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METHOD OF DETERMINING THE EFFICIENCY OF HELIOCOLLECTOR IN SYSTEM WITH FORCED CIRCULATION OF COOLANT

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The potential of solar energy for Poland is analyzed. The efficiency of solar collectors installed in the mechanical heating system is researched.The dependences between the angles fall heat flux and intensity of the heat flux on the effectiveness of solar collector is established.

Introduction. In fact, fuel and energy resources are getting more ad more expensive, population is trying to improve and find more efficient, cheaper ways of obtaining energy. Among all renewable sources of energy solar radiation offers the most opportunities of direct use. It gives possibilities to test and implement new technology of production and processing but also for proper storage and efficient management of resources. Actually, it requires series of research and making substantial changes in solar global economy, but it also requires a financial background.

Formulation of the problem. Currently there is a number of solar collectors that are different in design, and technical and economic indicators. Flat solar collectors have proved themselves as quite effective and easy to use. But these solar collectors are expensive, elaborately designed and have low solidity of the top covering because of the application of glass or plastic as the transparent top cover. Consequently, at present it is important to improve and develop new combined solar collectors where the top covering of the solar collector is made of corrugated roofing material of the building. This kind of the solar collector will allow to reduce its cost maximally and increase its durability.

The main material. Nowadays many investors in Poland decide to buy solar systems in fact of financial support from European Union. With average sun radiation on level around 950-1050 $[\frac{kWh}{m^2}]$, what means that Poland is situated in moderate conditions, the most efficient are absorbing and vacuum solar collectors. The most popular use of solar collectors in Poland is for heating a water for tap water systems and networks (DHW = disposal hot water), rarely for supporting a central heating systems. It means, that practically the most proper angle of solar collector is around 45-50°. Potential of solar energy in Poland is shown on fig. 1.

Fig.1. Annual solar radiation on teritory of Poland

Today, it is important to conduct research that would allow to evaluate potential of use of solar collectors in solar heating systems and conduct simulations of their work. Experimental setup for investigating the impact of angles of incidence of radiationon the efficiency of the solar roof mountedat the National University "Lviv Polytechnic". The experimental setup is shown on fig.2.

For our research we used mechanical solar system with two water tanks. The mechanical systems in general have better efficiency than gravity systems because of installing an additional supporting equipment for proper pressure and flow water. In account of this kind of regulation, there is no limitation about pipes conduction. Regulation of this kind of systems is easier, but also the price of installation is accordingly higher. Mechanical system is commonly used nowadays - many companies works about improvement of efficiency but also reduction of costs for professional installations.

Cold water from first water tank (6) situated above is going through solar collector (3). Absorber of solar collector captures heat from imitator of insolation (1) and transfer it to water. The water is going down to warm water tank (9) and then manually transported to upper tank. The amount of water going through installation is 10 liters per hour.

In installation water tank has water capacity 10 liters. Temperatures were measured every 15 min in time of 3,5 hours by thermometers. Temperature was measured in 3 points – inside water tank, in pipe of cold water – input pipe of solar collector (7) and in pipe of warm water – output pipe of solar collector (4).

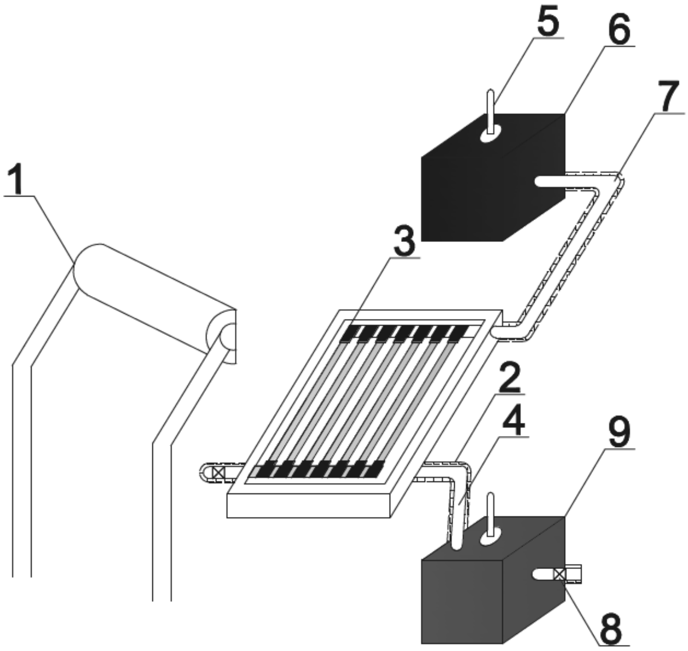

Fig. 2. Scheme of mechanical solar system: 1 – lamp-imitator of insolation; 2 – insulation; 3 – solar collector; 4 – pipe of warm water (output pipe); 5 – thermometer; 6 – cold water tank; 7 – pipe of cold water (input pipe); 8 – cutting valve; 9 – warm water tank

We considered 3 main factors:

- *I* – intensity of insolation - radiation (300/900 $[\frac{W}{m^2}]$)
- α – azimuth angle of sunlight (30°/60°/90°)
- β – angle of solar collector inclination (tilt) (30°/60°/90°)

The intensity of the flow of the energy emitted by the source (infrared lamp) was measured by an actinometer. Depending on the intensity, imitator of sunlight was situated in different distance from solar collector: for *I* = 300 $[\frac{W}{m^2}]$ in distance of 100 cm; for *I* = 900 $[\frac{W}{m^2}]$ in distance of 50 cm

The following diagram (fig. 3) shows difference between the highest and the lowest temperatures we gained during the heating.

For all combinations of angles and both intensities the maximum difference of temperature was 6 K. The biggest difference we got for *I* = 900 $[\frac{W}{m^2}]$, α=90°, β=90, the lowest for *I* = 300 $[\frac{W}{m^2}]$, α=90°, β=30° what also has results in calculated amount of heat. The differences of temperatures for most opposite cases is around 1-1,5 K.

For calculation of amount of heat for mechanical system we use the following formula:

$$Q = c_p \cdot \dot{V} \cdot \Delta T \quad (1)$$

where Q – amount of heat gained by heating a water [W]; $\dot{V}$ – amount of water going through pipes per one hour [l/h]; ΔT – difference of temperatures in water tanks [K].

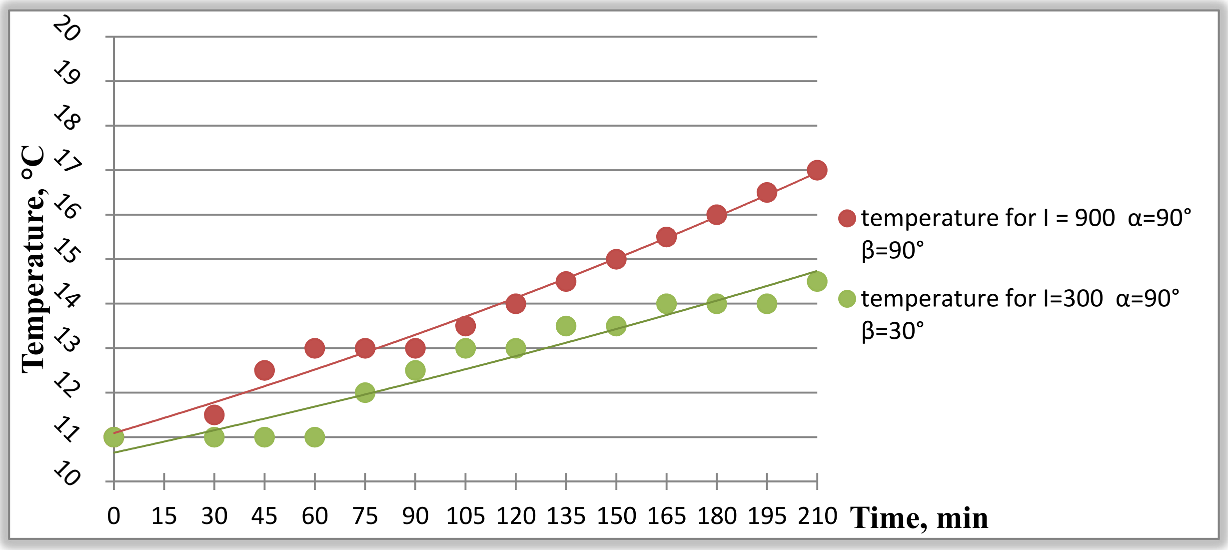

Fig.3. Diagram of temperatures for $I = 900$ $[\frac{W}{m^2}]$, α=90°, β=90°

For better view of research we prepared equation of approximation for results:

$$Q = (165{,}25 - 0{,}0376 \cdot I) + (0{,}1758 + 0{,}0002 \cdot I) \cdot \beta + (-0{,}0917 + 0{,}0004 \cdot I) \cdot \alpha + (0{,}0135 - 1{,}4667 \cdot 10^{-5} \cdot I) \cdot \alpha \cdot \beta \quad (2)$$

Efficiency of aperture depends on many factors and it is important to mention them on every stage of projecting. Our research shows influence of 3 factors on efficiency of acquisition energy from solar radiation but also indirectly shows dissimilarities in systems with different fluid flow.

The most basic formula to describe efficiency of solar collectors, containing coefficient of heat losses is as follows:

$$\eta = \eta_0 - \frac{k_1 \cdot \Delta T}{E_g} - \frac{k_2 \cdot \Delta T^2}{E_g} \quad (3)$$

where η – efficiency of solar collector; η_0 – optical efficiency; k_1 – coefficient of heat losses $[\frac{W}{m^2 \cdot K}]$; k_2 – coefficient of heat losses $[\frac{W}{m^2 \cdot K}]$; ΔT – differences of temperatures [K]; E_g – power of radiation $[\frac{W}{m^2}]$.

Another formula, which takes into consideration solar irradiance and general amount of energy:

$$\eta = \frac{Q_E}{I_o \cdot A_o} \quad (4)$$

where Q_E – rate of (useful) energy output [W]; I_o – solar irradiance falling on collector aperture $[\frac{W}{m^2}]$; A_o – aperture area of collector $[m^2]$.

There are also equations for different types of collectors. For concentrating thermal collectors it presents:

$$I_o = I_{b\,a} \quad (5)$$

where $I_{b\,a}$ – direct (beam) irradiance on a collector aperture $[\frac{\mathrm{W}}{\mathrm{m}^2}]$.

$$\eta = \frac{m \cdot c_p \cdot (T_{out} - T_{in})}{I_{b\,a} \cdot \cos\varphi \cdot A_o} \tag{6}$$

where φ - the angle of incidence generated by azimuth angle of sunlight and angle of solar collector inclination (tilt).

For our final calculations we used formula for flat – plate collectors:

$$I_o = I_{t\,a} \tag{7}$$

where $I_{t\,a}$ – global irradiance on a collector aperture $[\frac{\mathrm{W}}{\mathrm{m}^2}]$

$$\eta = \frac{m \cdot c_p \cdot (T_{out} - T_{in})}{I_{t\,a} \cdot A_o} \tag{8}$$

The big influence on the results of efficiency for solar collectors has heat losses. To get know the amount of heat losses we have to realize the general amount of heat captured by collector.

$$Q_E = E_{opt} - Q_{loss} \tag{8}$$

where Q_E - rate of "useful" energy leaving the absorber [W]; E_{opt} - rate of optical (short wavelength) radiation incident on absorber [W]; Q_{loss} - rate of thermal energy loss from the absorber [W].

$$Q_E = m \cdot c_p \cdot (T_{out} - T_{in}) \tag{9}$$

where m – mass flow rate of heat transfer fluid $[\frac{kg}{s}]$; c_p- specific heat of heat transfer fluid $[\frac{J}{kg \cdot K}]$; T_{out} - temperature of heat transfer fluid leaving the absorber [K]; T_{in}- temperature of heat transfer fluid entering the absorber [K].

$$E_{sol} = I_o \cdot A_o \tag{10}$$

where E_{sol} - incident solar resource [W]; I_o - solar irradiance entering the collector aperture (global (total) or direct (beam)) $[\frac{\mathrm{W}}{\mathrm{m}^2}]$; A_o - aperture area of the collector $[\mathrm{m}^2]$.

$$E_{opt} = \Gamma \cdot \rho \cdot \tau \cdot a \cdot I_o \cdot A_o \tag{11}$$

where Γ – capture fraction (fration of reflected energy entering or impinging on receiver); ρ – reflectance of any itermediate reflecting surfaces; τ – transmittance of any glass or plastic cover sheets or windows; a – absorptance of absorber or receiver surface.

The heat losses are complex of 3 main aspects:

$$Q_{loss} = Q_{loss\,convection} + Q_{loss\,radiation} + Q_{loss\,conduction} \tag{12}$$

$$Q_{loss\,convection} = \psi_c \cdot A_r \cdot (T_r - T_a) \tag{13}$$

where ψ_c – average overall convective heat transfer coefficient $[\frac{\mathrm{W}}{\mathrm{m}^2 \cdot \mathrm{K}}]$; A_r – surface area of receiver or absorber $[\mathrm{m}^2]$; T_r – average temperature of receiver [K]; T_a – ambient air temperature [K];

$$Q_{loss\,radiation} = \varepsilon \cdot \sigma \cdot A_r \cdot ({T_r}^4 - {T_{sky}}^4) \tag{14}$$

where ε – emittance of the absorber surface (or cavity in the case of cavity receiver); σ – the Stefan Boltzmann constant ($5{,}67\cdot 10^{-8}$ $[\frac{\mathrm{W}}{\mathrm{m^2 \cdot K}}]$); T_{sky} – the equivalent black body temperature of the sky [K]

$$Q_{loss\ conduction} = \chi \cdot \Delta x \cdot A_r \cdot (T_r - T_a) \quad (15)$$

where χ – equivalent average conductance $[\frac{\mathrm{W}}{\mathrm{m^2 \cdot K}}]$; Δx – the average thickness of insulating material [m].

After considering all equations above and putting them all together, we receive:

$$\mathrm{Q_{loss}} = \psi_c \cdot \mathrm{A_r} \cdot (\mathrm{T_r} - \mathrm{T_a}) + \varepsilon \cdot \sigma \cdot \mathrm{A_r} \cdot \left(\mathrm{T_r}^4 - \mathrm{T_{sky}}^4\right) + \chi \cdot \Delta \mathrm{x} \cdot \mathrm{A_r} \cdot (\mathrm{T_r} - \mathrm{T_a}) \quad (16)$$

$$Q_E = E_{opt} - Q_{loss} = \Gamma \cdot \rho \cdot \tau \cdot a \cdot I_o \cdot A_o - \psi_c \cdot A_r \cdot (T_r - T_a) + \varepsilon \cdot \sigma \cdot A_r \cdot ({T_r}^4 - {T_{sky}}^4) + \chi \cdot \Delta x \cdot A_r \cdot (T_r - T_a) \quad (17)$$

$$Q_E = m \cdot c_p \cdot (T_{out} - T_{in}) = \Gamma \cdot \rho \cdot \tau \cdot a \cdot I_o \cdot A_o - A_r \cdot [h'(T_r - T_a) + \varepsilon \cdot \sigma \cdot \left({T_r}^4 - {T_{sky}}^4\right)] \quad (18)$$

where *h'* - combined convection and conduction coefficient $[\frac{\mathrm{W}}{\mathrm{m^2 \cdot K}}]$.

Conclusion. The losses of heat has very huge influence on efficiency of the solar collector which can not be ignored. In our case, efficiency was counted by formula containing global irradiance falling on collector aperture and differences of temperatures in output and input pipes. The efficiency of mechanical solar system is around 60-70%, depending on factors we considered in research. The biggest influence on results had difference of temperatures. In these kind of system, a very big impact was the fact that water was poured back to the upper cold water tank manually. It didn't generate additional costs of system, but resulted in relatively large measurement errors. In more mechanized, circulating systems where speed and other factors like: materials, kind of working medium etc. efficiency is more specified and adequate higher.

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МЕТОДИКА ВИЗНАЧЕННЯ ЕФЕКТИВНОСТІ ГЕЛІОКОЛЕКТОРА У СИСТЕМІ З ВИМУШЕНОЮ ЦИРКУЛЯЦІЄЮ ТЕПЛОНОСІЯ

О. Т. Возняк, О. М. Пона, А. Ельтман, С.П. Шаповал, Н.А. Сподинюк

Проаналізовано потенціал використання сонячної енергії для Польщі. Досліджено ефективність сонячних колекторів, встановлених в механічній системі теплопостачання. Встановлено залежності між кутами падіння теплового потоку та інтенсивністю теплового потоку на ефективність сонячного колектора.

МЕТОДИКА ОПРЕДЕЛЕНИЯ ЭФФЕКТИВНОСТИ ГЕЛИОКОЛЛЕКТОРА В СИСТЕМЕ С ПРИНУДИТЕЛЬНОЙ ЦИРКУЛЯЦИЕЙ ТЕПЛОНОСИТЕЛЯ

О. Т. Возняк, О. М. Пона, А. Ельтман, С.П. Шаповал, Н.А. Сподинюк

Проанализированы потенциал использования солнечной энергии для Польши. Исследована эффективность солнечных коллекторов, установленных в механической системе теплоснабжения. Установлены зависимости между углами падения теплового потока и интенсивности теплового потока на эффективность солнечного коллектора.