INVESTIGATION OF AIR HEATING SOLAR COLLECTOR WITH ENERGY CONCENTRATOR

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Abstract. The paper discusses the procedures of development and experimental investigation of the solar collector for air heating, using a solar energy concentrator. The collector consists of the solar energy concentrator, made of polished stainless sheets bent according to parabola with total aperture area 3.6 m^2. In the focus of the concentrator a heat absorber tube assembled from specific form separate aluminium elements with a wall density 0.15 mm and painted in black tarnished colour is placed. The form of absorber elements is creating a turbulent air flow in the absorber tube, which increases the heat exchange through its wall. By a centrifugal ventilator the air flow of changeable intensity in the absorber tube has been created. The electric motor of the ventilator was fed by direct current produced by an amorphous silicon flexible photovoltaic module. On sunny September 11, 2015 day the efficiency of the collector was 73.7 %. The heated air temperature increment reached 57.3 ºC. Such air can be used for room heating or drying needs.

Keywords: solar collector, air heating, solar radiation concentrator.

Introduction

In the laboratory of the Ulbroka Research Centre of the Faculty of Engineering of the Latvia University of Agriculture a two meters long parabolic shape solar collector for air or water heating with a solar energy concentrator has been developed and investigated. The novelty of the research is to create an outdoor air heating device using the solar radiation energy both for air heating and production of electric current used for an air blowing ventilator feeding. The device will be useful in case the electric grid is not available or the use of electricity from the grid is not cost efficient. For further development of the device and its industrial production as a common unit, the described experimental investigation for substantiation of its separate components size and material has been carried out. The objective of the research is to ascertain the heat transfer intensity from the solar energy concentrator to the air, running into the absorber tube depending on its velocity, the solar radiation intensity, the outside air temperature, relative humidity, wind speed and other parameters, as well as to compare the obtained amount of heat energy, if instead of the air tube absorber a metal tube with running water is used.

Materials and methods

The collector consists of a solar energy concentrator 1, made of two polished stainless sheets each of 1 x 2 m area, put together and bent according to parabola with total aperture area 3.6 m^2 (Fig.1).

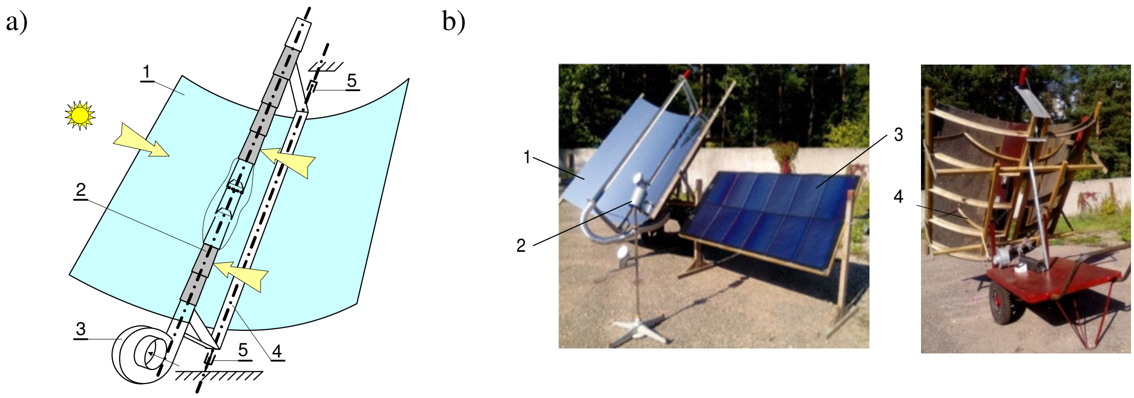

Fig.1. **Solar collector with energy concentrator:** scheme (a) 1 – solar concentrator; 2 – absorber; 3 – ventilator; 4 – frame; 5 – bearingson the polar axis; photo (b) 1 – solar collector; 2 – device MMD-4; 3 – solar 97W flexible module; 4 – movable device

Solar energy concentrators are optical devices increasing the intensity of solar energy flow. Their use results in the decrease of absorber surface area of solar energy devices and increase of the obtained temperature of solar collectors or voltage (power) of solar photo-electric devices [1]. The obtained hot air for heating or drying, but hot water for washing or heating needs is foreseen to be used. In the focus of the solar energy concentrator at a distance 0.5 m from its centre a tube type heat absorber tube 2 assembled from specific form separate aluminium elements (Fig. 2) with a wall density 0.15 mm and painted in black tarnished colour was placed (Fig. 1 a). The form of absorber elements is creating a turbulent air flow in the absorber tube increasing the heat exchange intensity through its wall. By a centrifugal ventilator (Fig. 3) the air flow of changeable intensity in the absorber tubes has been created.

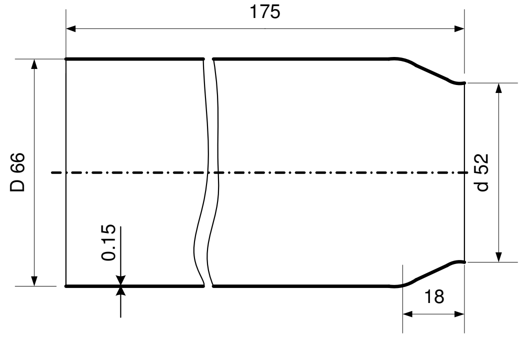

Fig. 2. **Aluminium element of absorber tube**

Fig. 3. **Centrifugal ventilatorwith direct currant electric motor: 12 V; 4.5 A**

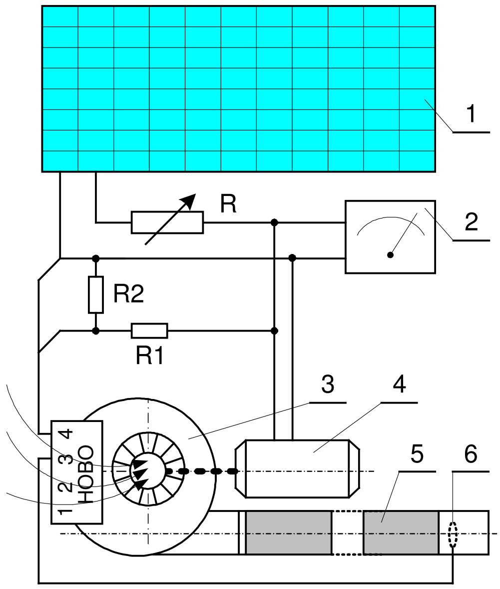

Fig. 4. **Parameter registration scheme:** 1 – 97 W flexible PV module; 2 – voltage indicator; 3 – ventilator; 4 – motor of the ventilator; 5 – absorber; 6 – temperature changing sensor; R – voltage regulator; R1R2 – motor voltage divider

The nominal value of the resistances is chosen so that the entrance voltage of the HOBO-H08-007-02 register was 10 % of the electric motor voltage. With inner sensors the logger registers the temperature in operative range 0…100 ºC with accuracy ±1.5 ºC and the relative humidity with accuracy ±10 % of the surrounding air flowing into the ventilator. With outer sensors using the temperature changing sensor 6, placed in the absorber tube, the temperature of the air outlets of the absorber tube with accuracy ±1.5 ºC and the voltage delivered to the ventilator's electric motor from the voltage divider R1R2 in operative range 0…2.5 V_{DC} with accuracy ±10 mV ±3 % of reading has been measured (Fig. 4). The necessary voltage for the ventilator's electric motor powering according to the voltage indicator 2 is possible to adjust by the voltage regulator R with accuracy ±10 mV ±3 %

of reading. The intensity of solar radiation was measured and registered using the device MMD-4 [2]. All the data were measured with 2 minutes interval. The delivered voltage to the electric motor was measured and registered in order to use it for calculation of the air flow velocity into the absorber tube, because there is a direct relationship between the delivered values of voltage to the ventilator's electric motor and the velocity of the air flow into the ventilator (Fig. 5). These coherences were obtained experimentally during a clear sunny day at normal working regime of the collector and different electric motor voltage values. The corresponding values of the consumed electric current and air flow velocity at the inlet into the ventilator were measured and recorded. The velocity of the air flow was measured using an air flow velocity meter Lutron YK-2001TM with an anemometer AM-04 with accuracy ±3 %.

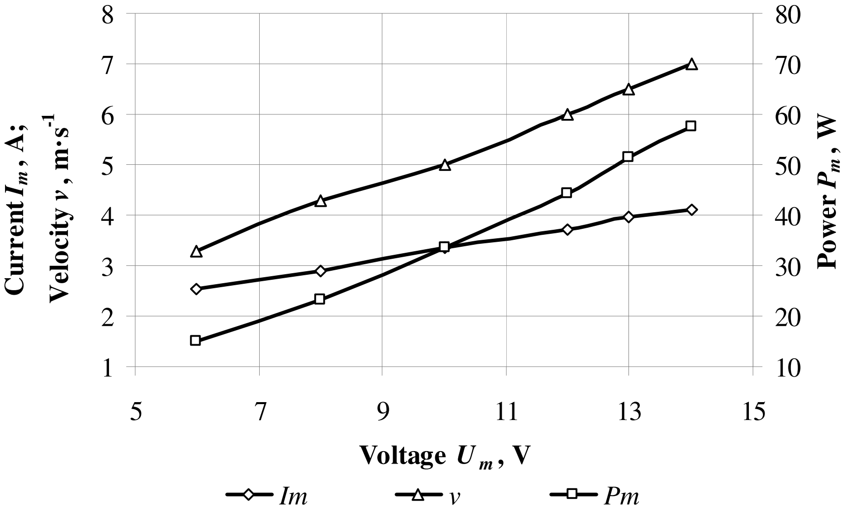

Fig. 5. **Characteristic lines of centrifugal ventilator used in experimental investigation:**
I_m – motor current, A; v – velocity of air inlet, m·s^{-1}; U_m – motor voltage, V; P_m – motor power, W

The investigation was started on August 15, 2015 at 12:00 o'clock. The solar collector and solar battery module were directed to the sun and during the experimental investigation tracking it. The data register HOBO-H08-007-02 was ready for operation. At 12:30 to the electric motor of the ventilator had been delivered voltage 14 V and in every 10 minute the voltage was changed on 12, 10, 8 and 6 V. For voltage measuring a digital multimeter "Finest" Model 707 with accuracy 0.05 % + 2 digits was used.

For calculation the power of the collector, its efficiency and the change in temperature of the hot air for each volume of the ventilator motor's voltage the mean value of four measurements has been used. In continuation the power and efficiency of the collector, as well as the change of the hot air temperature was computed depending on the productivity of the ventilator. In order to calculate the amount of the air gone through the absorber, the ventilator characteristic line (Fig. 5) reflecting dependence of the air inlet into the ventilator on voltage delivered to the ventilator was used. As the air flow velocity into the ventilator and its inlet opening are known, it is possible to calculate the amount of the air gone through the ventilator and absorber during a unite of time. For calculation the power of the collector I – d diagram was used, from which the coherence between the air temperature and enthalpy has been read.

Results and discussion

In experimental investigation and theoretical calculation such technical parameters of the air heating collector as its power, efficiency and increased heated air temperature depending on the productivity of the ventilator are obtained and presented for September 11 and September 13, 2015 (Fig. 6; Fig.7). At each of the ventilator's motor voltage value five measurements were made, and for calculation of the ventilator's motor power, productivity and heated air temperature the average value of these measurements was computed and used. Coherence between the ventilator productivity and air flow velocity in the absorber tube has been stated. From the curves it follows that at increasing the ventilator efficiency, the heat power of the collector and its efficiency increases, but the growth of the air temperature in the collector decreases.

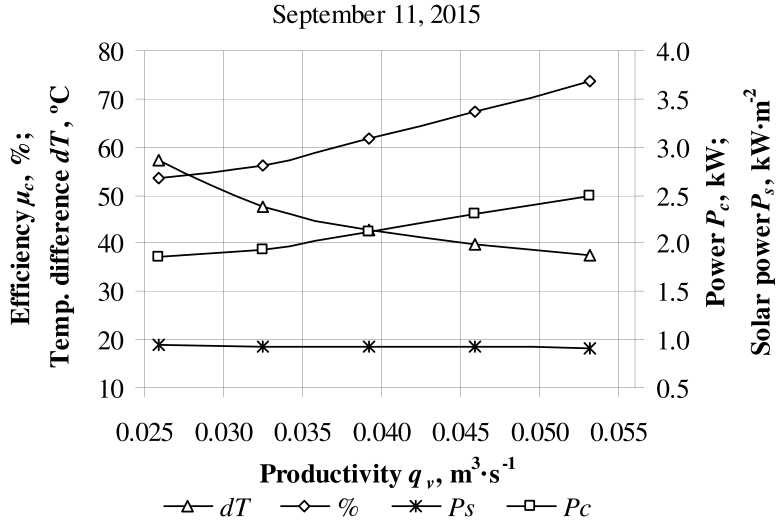

Fig. 6. **Experimental results:** μ_c – collector efficiency, %; dT – temperature difference, ºC; q – ventilator productivity, $m^3 \cdot s^{-1}$; P_c – collector power; P_s – solar power, $kW \cdot m^{-2}$

That causes the increase of the collector power and efficiency. For, example, Fig. 6 shows that at the change of the ventilator productivity from 0.025 to 0.055 $m^3 \cdot s^{-1}$ (the velocity of the air flow into the absorber tube was from 10.6to 21.5 $m \cdot s^{-1}$) the power of the collector increases from 1.86 to 2.50 kW, the collector efficiency from 53.7 to 73.7 %, but the increase of the outlet air temperature decreases from 57.3 to 37.5 ºC.

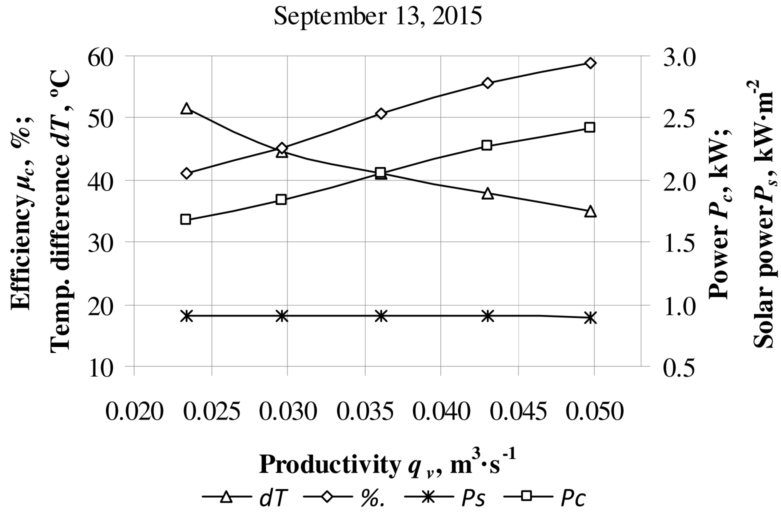

Fig. 7. **Experimental results:** μ_c – collector efficiency, %; dT – temperature difference, ºC; q – ventilator productivity, $m^3 \cdot s^{-1}$; P_c –collector power, kW; P_s – solar power, $kW \cdot m^{-2}$

In Fig. 7 experimental data obtained on September 13, 2015 are presented. These data differ from those obtained on September 11 insignificantly. Decrease in the collector power by 0.08 kW was due to lower intensity of solar radiation and stronger wind. Choosing the regime of the ventilator operation, the ventilator power has to be considered. At higher power of the ventilator the higher power of the solar battery module will be needed. From Fig. 6 it is seen that using a thin wall tube absorber made of elements with cones, it is possible to get an air heater of high thermal parameters with efficiency up to 73.7% even in September, which corresponds to selective solar collectors for water heating.

In Fig. 6 and Fig. 7 the collector power, efficiency, inlet and outlet air temperature is given depending on the ventilator productivity. If the mention parameters are to be evaluated depending on the velocity of the air flow into the absorber tube, then for recalculation the obtained during the investigation coherences can be used. As it was noticed at water heating by the developed collector better results have been obtained, when instead of the air tube absorber a 2 m long aluminium tube of 45 mm diameter painted in black tarnished silicon colour was used. During several days in August 2015, similar to described on September 11 and September 13 experimental investigation were performed. Similar results were obtained, but the numerical values were depending on the outdoor air temperature, velocity of wind and solar radiation intensity on the day of investigation.

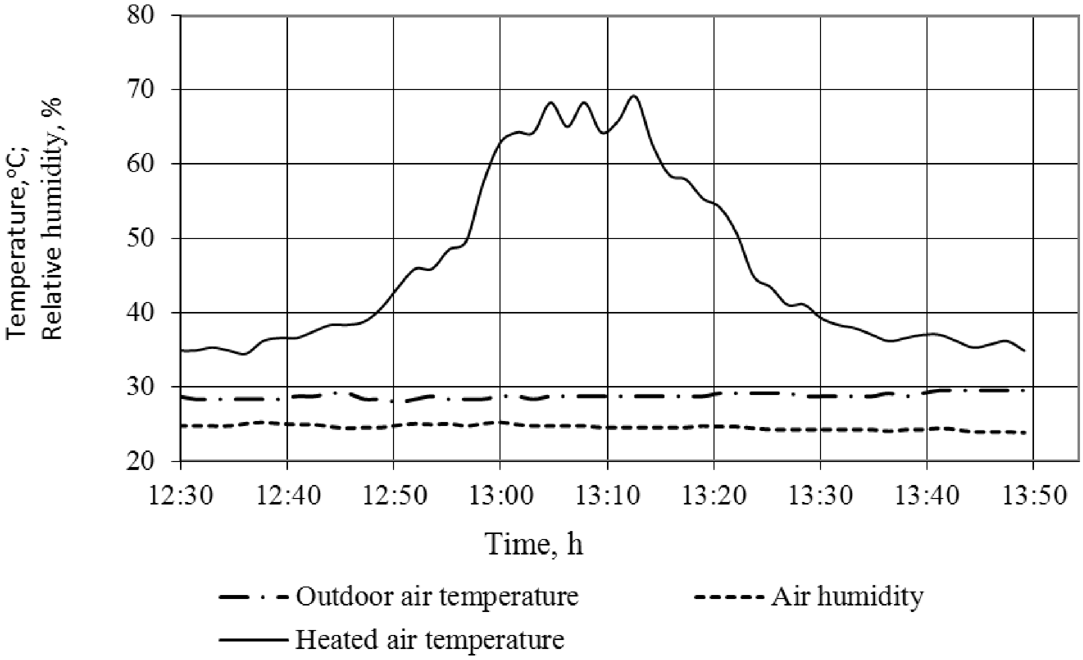

Fig. 8. **Outlet air temperature of stationary working (without tracking the sun) air heating collector with parabolic solar concentrator(July 3, 2015)**

To ascertain the necessary time span for turning the collector in order to track the sun, in the middle of a sunny day, when the collector was in fixed position, the temperature of the outlet air as the function of time was established. From Fig. 8 it follows that without decreasing the collector power the collector turning time is in every 10 minutes.

It should be noticed that at calculation of the efficiency of the collector the size of the solar battery was not taken into account. At the valuation of the collector as a system it has be considered.

Conclusions

1. A parabolic solar collector with a solar radiation concentrator and a tube type absorber for air heating has been developed and experimentally investigated.
2. At the solar radiation intensity 0.899-0.940 $W \cdot m^{-2}$ and velocity of air flow into the absorber tube from 10.6 to 21.5 $m \cdot s^{-1}$, the obtained collector efficiency is from 53.9 to 73.7 % (September 11), and 41 to 59 % (September 13), which is similar to the water heating collector efficiency, due to fast heat energy transformation through the absorber thin aluminum tube wall and air flow turbulence in the absorber tube.
3. Changing the air flow velocity into the absorber tube from 10.6to 21.5 $m \cdot s^{-1}$, the heated air temperature increment decreases from 57.3 to 37.5 ºC (September 11) and from 51 to 35 ºC (September 13).
4. At the decrease of the outlet air temperature the absorber surface temperature and heat losses from it decrease, what causes the increase of the collector power and efficiency.
5. In order to track the sun without significant decreases in the collector power, its turning time can be in every 10 minutes.
6. The heated by the collar collector hot air temperature largely depends on the movement of the surrounding air (wind). Therefore, in order to increase the heated air temperature it is recommended to place the absorber tube into another tube of transparent material.

References

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