The Investigations of Heating Process in Solar Air Heating Collector

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Abstract. The aim of the research is to find the optimal technical solutions, utilized materials as absorbers, operation parameters and power possibilities for a solar collector. Different absorbers of sun radiation, the absorbers' ability and efficiency in air heating solar collector are compared.

0.1 x 0.5 x 1.0 meters long equipment for experimental research into the materials of solar air heating collector was built. The experimental data were measured and recorded in the electronic equipment REG. The investigations are devoted to the sun following collectors, which guarantee perpendicular location for all experimental time of the plane of absorber to the flow of the sun radiation. The collector covered material was a polystyrol plate and absorbers were: a) black colored steel tinplate and b) slices of black colored beer cans.

The use experimental data received expressions of heating degree of air in collector depending on sun radiation and distance from absorber (steel tinplate) at 35 cm and 60 cm from inlet.

In favorable weather conditions the heating degree of the ambient air with absorber black colored slices of beer cans reaches more than $\Delta T = 10^{o}$ C at the air velocity 0.9 m s^{-1}.

Key words: Solar collector, air, temperature, absorber

INTRODUCTION

The greatest advantage of solar energy compared to other forms of energy is that it is clean and can be supplied without environmental pollution. Over the past century, fossil fuels provided most of our energy, because they were much cheaper and more convenient than energy from alternative energy sources, and until recently, environmental pollution has been of little concern. The limited reserves of fossil fuels cause a situation in which the price of fuels will accelerate as the reserves are diminishing.

Solar energy is used to heat and cool buildings (both actively and passively), to dry production, to heat water for domestic and industry use, to heat swimming pools, to generate electricity, for chemistry applications, and many more operations (Kalogirou, 2009).

The application of solar energy is completely dependent on solar radiation, a low-grade and fluctuating energy source. An intrinsic difficulty in the use of solar energy lies in the wide variation of solar radiation intensity. The availability of solar radiation depends not only on location, but also on the season. Extreme differences are experienced between summer and winter, and from day to day.

In general, solar water and solar air heaters are flat-plate collectors (FPCs), consisting of an absorber, a transparent cover, and backward insulation. Despite the similarity in design, the different modes of operations and different properties of the heat transfer medium greatly affect the thermal performance and electric energy consumption for forcing the heat transfer medium though the collector. Solar water heaters are operated as a closed-loop system whereas, in most cases, solar air heaters are operated in the open-loop mode.

The performance of solar air heaters is mainly influenced by meteorological parameters (direct and diffuse radiation, ambient temperature, and wind speed), design parameters (type of collector, collector materials) and flow parameters (air flow rate, mode of flow). The principal requirement of these designs is a large contact area between the absorbing surface and the air.

The efficiency of a solar collector depending on collector covering materials (polyvinylchloride film, cell polycarbonate PC, translucent roofing slate), the absorber (black colored wood, steel-thin plate, etc.), together with different air velocities in the collector has been investigated (Lauva et al., 2006; Aboltins et al., 2007; Palabinskis et al., 2008; Aboltins et al., 2009). The main efficiency parameter of a solar collector is the air heating degree which we choose as criterion of efficiency.

The FPC absorber plane is perpendicular to the flow of sun radiation at the sun following collector; therefore, this type is more powerful than a stationary collector. The sun rays fall at an angle to the collector plane (i.e. they fall at an angle to the covered material), which gives more reflection.

MATERIALS AND METHODS

The aim of our investigations was to specify the air heating degree of solar collector at distance from the absorber's steel-thin plate.

Experimental results and statistical processing data were used to find connectedness between collector length, sun radiation to absorber plate and air temperature exchange in FPC with absorber steel-thin plate. Expressions were got for air temperature over and under the steel-thin plate absorber in the solar collector (Aboltins et al., 2009).

In this article we are studying the influence of collector thickness on air heating degree at 35 cm and 60 cm length from input. In the laboratory a 0.1 x 0.5 x 1.0 meter long experimental solar collector was constructed for investigation into the properties of absorber materials. Air velocity in the experiments was $v = 0.9\ m\ s^{-1}$. Our investigations concerned the sun following collectors, which guarantee perpendicular location of the absorber plane from the flow of sun irradiance.

In the experiments, the collector covering material was a polystyrol plate. This material has gained immense popularity due to such properties as safety, mechanical crashworthiness, translucence and high UV radiation stability. The covering material – polystyrol plate – reduced irradiance by 12-15%.

We studied a situation when the absorber (a black steel-thin plate) was put at the bottom of the collector (Figs. 1-2)

Experimental data are recorded by means of an electronic metering and recording equipment for temperature, radiation and lighting REG (REG, 2004). It is equipped with 16 temperature transducers and metering sensors for solar irradiance and lighting. Reading time of data can be programmed from 1 to 99 minutes (1 minute in our case).

Fig. 1. Sun following collector with steel-thin plate absorber.

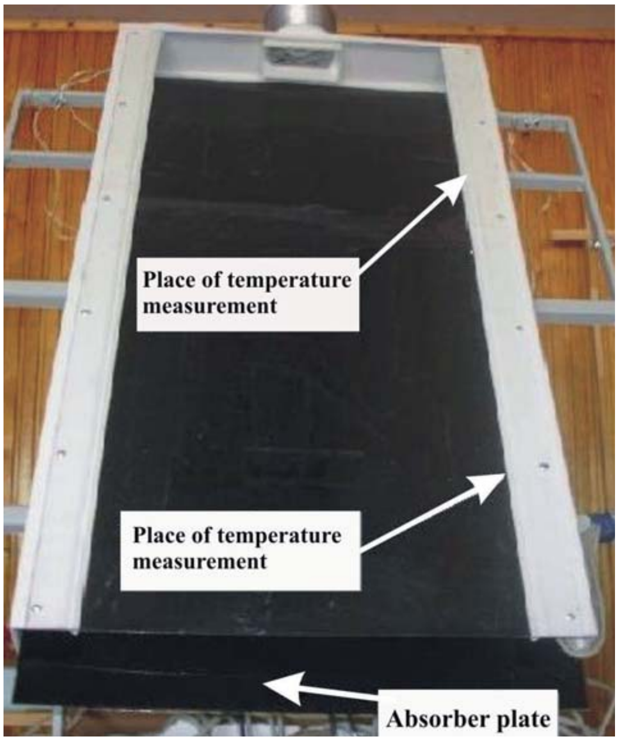

Fig. 2. View of solar collector with steel-tinplate absorber.

The recorded data are stored in the REG memory (there is place for 16,384 records) and in case of need it is transferred to a computer for archiving with further processing. For evaluation and analysis of results, the software REG-01 has been developed, which is meant for transferring to the computer and processing the recorded data. Information is stored in the form of a table and in case of need it is depicted as a graph.

RESULTS AND DISCUSSION

Using experimental results and statistical processing data we received connectedness between distance from absorber, sun radiation to absorber plate and air temperature exchange in collector. We got expressions for air temperature exchange over steel-thin plate absorber in FPC at 35 cm and 60 cm from inlet.

Temperature exchange ΔT over absorber at 35 cm distance from input can be expressed with the following equation:

$$\Delta T = 0.00385 \cdot R + 0.213 \cdot y - 0.032 \cdot y^2 - 4.6 \cdot 10^{-5} \cdot R \cdot y - 0.8, \qquad (1)$$

where y - distance from absorber, (cm), R - sun radiation (W m^{-2}).

Close connection of this expression shows coefficient of determination $\eta^2 = 0.804$ in temperature increase domain $\Delta T \in (0;3)\ ^{O}C$. The graphical interpretation of this expression is shown in Fig. 3.

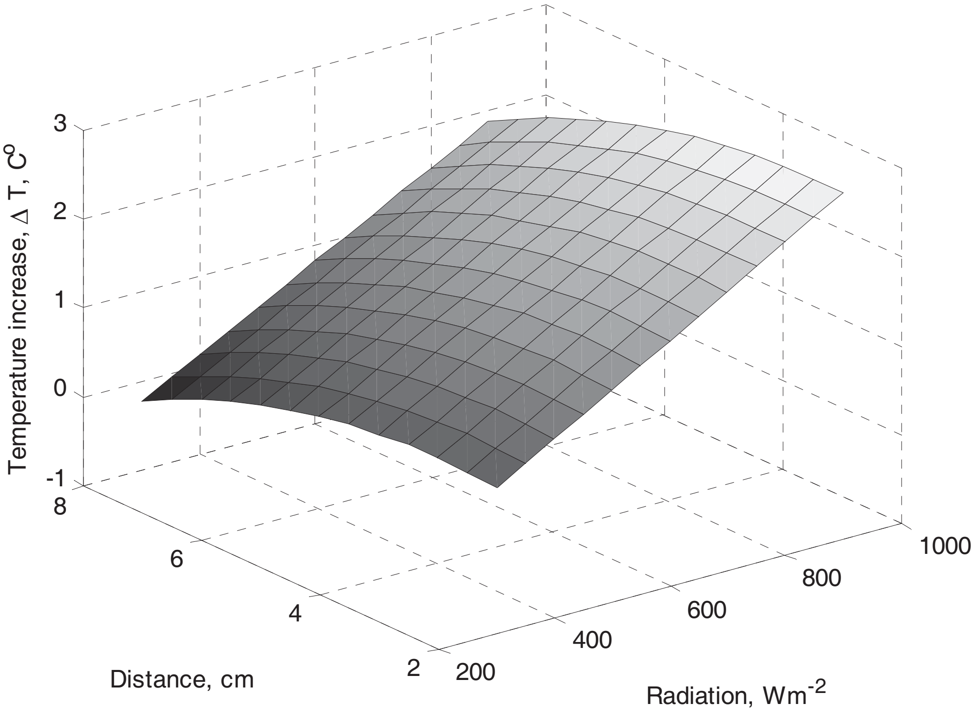

Fig. 3. Plot of air temperature increase ΔT depending on distance over absorber y (cm) and radiation R (W m^{-2}) at 35 cm from inlet.

Temperature exchange ΔT over absorber at 60 cm from inlet can be expressed with the following equation:

$$\Delta T = 1.57 + 0.011 \cdot R - 4.15 \cdot 10^{-6} \cdot R^2 - \\ - 0.348 \cdot y + 0.037 \cdot y^2 - 2.06 \cdot 10^{-4} \cdot R \cdot y \quad (2)$$

with coefficient of determination $\eta^2 = 0.855$.

The visual interpretation of expression (2) is shown in Fig. 4 as contour plot.

The efficiency of solar air collectors is influenced both by the design and air circulation and by the properties of the material used for cover, absorber and insulation. Considering its short useful life, the material and the production costs are the main selection criteria. The influence of air circulation on the efficiency is relatively low for a low temperature rise, while solar air heaters with air flow underneath or above the absorber show significantly higher value of efficiency in a higher temperature range.

We tested new absorber materials which can be used in hand made air heated solar collectors. These materials must be cheap, light and simple to use. We made a panel of colored 3 cm wide slices of beer cans, which was attached to the pressboard with 9 rows perpendicular to the airflow (Fig. 5-6).

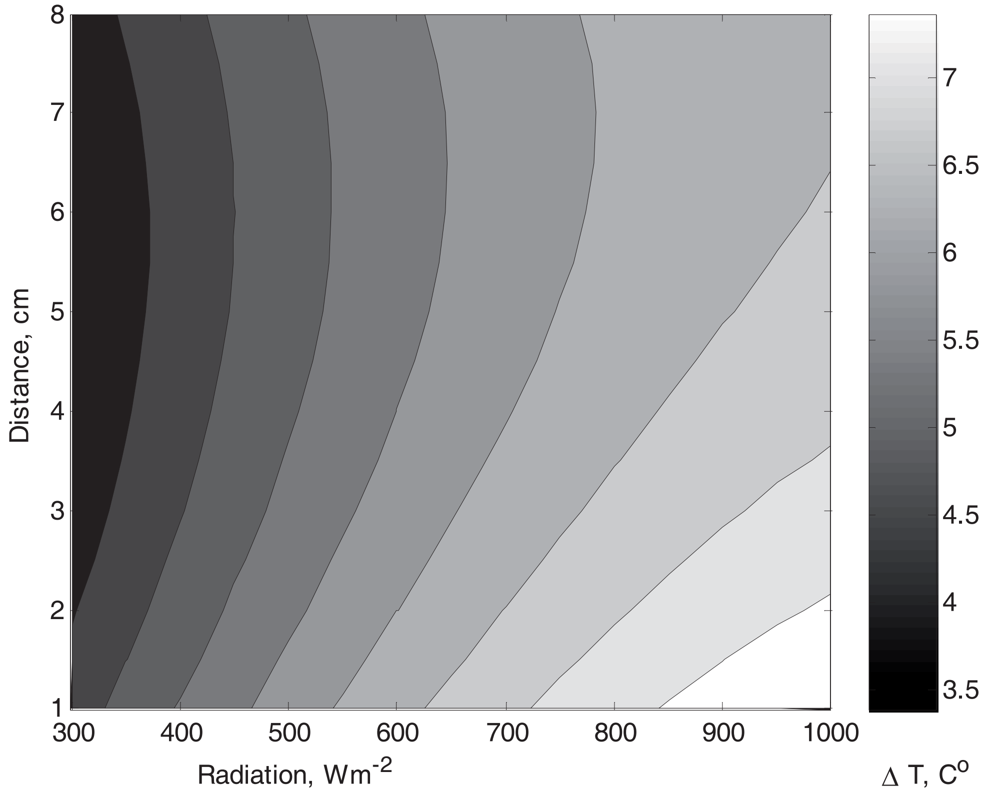

Fig. 4. Contour plot of air temperature increase ΔT depending on distance y (cm) over absorber and radiation of the sun R (W m^{-2}) at 60 cm from inlet.

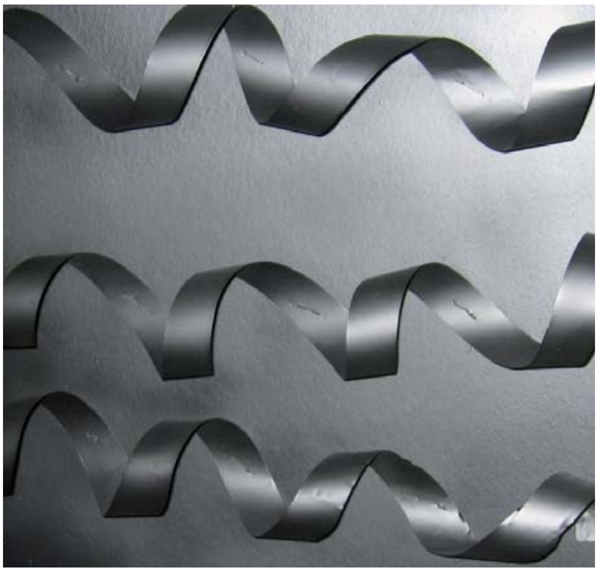

Fig. 5. Black colored slices of beer cans as absorbers of air collector.

Fig. 6. Air heating solar collector with absorber black colored slices of beer cans.

The area of the slices was 0.26 m^2. These slices help to mix air flow in collector and rise outlet air temperature.

The air heating experiments with this collector were made in different weather conditions. The instrument for measuring solar radiation is a pyranometer. The data on sun radiation depend on the clouds and shadows, and we aligned the experimental data with the method of least squares, using the following function (Vedenjapin, 1967):

$$\overline{y_i} = \frac{1}{35}[17y_i + 12(y_{i-1} + y_{i+1}) - 3(y_{i-2} + y_{i+2})]$$

where $\overline{y_i}$ - aligned data, y_i - experimental data, i - ordinal number.

Experimental data show that temperature difference in outlet of collector reaches up to 9-11 degree with sun radiation 1,000 W m^{-2} in different weather conditions. One of experimental (31 July 2009) data graph we can see in Fig. 7.

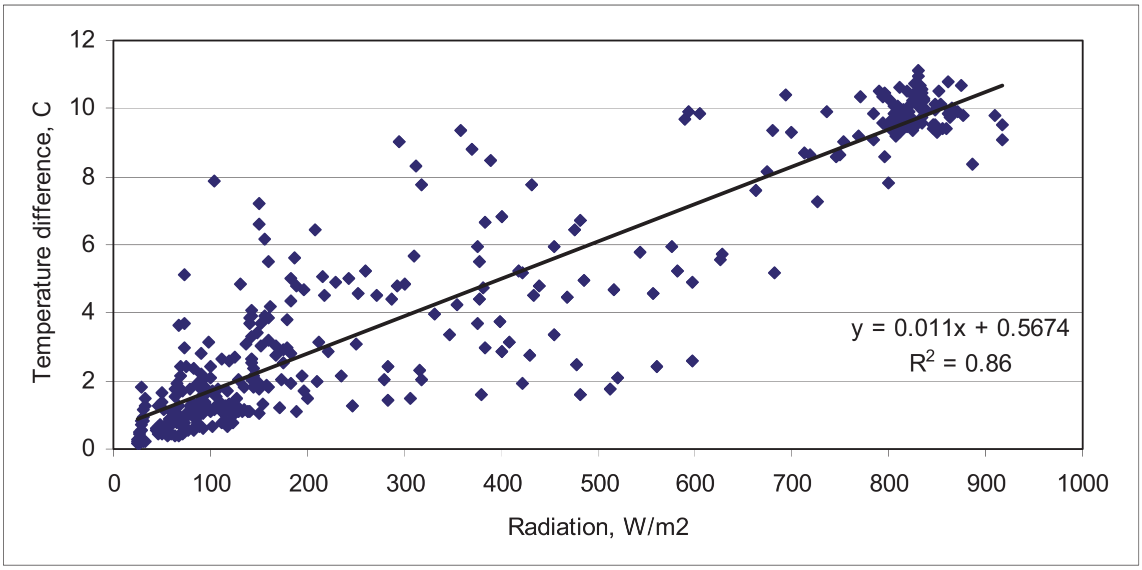

Fig. 7. Air heating temperature difference in case of black coloured slices of beer cans absorber depending upon solar radiation in a sun following collector (11:00 to 20:00 o'clock).

The slope of connection between sun radiation and ambient air temperature increase in collector outlet is in the range [0.009; 0.012].

This type of absorber gives better results than other types of absorbers (black colored wood, steel thin plate). Sun following collector's efficiency (air temperature grows) is closely dependent on sun radiation. The plate of this collector was perpendicular to the flow of sun radiation. The ambient air temperature grows in stationary collector outlet in case of a similar absorbent (slices of cans) and the location of absorbent is three, four degree less than that of the sun following collector.

The efficiency of this absorber material can be explained with the type of absorber which mixes air flow in the thickness and width of the collector area. It is important because without air mix, air exchange at corners and near sides of collector will not take place.

CONCLUSIONS

1. Theoretical expressions for air temperature which exchanging over steel-thin plate absorber in FPC at 35 cm and 60 cm from inlet are obtained. These expressions show temperature decrease depending on distance,
2. Absorber black colored slices of beer cans can use solar collectors for air heating. Experimental data show the temperature difference in the outlet of a sun following collector which reaches up to 9-11 degrees with sun radiation 1,000 W m^{-2}at different weather conditions.
3. When comparing a sun following and a stationary collector's temperature heating degree, then in the former it is 3-4 degrees higher (with sun radiation 1,000 W m^{-2}) than in the latter with absorber black colored slices of cans.
4. An air solar collector is due to its physical and mechanical properties suitable for heating the air in Latvia. In favorable weather conditions, heating degree of ambient air reaches over 10 degrees at exit with absorber length 1m and air velocity v = 0.9 m s^{-1}.

REFERENCES

Kalogirou, S. 2009. *Solar energy engineering: processes and systems,* Academic Press Elsevier Inc.

Lauva, A., Aboltins, A., Palabinskis, J., Karpova-Sadigova, N. 2006. *Comparative studies of the solar material collector.* Proceedings of the 5th International Scientific Conference 'Engineering for Rural Development' 18-19 May, Jelgava, pp. 90-94.

Aboltins, A., Palabinskis, J., Lauva, A., Skujans, J., Iljins, U. 2007. *The material investigations of solar collector,* Proceedings of the 6th International Scientific Conference 'Engineering for Rural Development' 24-25 May, Jelgava, pp. 18-23.

Palabinskis, J., Lauva, A., Aboltins, A., Karpova-Sadigova, N. 2008. *Movable Air Solar Collector and its Efficiency.* 7th International Scientific Conference 'Engineering for Rural Development', Jelgava, Latvia, 29-30 May, Jelgava, pp, 51-56.

Palabinskis, J., Aboltins, A., Lauva. A., Karpova-Sadigova, N. 2008. *The comparative material investigations of solar collector*. Proceedings of the Agronomy Research. Volume **6** 'Engineering of Agricultural Technologies'. Special Issue, Kaunas, pp. 255-261.

Aboltins**,** A., Palabinskis, J., Lauva, A., Rušķis, G. 2009. *The investigations of air solar collector efficiency.* Proceedings of the 8th International Scientific Conference 'Engineering for Rural Development', Jelgava 28-29 May pp. 176-181.

Aboltins**,** A., Palabinskis**,** J., Lauva, A., Rušķis., G. 2009. *The steel-thin plate absorbers investigations in air solar collector.* Proceedings of the 8th International Scientific Conference 'Engineering for Rural Development' Jelgava 28-29 May, pp. 182-187

REG 2004. Technical description and using instruction, Riga, 11 pp. (in Latvian).

Vedenjapin, G. V., 1967. *The general methodology of experimental research and treatment of experimental data.* Kolos, Moskva (in Russian).