

Determination the parameters and modes of new heliocollectors constructions work for drying grain and vegetable raw material by active ventilation

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Abstract: The article presents the results of experimental studies of the air heating efficiency in heliocollectors with different surface forms developed in order to justify their use in equipment for active ventilation of grain and feed raw materials.

Keywords: solar radiation; energy saving; heat transfer intensification; temperature; hydraulic resistance

Time of harvesting and post-harvest processing of cereals, fodder (grass) and technical (flax, hemp) crops coincides with the maximum intensity of solar radiation entering the Earth. Therefore, the use of solar radiation for the heating of atmospheric air, which is used as a drying agent for active ventilation of plant materials, is a very effective measure for intensifying drying and energy conservation. The most effective solar energy for heating air in a significant amount (30,000–50,000 m³·h⁻¹) is used in solar collectors. That is why the problem of increasing the efficiency of heliocollectors, in the conditions of the high cost of traditional heat sources, is never more relevant and requires further improvement of existing structures.

The efficiency of solar energy use when drying agricultural raw materials is substantiated in different works (POPOV et al. 2002; BELOGLAZOVA, ROMANOVA 2014; MULLIAR et al. 2015). The issue of calculations and modelling of technological objects solar heat supply is considered in works of BOGDA-

NOVICH and GRIGORIEV (2008), BOGDANOVICH and GRIGORIEV (2011) and KUPRENKO et al. (2016).

New designs of non-frame film heliocollectors have been investigated (KOVALEV et al. 2011; BELOGLAZOVA, ROMANOVA 2014). In works of KOTOV (2002) and TUNIK (2016) the design of the hearth heaters of air have been developed and their parameters for fixed values of air flow determined. Experimental studies have not covered all the regimes of operation of heliocollectors in conjunction with active ventilation equipment.

The article presents the experimental determination of thermal (technological) and energy characteristics of frame heat heater with heat exchange intensifiers.

MATERIAL AND METHODS

The air from the solar collector to the grain mass was fed by one or two serially connected

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medium-pressure fans of the type VCP-3 (Grand-vent, Ukraine). The relative humidity of the air was measured by an aspiration psychrometer MB-4M (Skloprylad PLC, Ukraine), temperature – by thermometers – TL-4 (Termopribor PLC, Russia), and by thermo-vapour of the TCC type (Ukraine). The velocity of air at the exit from the solar collector was measured by the cup anemometer-MS-13 (Sphere, Ukraine), the intensity of the solar radiation was measured by a portable pyroglyometer – B2B (NPO ATTECH, Russia).

Changes in the moisture content of grain materials were determined by decreasing the grain weight in the cassettes, and the average and initial moisture content of the grain was determined by the standard method according to GOST 13586.5-93 (method of moisture content determination).

For the processing of experimental data, mathematical and statistical methods of the theory of planning the experiment using elements of probability theory were used.

RESULTS

Experiments on the determination of thermal energy efficiency of heliocollectors have been carried out on an experimental equipment with an artificial and natural source of radiation. The scheme of installation is shown in Fig. 1.

The equipment contains a ventilation plant with a centrifugal fan (1) (Fig. 1a) which is connected to the distributor collector (2) (Fig. 1a) with four channels (3) (Fig. 1a) insulated from each other and

from the lower side from the external environment. At the bottom of each channel, there are the metal plates fixed and painted in black. In the upper part of the channels were installed absorbers of solar radiation, made of duralumin thickness of 0.2 cm and painted in black. One channel above was covered with a polyethylene film (translucent) and represented a model of a “black box” type heliocollector to compare the characteristics of the model with the solar collectors being investigated (Fig. 2).

The collectors of three types without a translucent shelter with an external heat-receiving surface were investigated: plane with a smooth surface; plane with artificially discrete rough surface (5) (Figs 1c, d) in the form of the transverse heated air flow in the channel on the inner surface of the radiation absorber of flexible inserts (plastic cords, or wires with a diameter of 0.5–0.6 cm) – turbulators; the third type (4) (Fig. 1b) of the collectors was an insulated canal which upper surface had small holes of 75 mm in diameter and arranged in a chess sequence with S_1 (distance between the holes) = 150 mm. In these holes, cylindrical surfaces are mounted in height that is equal to the height of the canal, so that within the channel perpendicular to the absorbing surface is a tube of pipes that is transversely washed by air.

To determine the rational parameters of turbulators of the type “artificial rough” of the surface, preliminary simulation of the analytical and calculation method of height influence and the step of placing turbulators were carried out. At the same time, under the condition that provides intensification of heat exchange at minimum energy costs for transport of coolant, the correlation E. Kalinin was taken (KALINICHENKO 2005; SPIRIN, GUNKO 2015), as Eq. 1:

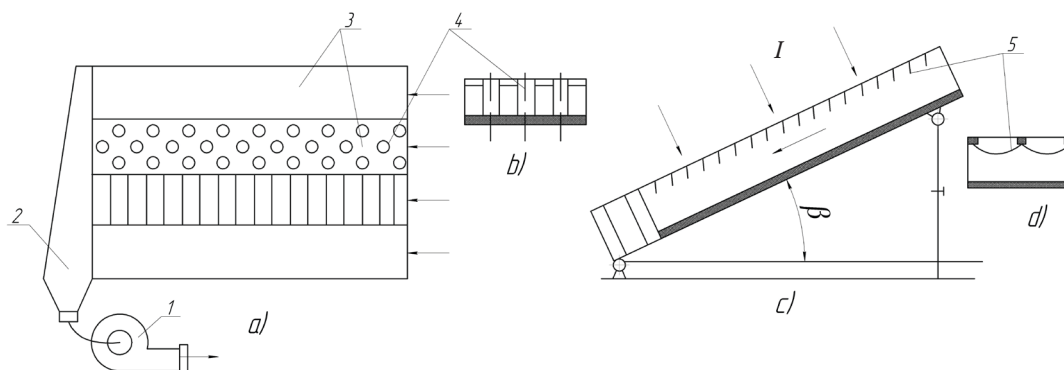


Fig. 1. Scheme of experimental equipment for the study of heliocollectors: the top view (a), a fragment of the side view (b), the front view (c), an enlarged fragment of the front view (d)

1 – centrifugal fan; 2 – distributor collector; 3 – each of the four air conduits; 4 – a channel with vertical cylindrical inserts; 5 – channel with discrete flexible inserts – turbulators; I – direction of sunlight; β – angle of the panel to the horizon

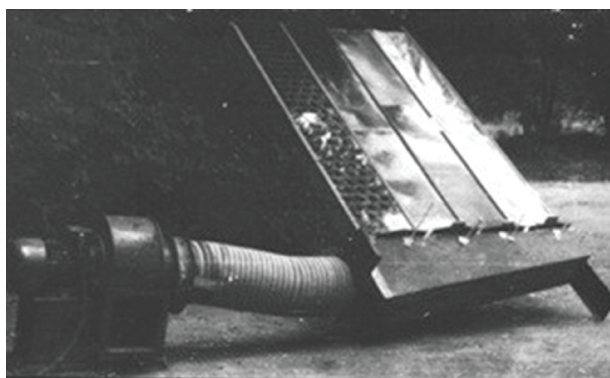


Fig. 2. Frontal view of the experimental equipment

$$\frac{Nu_T}{Nu_{ss}} \geq \left(\frac{\xi_T}{\xi_{ss}} \right) \left(\frac{Re_T}{Re_{ss}} \right) \left(\frac{\alpha_T}{\alpha_{ss}} \right) \quad (1)$$

where: Nu_T – Nusselt's criterion for a turbulent channel, Nu_{ss} – Nusselt's criterion for a smooth surface channel, ξ_T, ξ_{ss} – coefficients of hydraulic resistance; Re_T, Re_{ss} – Reynolds number for the turbulent channel and the flat surface; α_T, α_{ss} – coefficients of heat exchange for a surface with intensifiers and a smooth surface

The results of experimental studies of plane surfaces and surfaces with heat exchange intensifiers are shown in Figs 3a, b in the form of dependencies of the degree of heating the air at the channel outlet from the specific air flow per 1 m² area of the heliocollector at an intensity of radiation of 800 W·m⁻².

The analysis of the above graphic dependencies makes it possible to note that the presence of heat exchange intensifiers on the inner surface of the heat absorber gives the opportunity to increase the air temperature at the outlet of the channel in all the studied ranges of the change in the specific air flow from 47 to 198 m³·h⁻¹·m⁻². The degree of increase in the heating of air is most significant at low air flow (50 m³·h⁻¹·m⁻²); at high values of air flow (150 to 200 m³·h⁻¹·m⁻²) the efficiency of turbulence decreases.

As it is known from KOTOV (2002) and PLESHKA and VYRLAK (2011), the efficiency of heliocollectors is negatively affected by the increase in wind speed, which leads to an increase of heat losses to the environment.

The conducted experiments showed that when applying turbulating devices on the internal surface of the absorber, the effect of wind speed on thermal efficiency decreases. This allowed to raise the temperature of air heating. At wind speeds of 3 m·s⁻¹ and specific air flow rates of 100 m³·h⁻¹·m⁻², the degree of air heating increased from 7.5 to 90°C. It increased thermal performance by 15–16%.

Measurements of air pressure loss in a channel with a developed surface and calculations of the hydraulic resistance of the channel up to 15 m long have been established to increase the pressure loss in 2–2.5 times compared to the channel with a smooth surface. The maximum value of the required head of the fan is 30–60 Pa, which increases the power of the fan by 10% relative to the thermal power of the heliocollector.

The maximum value of thermal efficiency due to the use of a turbulating device is increased from 0.5 to 0.6, ie by 16.6%.

Thus, the determined parameters and operating modes of the heliocollector with the intensifying devices prove the possibility of creating heliocollectors without a translucent cover with an efficiency of more than 0.5.

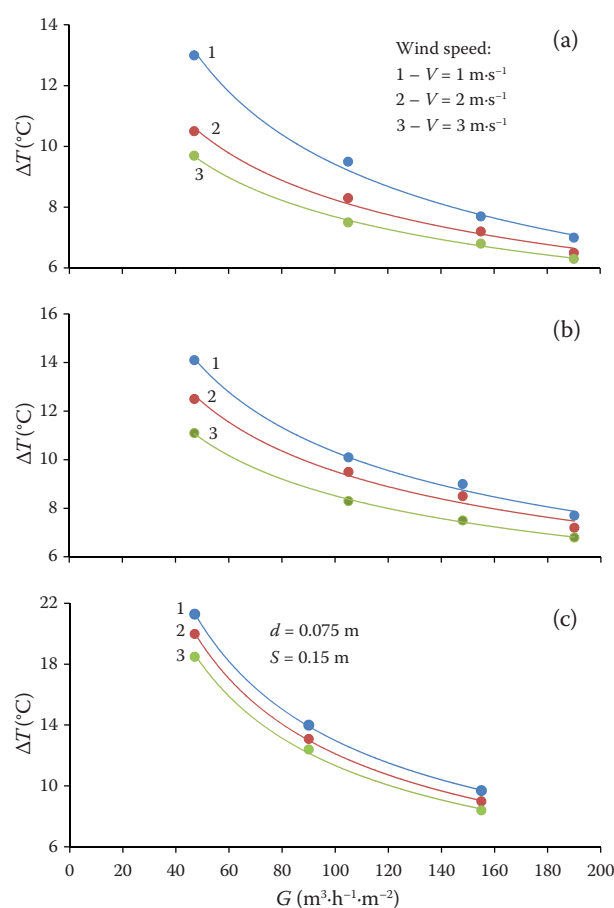


Fig. 3. Dependence of the degree of air heating (y -axis) in the plane collector (a), in the collector with turbulizers (b), in the collector with cylindrical inserts (c) on the specific air flow

T – temperature; G – specific air flow rate, d – diameter of the cylindrical insert, S – distance between the inserts

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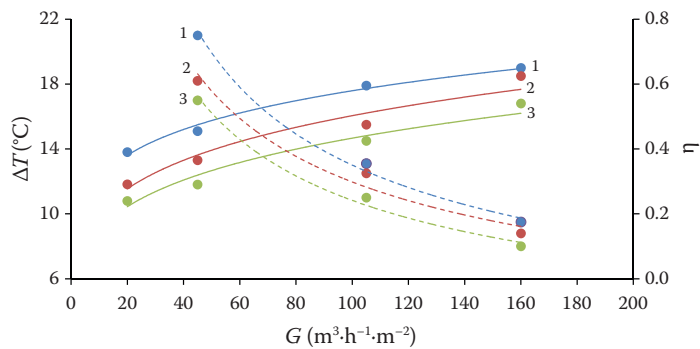


Fig. 4. Thermal energy characteristics of the tested collectors, depending on the specific air flow

T – temperature (dashed line); G – specific air flow rate; η – coefficient of performance (solid line); 1 – cylinder inserts; 2 – turbulent devices; 3 – smooth

Further improvement of the efficiency of plane solar collectors can go along the way of reducing the surface of the heat transfer of the absorber, while simultaneously increasing the heat exchange surface and the intensity of heat transfer.

Such a direction is realized in a heliocollector with cylindrical inserts (Fig. 1b).

The results of studies of this type of heliocollector are shown in Fig. 3c in the form of dependencies of the degree of temperature increase on the specific air flow.

To compare the obtained results with the detection of the efficiency of all investigated types of absorbers, all experiments were carried out in one interval of specific air flow rates. But at the same time, the speed of air relative to the heat exchange surfaces in the collector with cylindrical inserts was twice as large.

The analysis of the research results shows that the application of the developed heat transfer surface in the form of tube bundles allows to increase the temperature of heating up to 20°C (Fig. 3c).

It reduces the negative impact of increasing the wind speed. The dispersion of the air temperature at the outlet from the channel does not exceed 2°C when the wind speed changes to 3 m·s⁻¹.

The efficiency of such a collector can be increased to a value greater than 60%.

In experimental studies of a heliocollector with a developed surface of the helio-absorber, the diameter of the cylindrical inserts did not change, and only the specific air flow was changed.

The thermoelectric characteristics of experimentally studied types of helium heaters are given in Fig. 4.

The heliocollector with intra-chamber cylindrical inserts has the greatest thermal efficiency. At the highest value of the efficiency of the collector, the degree of heating is 18–20°C.

With such values of the degree of temperature rise, the heliocollector of this type is most appropriate to be used for heating the air used as a dry-

ing agent in equipment for drying grain and fodder plant materials by active ventilation.

For a complete set of equipment: part of a tank with ventilation (PTV-160; Private Instrumentation Enterprise, Ukraine) with a capacity of 160 t of grain, it is necessary to use a heliocollector with a surface of 500 m². With air flow of 64,000 m³·h⁻¹, this collector provides air heating at 10°C. It enables to reduce the consumption of electricity by 4–8 kWh per year for a ton of grain, or to increase the productivity of equipment at the use of the released power of electric air heaters.

CONCLUSION

The conducted experimental studies confirmed the validity of the principles of increasing the efficiency of heliocollectors for heating the air due to the developed heat transfer surface. But in the course of the study, it has been discovered that not all the regime parameters sufficiently increase the thermal performance of the collectors with a developed surface, therefore further research is needed to detect the influence of the geometrical characteristics of the absorbers of radiation and the modes of the air heating process on the thermal efficiency of helium heaters.

References

- Beloglazova T., Romanova T. (2014): The effectiveness of the implementation of solar collectors. *Problems of Modern Economics*, 54: 357–359.
- Bogdanovich P., Grigoriev D. (2008): Heat-efficiency of the GC of the all-season solar control plant. *Collection of Scientific Articles: Agriculture. Problems and Perspectives*, 2: 162–168.

<https://doi.org/10.17221/73/2017-RAE>

- Bogdanovich P., Grigoriev D. (2011): Thermal helium equipment with improved operational characteristics. In: Proceedings of the XIV International Scientific and Practical Conference: Modern Technologies of Agricultural Production, Grodno, Jan 17, 2011: 7–8.
- Kalinichenko R. (2005): Energy-saving modes of drying and active ventilation of grain when stored in a farm. [Ph.D. Thesis.] Kyiv, National Agrarian University.
- Kovalev O., Ilyin A., Ilyin R. (2011): Investigation of singularities of heat transfer in flat solar heaters. *Vesnik of Astrakhan State Technical University*, 52: 60–66.
- Kotov B. (2002): Mathematical modeling of air heating in solar collectors for drying of plant material. *Electrification and Automation of Agriculture*, 1: 107–109.
- Kuprenko A., Komogortsev V., Isaev H., Chenik A., Shkuratov G. (2016): Control of thermal balance of an air heliocollector with a heat accumulator. *Tractors and Agricultural Machines*, Zhytomyr, 4: 33–36.
- Mulliar A., Erk A., Pastushin E. (2015): Drying of herbs seeds using a heliocollector. Technologies and technical means of mechanized production of plant growing products and livestock breeding. Collection of Scientific Articles of the IAEP, 87: 254–258.
- Pleshka M., Vyrlak P. (2011): Development and experimental studies of a matrix solar air collector. *Vesnik of MGSU*, 7: 109–117.
- Popov V., Akhmedov M., Pastushin E. (2002): Drying of hay using solar energy. Technologies and technical means of mechanized production of plant growing products and livestock breeding. Collection of Scientific Articles GNUSS NIIMESK All-Russian Academy of Sciences St. Petersburg, 73: 173–178.
- Spirin A., Gunko I. (2015): Application of heat accumulators in air gel air heaters. In: Gulko L. (ed.): Proceedings of the VIII International Scientific Conference: Forages and Feed Protein, Vinnytsia, Dec 15, 2015: 47–48.
- Tunik A. (2016): Mathematical model of heat and mass transfer processes in a flat solar collector SU N 1. *Vesnik MGSU*, 1: 126–142.

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