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Dependence of Engineering-and-Economical Indicators of Flat-Plate Solar Water-Heating Collectors from Temperature of Water Heating in Double-Circuit Hot-Water-Supply Systems

Rabbonokul Rakhmanovich Avezov[1], **Nilufar Rabbanakulovna Avezova**[1,2], **Shamsiddinkhodja Ibragimkhodjaevich Suleymanov**[2], **Azizboy Ergashbayevich Khaitmukhamedov**[1], **Akmal Ulashevich Vokhidov**[2]

[1]*International Solar Energy Institute, Tashkent, Uzbekistan*
[2]*Physical-Technical Institute SPA "Physics-Sun" of Academy Sciences of Republic of Uzbekistan, Tashkent, Uzbekistan*

ABSTRACT

In this paper are given results of estimated researches by definition of dependence of engineering and economical indicators of flat-plate solar water-heating collectors (FSWHCs) from temperature of water heating in double-circuit hot-water-supply systems (HWSSs).

Keywords: Temperature of water heating; FSWHC; HWSSs.

Abbreviations:

SR	:Solar Radiation
SE	:Solar Energy
FSWHCs	:Flat-Plate Solar Water-Heating Collectors

INTRODUCTION

In solving the problems of saving of traditional fuel and energy resources, mitigation of ecological strength and improving of social and living conditions of the population is important extension of scales of use local non-traditional and renewable energy sources. In climatic conditions of the Republic of Uzbekistan is one of perspective local non-traditional and renewable energy sources is energy of the solar radiation (SR) which technical potential consists of 180 million tons of oil equivalent that more, than three times exceeds annual need of the republic for energy resources [1] .

The most prepared field for large-scale application of solar energy (SE) in the republic, as well as around the world, is considered its conversion to low-potential heat by means of flat solar water-heating collectors (FSWHCs) and its use as a source of thermal energy in the hot-water-supply systems (HWSSs) of the inhabited, household and social objects which are the main consumers of heat of the same temperature potential.

The real scale of use of SE in the HWSSs, other things being equal, depend on the engineering–economical performance of their basic element – FSWHCs which, in turn, along with cost indexes, depend on their resource performances, i.e. annual heat efficiency depending on temperature received from them of hot water, the having consumer importance for subscribers of the HWSSs.

Resource performances of FSWHCs in the HWSSs as the solar-water-heating units (SWHUs), in turn, can be determined by a way of carrying out their corresponding thermal tests in natural conditions in the characteristic regions of the republic different generally on arrival of SR and temperature of external air. However, different period and dissimilarity of conditions of carrying out tests will complicate to establish reliable interrelation of resource performances of the solar collectors (SCs) of considered type and HWSSs on their basis from long-term average meteorological data and a temperature mode of their operation. Therefore, it is considered more rational determination of heat efficiency of FSWHCs by a calculation way depending on temperature of hot water received from

***Address for correspondence:**

avezov@uzsci.net

them on the basis of use of the long-term average meteorological given districts on the set optical and thermal engineering characteristics of their elements, established calculation or experimental modes.

In the works [2-5] devoted to determination of coefficient of replacement of thermal load and seasonal heat efficiency of systems of a solar heat supply (SHS), as basic data are used average (long-term) values of the monthly sums of arrival of the total SR falling on a horizontal surface and average monthly ambient temperature (external air). Accuracy of the calculations executed by the technique used in these works, which received the name "f-method", on the nature is rather low and for this reason they are used for preliminary definition of the integrated thermal engineering characteristics, forecasting of scales of application and thermal optimization of parameters of elements of the considered systems.

METHODOLOGY OF CALCULATION

Unlike this method, we for the purpose of support of high accuracy of the received results, in this message for determination of engineering-and-economical performances of FSWHCs in the HWSSs used the day courses of hourly average values of arrival summary of SR, falling on a beam-receiving surface (BRS) oriented to the south and oblique at an angle $\alpha = 30^0$ to the plane of the horizon of FSWHCs and ambient temperature for characteristic days of months of year which correspond to average monthly values of these meteoparameters with the appropriate detail accounting of influences of the sizes of side elements of the casing of FSWHCs and the partial absorption of SR the translucent covering (TC) on its thermal engineering characteristics.

Calculations are executed for FSWHCs of average quality with the single-layer TC of the case from a windowpane thickness (δ_w) 0,004 m and extinction coefficient (β_g) 35 1/m, with usual (i.e. not selective) covering on a surface of beam absorber heat-exchange panel (BAHP) from a silicon-organic varnish of KO 822 of the black colour with an insignificant additive of soot (for gloss removal) having the directed absorptive ability (α_p^{dir}), equal radiating ability (ε_p) 0,97. Calculated value of the provided coefficient of total thermal losses of BAHP through the protecting elements of FSWHCs without partial absorption of SR of TC of its case ($K_{ref_{p-o}}$) 7,5$W/(m^2 \cdot {}^\circ C)$. Value of coefficient of thermal efficiency of BAHP of FSWHCs (η_{hp}) characterizing degree of its heat engineering perfection, 0,89.

Value of thermal efficiency of double-circuit HWSSs, considering existence of the intermediate heat exchanger in system (η_{HWS}), at values $K_{ref_{p-o}}$ = 7,5 $W/(m^2 \cdot {}^\circ C)$, heat transfer coefficient between the calefacient and heating environments of the considered heat exchanger (K_{he}) 800 $W/(m^2 \cdot {}^\circ C)$, the area of a frontal surface of the FSWHCs case (F_{fr}) 1,94m^2 and surface area of heating of the calefacient tubes (or a coil) the intermediate heat exchanger (F_{he}) 0,388m^2, i.e. at value of the relation of $\frac{F_{fr}}{F_{he}} = 0,2$, determined by expression [6]

$$\eta_{HWS} = \left(\frac{1}{\eta_{hp}} + \frac{K_{ref_{p-o}} F_{fr}}{K_{he} F_{he}} \right)^{-1} \tag{1}$$

equals 0,85.

Calculations are executed for conditions of Tashkent city (φ = 41,33°) for values of temperatures of hot water at the outlet from double-circuit HWSSs ($t_{f_{out}}$) 37, 45 and 55°C, which have the consumer importance for subscribers of this system.

As basic data by determination of cost of the thermal energy (C_{te}) generated in the SWHUs, and traditional fuel (S_{tf}) replaced by them, and also specific (carried to unit of area of a frontal surface of the case of FSWHCs quantity of last (G_{tf}) due to use of FSWHCs in HWSSs within a year (or for defined the periods of year) depending on temperature of hot water of HWSSs fed to subscribers

($t_{f_{out}}$) at given values of thermal efficiency of traditional heat-generating installations (η_{hg}), specific calorific ability of replaced traditional fuel (q_{tt}) and the fixed specific cost of SWHUs consisting of FSWHCs, the intermediate heat exchanger, a storage container of hot water, a pipe binding, circulators, installation and construction works, etc. are used results of calculation researches on definition of average monthly courses of value of average annual heat efficiency of FSWHCs of average quality in double-circuit HWSSs [6].

The cost of the thermal energy generated by SWHUs, depending on temperature of the hot water of HWSSs fed to subscribers ($t_{f_{out}}$) according to a methodology [7] can be determined from

$$C_{te} = \frac{K_{spec}^{SWHU} E_n + \sum E_{i_{spec}}^{yr}}{Q_{usf_{spec}}^{yr}} \tag{2}$$

where E_n - standard coefficient of depreciation of SWHUs; $\sum E_{i_{spec}}^{yr}$ - total annual operational costs of SWHUs; K_{spec}^{SWHU} - installed specific (carried to unit of area of a frontal surface of the case of FSWHCs) cost of SWHUs in HWSSs.

CALCULATION THE BASIC ENGINEERING AND ECONOMIC INDICATORS

Value of annual average specific heat efficiency of FSWHCs $Q_{usf_{spec}}^{yr}$ in (1) depending on $t_{f_{out}}$ according to [6] is determined from

$$Q_{usf_{spec}}^{yr} = 3029,32 - 32,9\left(t_{f_{out}} - 37\right), \frac{MJ}{\left(m^2 \cdot year\right)} \tag{3}$$

Substituting (3) into (2), we obtain

$$C_{te} = \frac{K_{spec}^{SWHU} E_n + \sum E_{i_{spec}}^{yr}}{3029,32 - 32,9\left(t_{f_{out}} - 37\right)}, USD/MJ \tag{4}$$

In particular, at E_n =0,1 and $\sum E_{i_{spec}}^{yr}$ =0,1 K_{spec}^{SWHU} expression (4) can be presented as

$$C_{te} = K_{spec}^{SWHU}\left[15146,6 - 164,5\left(t_{f_{out}} - 37\right)\right]^{-1}, USD/MJ \tag{5}$$

Fig. 1 shows the results of calculation studies on determination of dependence of cost of the thermal energy generated by SWHUs in the HWSSs, i.e. "Solar Thermal Energy" C_{te} from ($t_{f_{out}}$) and K_{spec}^{SWHU} within changes ($t_{f_{out}}$) from 37 to 55°C.

The amount of the replaced traditional fuel due to use of solar energy with the help of FSWHCs in HWSSs (i.e. "solar fuel") carried to unit of area of a frontal surface of the casing FSWHCs G_{spec}^{tf} according to the methodology [7] can be determined from

$$G_{spec}^{tf} = \frac{Q_{usf_{spec}}^{yr}}{\eta_{tg} q_{tf}}, \tag{6}$$

where η_{tg} -thermal efficiency, i.e. the efficiency (E) of the traditional heat-generating (water-heating) installation in HWSSs; q_{tf} -calorific ability of the replaced traditional fuel.

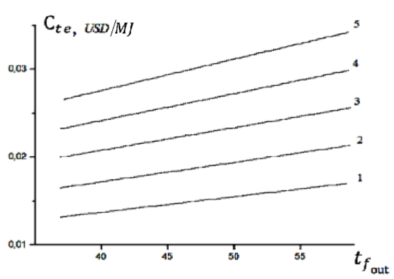

Fig1. *Dependence of the cost of solar thermal energy C_{te} from $t_{f_{out}}$ and K_{spec}^{SWHU} = 1,2,3,4 and 5 - respectively, at K_{spec}^{SWHU} = 200,250,300 and 400 USD/m^2 .*

Substituting values $Q_{usf_{spec}}^{yr}$ from (3) to (6) taking into account the value of q_{tf} = 0,8 and $q_{tt} = 35\ MJ/Nm^3$ (for natural gas), we obtain

$$G_{spec}^{tf} = 108,19 - 1,175\left(t_{f_{out}} - 37\right), nm^3/\left(m^2 \cdot year\right) \tag{7}$$

Dependence G_{tf} from $t_{f_{out}}$ is shown in Fig. 2.

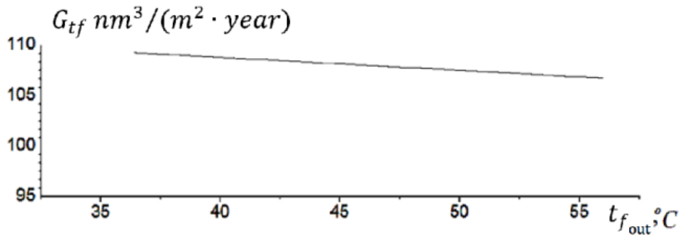

Fig2. *Dependence G_{spec}^{tf} from $t_{f_{out}}$ at η_{tg} = 0,8 and $q_{tf} = 35\ MJ/nm^3$.*

The specific cost of the "solar fuel" replaced by FSWHCs in HWSSs G_{spec}^{sf} within a year according to methodology [8] can be determined from

$$G_{spec}^{sf} = \frac{K_{spec}^{SWHU} E_n + \sum E_{i_{spec}}^{yr}}{G_{spec}^{tf}} \tag{8}$$

Substituting values G_{spec}^{tf} from (7) to (8) and taking into account values E_n =0,1 and $\sum E_{i_{spec}}^{yr}$ =0,1 K_{spec}^{SWHU}, we obtain calculated expression for definition of C_{sf} depending on $t_{f_{out}}$ and K_{spec}^{SWHU}, i.e.

$$G_{spec}^{sf} = K_{spec}^{SWHU}\left[540,95 - 5,875\left(t_{f_{out}} - 37\right)\right]^{-1}, \tag{9}$$

In fig. 3 are given results of calculated studies on determination of specific cost of the replaced FSWHCs in HWSSs of "solar fuel" of G_{spec}^{sf}, $USD/nm^3 \cdot year$ (in this case natural gas with calorific ability of $35\ MJ/nm^3$ from $t_{f_{out}}$ and K_{spec}^{SWHU} within changes of $t_{f_{out}}$ from 37 to 55°C.

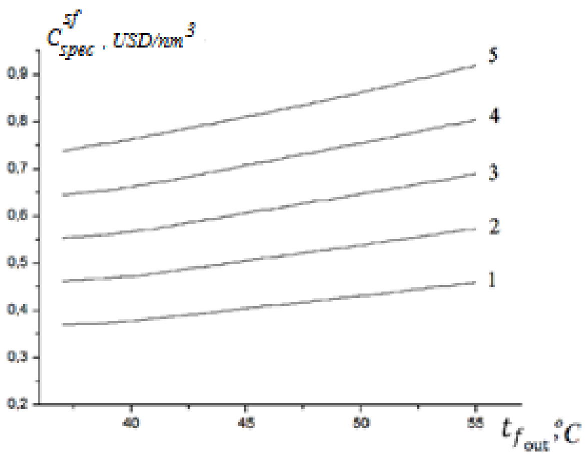

Fig3. *Dependence of the specific cost of natural gas, replaced by FSWHCs in HWSSs within a year G_{spec}^{sf} from $t_{f_{out}}$ and K_{spec}^{SWHU} = 1,2,3,4 and 5 - respectively, at from K_{spec}^{SWHU} = 200; 250; 300; 350 and 400 USD/m^2.*

From the analysis of the graphic dependences given in fig. 1-3 follows that the main ways of increasing of engineering-and-economical efficiency of FSWHCs in HWSSs are:

- decreasing of one-time and operational costs of FSWHCs and other components of equipments of solar HWSSs;

- decreasing of temperature of heating of water at the exit from SWHUs to acceptable values from the point of view of suitability for its use in household sector.

When performing calculations for this article ecological aspects of use of solar energy in HWSSs aren't considered.

In case of execution of calculations for this article does not consider ecological aspects of use of solar energy in HWSSs.

4. CONCLUSION

1) It is established dependence of cost of solar thermal energy (C_{SE}) on specific SWHUs (K_{spec}^{SWHU}) and heating temperature, water at the outlet from it ($t_{f_{out}}$).
2) It is offered approximating expression for definition of amount of the replaced traditional fuel due to use of SE by FSWHCs of average quality of double-circuit HWSSs depending on temperature of heating of the hot-water pumped to consumers.
3) On the basis of generalization of the received results are specified the main ways of increase of engineering-and-economical efficiency of use of FSWHCs to HWSSs.

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AUTHOR'S BIOGRAPHY

Nilufar Rabbanakulovna Avezova is a scientist in the field of solar power, the leading researcher and the head of the laboratory "Low-potential solar and thermal installations", also is the head of fundamental, scientific-technical and innovative projects at the Physical-Technical Institute of SPA "Physics-Sun" of Academy of Sciences of the Republic of Uzbekistan. In the same time at the International Solar Energy Institute the head of department "Solar heat supply". Executive secretary of the international scientific journal "Applied Solar Energy".