a cylindrical solar collector was placed vertically, and energy output and effectiveness of the collector were not investigated, taking only temperature measurements.

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 determining the daily course of temperature and its dependence on meteorological conditions, and calculating energy output and effectiveness (as defined in our previous works, *e.g.* [7]) of the collector.

In this work, mainly the same collector has been investigated; its use in hemp drying will be considered later.

II. MATERIALS AND METHODS

New construction of solar collector – cylindrical solar collector (Fig. 1) has been investigated.

Fig. 1. Cylindrical solar collector.

It consists of two cylinders: inner is black-painted metal (galvanized 0.5 mm thick steel sheet, coated with black mat silicon color), and 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 collector surface throughout the entire day. Ends of cylinders are closed with metal discs, from inside covered with 3 cm thick Rockwool heat insulation. There are openings in the discs for the inflow of cold air and outflow of the 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 fan. There are two openings in every end allowing using the heated air both from the inner cylinder and from the space between the metallic cylinder and the transparent one, either together or separately.

Temperatures were registered using HOBO logger (Fig. 2). This logger is capable to measure air temperature and relative humidity and two external temperatures using sensors connected with cables. We used two loggers of that kind to measure ambient air temperature and relative humidity, inflow air temperature, outflow air temperature and relative humidity and temperature inside the cylinder and in space between the cylinder and outer transparent cover.

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Fig. 2. Temperature and air humidity logger HOBO.

Solar energy was measured using pyranometer CMP 6 from "Kipp&Zonen"(Fig. 3), corresponding to 1-st class of ISO. Global solar energy was registered after every 5 minutes.

Fig. 3. Pyranometer CMP 6.

Analysis of solar radiation data also gives a view on nebulosity.

Air flow was measured using anemometer (Fig. 4)

Fig. 4. Anemometer.

Measurements have 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 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. 5).

Fig. 5. 97W flexible PV module.

Energy outcome Q(J) from the solar collector has been calculated by (1):

$$Q = c \cdot m \cdot \Delta T, \quad (1)$$

where c is specific heat of the air, J kg^{-}1 K^{-1}; m is mass of the heated air, kg; ΔT is the difference between inflow and outflow air temperatures, K. The specific heat of air is calculated from (2)

$$c = \frac{i+2}{2} \cdot \frac{R}{\mu}, \quad (2)$$

where i is number of degrees of freedom, R is universal gas constant, J K^{-1}; μ is molecular mass, kg. The mass of heated air by (3) can be calculated

$$m = \frac{pV\mu}{RT}, \quad (3)$$

where p is atmospheric pressure, Pa; V is the volume of the heated air, m^3; T is air temperature, K. Volume of the heated air can be obtained by multiplying velocity of the air flow with cross-sectional area of 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 methods explained in our previous works [7].

III. Results and discussion

A. Daily course of collector's temperature

As it was expected, the cylindrical solar collector receives solar energy longer during the day rather than the flat one. Theoretically calculated daily course of power of cylindrical (a) and flat (b) solar collectors is shown in Fig. 6.

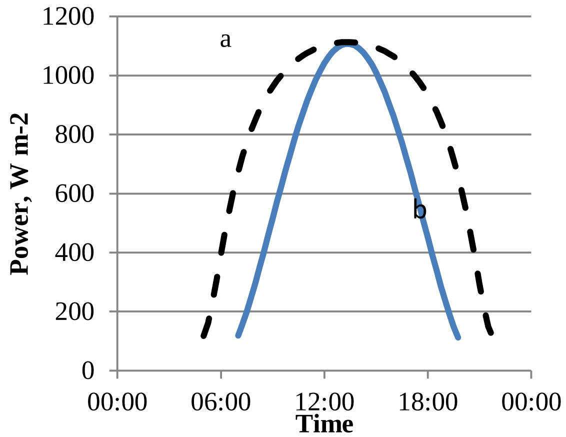

Fig. 6. Theoretically calculated daily course of power of cylindrical (a) and flat (b) solar collectors.

At midday the amount of 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 the energy earlier in the morning and ends later in the evening. Such situation has been observed

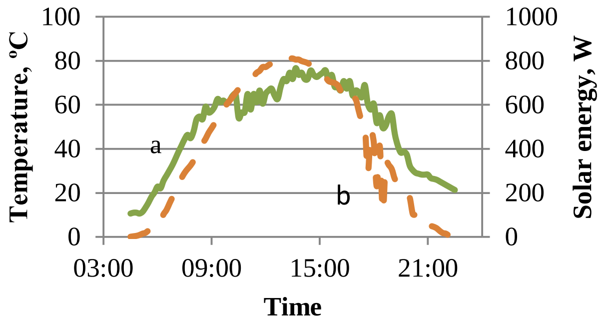

Fig. 7. Daily course of temperature of the air outflowing from the cylindrical solar collector (a) and global solar energy (b).

also experimentally. Fig. 7 shows daily course of temperature of the outflowing air from the cylindrical solar collector (a) in comparison with that of global solar energy (b), at almost sunny day of July 5.

Other interesting fact is that the cylindrical solar collector works rather well also on a partly cloudy day (Fig. 8).

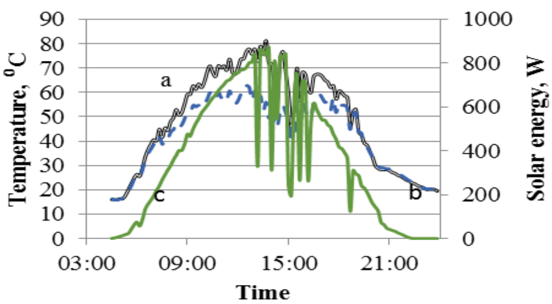

Fig. 8. Daily course of temperature of space between the cylinder and transparent coating (a) and inner cylinder (b), and of global solar energy (c).

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

Another interesting fact to be observed in this picture (Fig. 8) is that when clouds appear, solar energy among the clouds is higher than that of the clear day. It means that we receive not only direct radiation, but also reflected from the clouds, which, in general, moves in other direction than the direct one. Therefore, the cylindrical solar collector, which receives energy from all sides, has advantages in comparison with the flat one.

It might seem that the capability to receive radiation from all sides, when really radiation comes only from one side at the time, will result in large temperature difference between sun side and the dark side, but infrared pictures show that it is not so. Investigations show that at temperature of outgoing air 80°C temperature difference of several places of collector surface does not exceed 10°C, such difference is too small to show in grayscale pictures.

B. Effectiveness

Effectiveness of solar collector is defined [7] as 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 the efficiency that is 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 pyranometer, but for the calculation of energy received by a slope surface solar coordinates must be known as well as beam and diffused radiation separately. In contrast to efficiency, effectiveness 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 linear trendline taking into account that the intercept must be zero, because when solar energy is zero then also energy output from the collector is zero. The slope of this trendline is the effectiveness of the collector.

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

The plot of the daily sum of collector output energy with respect to those of the global solar energy on horizontal area (Fig. 9) without fan for 20-days period gives the slope of the trendline, *i.e.* effectiveness 0.26 with determination factor of the trendline $R^2 = 0.88$. The same plot for the collector with fan (Fig. 10) gives effectiveness 1.5 with determination factor $R^2 =$

0.85 for space between the cylinder and transparent cover (for 14-days period) and effectiveness 1.3 with determination factor 0.86 for the inner cylinder (measurements of 8-days period).

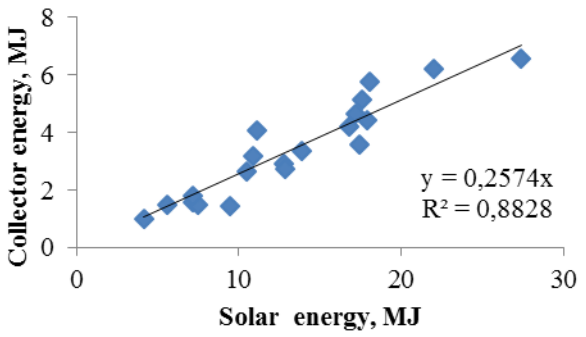

Fig. 9. Dependence of the daily sum of energy output from the cylindrical solar collector without fan on the daily sum of the global solar energy, June 16 to July 8

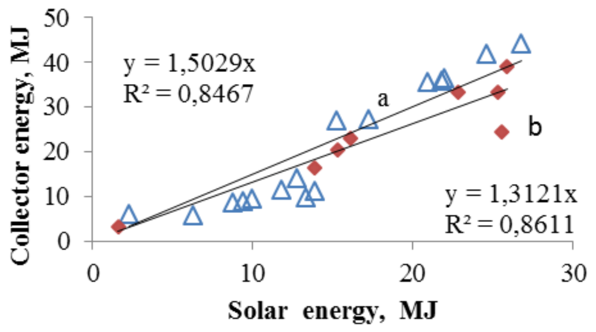

Fig. 10. Dependence of the daily sum of energy output from cylindrical solar collector with the fan on the daily sum of the global solar energy, a – space between cylinder and outer transparent cover, July 9 to 23, b – inner cylinder, July 24 to 31.

Further investigations will be carried out with adding the reflectors to the cylindrical solar collector, and using it for hemp drying.

IV. Conclusions

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

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