Prospects of solar-fuel technologies in Uzbekistan.

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Abstract

A double-loop solar fuel boiler installation scheme is studied. The following problems are considered:

- economic optimization of a heating surface of intermediate thermal exchangers in view of thermal efficiency of the solar water heating system;
- determination of the hot water load replacement factor of the solar water heating system;
- calculation of the specific area of solar collector's surface of the double-loop solar-fuel boiler-houses.

One of real ways of energy saving and reduction of emission of harmful products on combustion of organic fuel for municipal's heat supply systems is transition existing low-power and ineffective boiler-houses to solar-fuel technology. In Uzbekistan it is developed and successfully introduced as combined scheme of heating low-power (up to ~3÷5 MW) boilers and double-loop solar attachments [1], consisting of flat solar water-heating collectors and high-speed heat exchangers, for preheating feeding water (~ up to 40÷50 ^{o}C) (fig.1).

Fig.1. Field of the solar collectors working together with a boiler-house in the district "Vodnik". This project has been executed at support of program TACIS (2003).

Using of intermediate heat exchangers in the double-loop solar part's scheme in boiler-houses provide their all-the-year-round operation and reduce probability failure of solar collectors owing to freezing (in winter) and corrosive attack of water.

However thermal efficiency of double-loop systems is below than similar parameters of one-loop systems. The scientifically-proved solving of the given problem is economic optimization of a surface of heating intermediate heat exchanger in view of the resulted expenses for it and solar collectors in heat supply system.

On the basis of drawing up and the joint solving of the balance equations of mathematical model for separate elements and units of a solar double-loop systems equations for calculation of thermal efficiency of considered systems [2] are defined

$$\eta_{ss} = \eta_2 \cdot \left(\alpha \cdot \tau - U_c \cdot \frac{t_f - t_a}{q_S} \right) = \left(\alpha \cdot \tau - U_c \cdot \frac{t_f - t_a}{q_S^{\Sigma}} \right) \cdot \left(\frac{1}{\eta_c} + \frac{U_c \cdot F_c}{k_{EX} \cdot F_{EX}} \right)^{-1} \quad (1)$$

α - factor of absorption of solar radiation by a solar collector's surface; τ - factor of a sunlight transparent from a glass covering of a collector; q_S^{Σ} - density of a stream of the total solar radiation falling on a plane of a collector; η_2 - factor of thermal efficiency double-loop water-heating solar attachment; t_f –average mass temperature of the heat-carrier in the second loop (in intermediate exchanger); t_a – ambient temperature; $\eta_c = \eta_1$ – effectiveness ratio of an collector's absorber, characterized one-loop systems; U_c – resulted to unit of a collector's surface factor of total thermal losses; k_{EX} – intermediate heat exchanger's factor of a heat transfer; F_c and F_{EX} - the areas of a surfaces related to solar collectors and intermediate heat exchanger.

At $\frac{U_c \cdot F_c}{k_{EX} \cdot F_{EX}} \to 0$ or $U_c \cdot F_c \langle\langle k_{EX} \cdot F_{EX}$, as follows from (1), thermal efficiency of double-loop systems strive to similar parameters of one-loop systems.

For condition of maintenance equal thermal efficiency and temperatures of heating water in considered systems ($Q_1 = Q_2, t_{f2} = t_{f1}$) the increase of the solar collector's area ΔF in double-loop system (comparison with one-loop) is required. This is defined from parity

$$F_2 \cdot \eta_2 = \left(F_2 - \Delta F \right) \cdot \eta_1 \quad (2)$$

As the expenses connected with pipelines of solar attachment and system of water supply, pump units, a current consumption of electro energy and personal' salaries don't depend from $f_{opt} = \frac{F_{EX}}{F_c}$, than in this case the optimized part of the resulted expenses for double-loop solar-fuel system is defined from

$$Z = Z_{EX} + \Delta Z \quad (3)$$

$$\Delta Z = Z_2 - Z_1 \quad (4)$$

Z_{EX} – the resulted expenses for thermo exchanger; Z_2 и Z_1 – the resulted expenses for the solar collectors related to double- and one-loop systems.

In view of (2) equation (4) is

$$\Delta Z = \left(1 - \frac{\eta_2}{\eta_1} \right) \cdot Z_2 \quad (5)$$

Substituting equations η_1 and η_2 from (1) in (5) it is found

$$\Delta Z = z_2 \cdot F_c \cdot \frac{\eta_c \cdot U_c \cdot F_c}{k_{EX} \cdot F_{EX} + \eta_c \cdot U_c \cdot F_c} \quad (6)$$

z_2 - the specific expenses for the solar collectors related to double-loop systems.

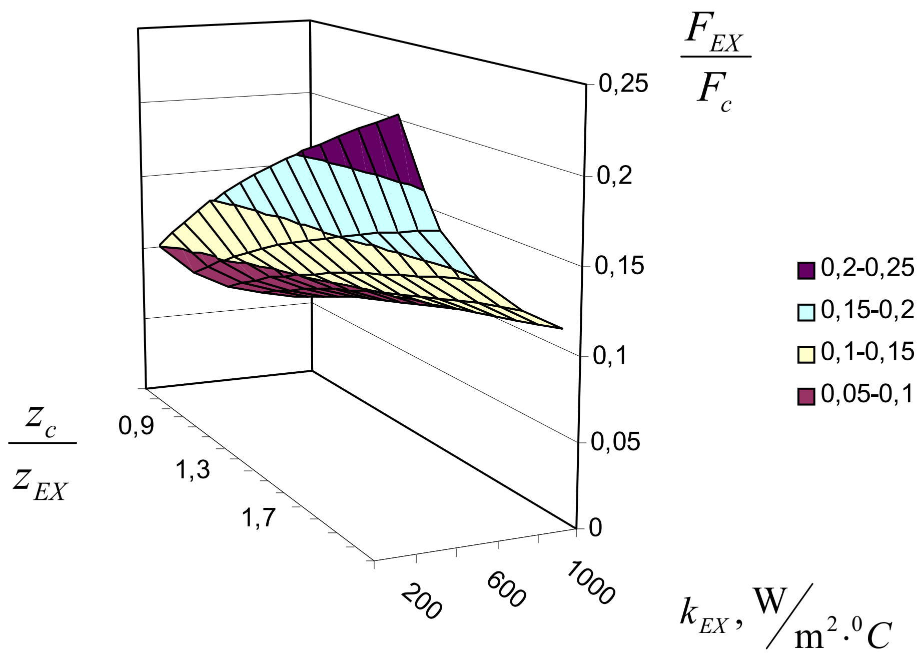

Fig. 2. Dependence of a parity of the areas of a heat exchanger [illegible] of double-loop system from its thermo technical properties and resulted expenses.

In view of (6) we receive from (3) equation of criterion function

$$Z = z_{EX} \cdot F_{EX} + z_c \cdot F_c \cdot \frac{\eta_c \cdot U_c \cdot F_c}{k_{EX} \cdot F_{EX} + \eta_c \cdot U_c \cdot F_c} \qquad (7)$$

где z_{EX} – the specific resulted expenses for unit of a intermediate heat exchanger's surface; z_c – the specific resulted expenses for unit of a solar collector's surface.

At differentiation of the given equation by $\overline{F} = F_{EX}/F_c$ and equating it to zero $\frac{\partial Z}{\partial \overline{F}} = 0$ required optimum parities of a heat exchanger's surface and the area of solar collectors could define from

$$\left(\frac{F_{EX}}{F_c}\right)_{optimum} = \sqrt{\eta_c \cdot \frac{U_c}{k_{EX}} \cdot \frac{z_c}{z_{EX}}} - \eta_c \cdot \frac{U_c}{k_{EX}} \qquad (8)$$

Results of optimization of double-loop solar system by equation (8) are presented in fig. 2.

On the basis presented technical and economic parameters of solar water-heating installations results of the modeling allow to define quickly and precisely the optimal development of double-loop for heat supply's systems. For conditions of Uzbekistan it is $f_{opt} = 1/\overline{F} = 10$.

The further purpose of calculations is determination of the surface area of a double-loop solar-fuel boiler-houses by dependence of their specific area (F_c^1,m^2 per 1 inhabitant) from temperature of heating water ($\Delta\overline{t}_{gelio}$), That practically it is very important at a stage of predesign studies of boiler-houses of considered type.

The offered design procedure by definition of the area of a solar collector's surface is based on use average per day values of initial parameters – climate characteristics ($\overline{t}_a$), ($\overline{q}_s^{\Sigma}$) and an optical system efficiency of a solar collector ($\overline{\eta}_o = \alpha \cdot \tau$), temperature of warm water heating by solar attachment ($\overline{t}_{gelio}$).

The quantity of the useful thermal energy produced by double-loop solar attachment within light day, is defined from equation

$$Q_{prod} = \overline{\eta} \cdot F_c \cdot \overline{q}_s^{\Sigma} \cdot h_{day}, \tag{9}$$

in this

$$\overline{\eta} = \eta_2 \left(\overline{\eta}_o - U_c \frac{\overline{t}_{gelio} - \overline{t}_a}{\overline{q}_s^{\Sigma}} \right) \tag{10}$$

- average per day thermal efficiency of double-loop solar attachment;

$$\overline{t}_{gelio} = 0.5 \cdot \left(\overline{t}_{gelio}^{inlet} + \overline{t}_{gelio}^{out} \right) \tag{11}$$

- average per day temperature of warm water in solar attachment (average on length of intermediate heat exchanger); $\overline{t}_{gelio}^{inlet}$ и $\overline{t}_{gelio}^{out}$ - average per day temperature of warm water relating to input and output intermediate exchanger of solar attachment.

The quantity of the useful thermal energy produced by double-loop solar attachment during light day, to the order c (9) also can be defined from equation

$$Q_{prod} = G_{gelio} \cdot \rho \cdot C_0 \cdot \left(\overline{t}_{gelio}^{out} - \overline{t}_{gelio}^{inlet} \right) \tag{12}$$

G_{gelio} - the day time using of warm water through intermediate exchanger of solar attachment; ρ and C_0 - related density and a specific thermal capacity of warm water.

The quantity of thermal energy produced solar-fuel boiler and released to the consumer for a day could be determine from equation

$$Q_{cons} = G_{day} \rho C_0 \left(t_h - t_c \right), \tag{13}$$

где G_{day} - the daily charge of the hot water produced by a boiler-house of considered type; t_h and t_c - related temperatures of hot water (output from boiler) and cold (initial) water.

Practical interest is represented with development of a technique for definition of factor of replacement of thermal loading by solar technical part of fuel boiler-houses in systems of hot water supply and corresponding economy of burnt organic fuel. It is considered the influence of parameters of an environment, optical and thermo technical qualities of gelio equipment and the scheme-technological decisions for boiler-houses of considered type. It is necessary to note, that existing approaches in a world practice were based on use of their integrated parameters of solar technical parts for the certain period (f-method) that does not give the full information.

The factor of replacement of thermal loading on hot water supply considered solar attachment can be defined from the attitude Q_{prod} to Q_{cons} in (13) and (14) at equality of values of day time and daily charges of warm and hot water through solar attachment and a boiler-house ($G_{gelio} = G_{day}$)

$$\varphi = \frac{Q_{prod}}{Q_{cons}} = \frac{\overline{\Delta t}_{gelio}}{t_h - t_c}, \tag{14}$$

In this

$$\overline{\Delta t}_{gelio} = \overline{t}_{gelio}^{out} - t_c \tag{15}$$

- average day time temperature of heating feeding water in the solar attachment.

In view of equations (10÷11), (14) and (15) equation (9) can be presented as

$$Q_{prod} = \left(\frac{1}{\eta_c} + \frac{U_c}{k_{EX}} \cdot f_{onm} \right)^{-1} \left(\overline{\eta}_o - U_c \frac{0.5\overline{\Delta t}_{gelio} + t_c - \overline{t}_a}{\overline{q}_s^{\Sigma}} \right) F_{gelio} \cdot \overline{q}_s^{\Sigma} \cdot h_{day} \tag{16}$$

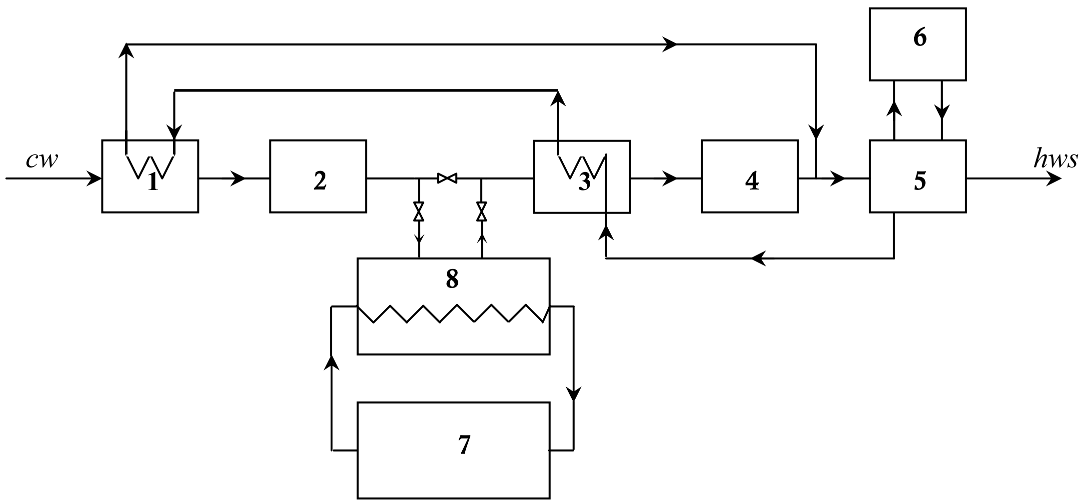

Fig. 3. The basic block the scheme of a double-loop solar-fuel boiler-house, realized in boiler house "Vodnik": *cw*-cold water; *hws*- on hot water supply.

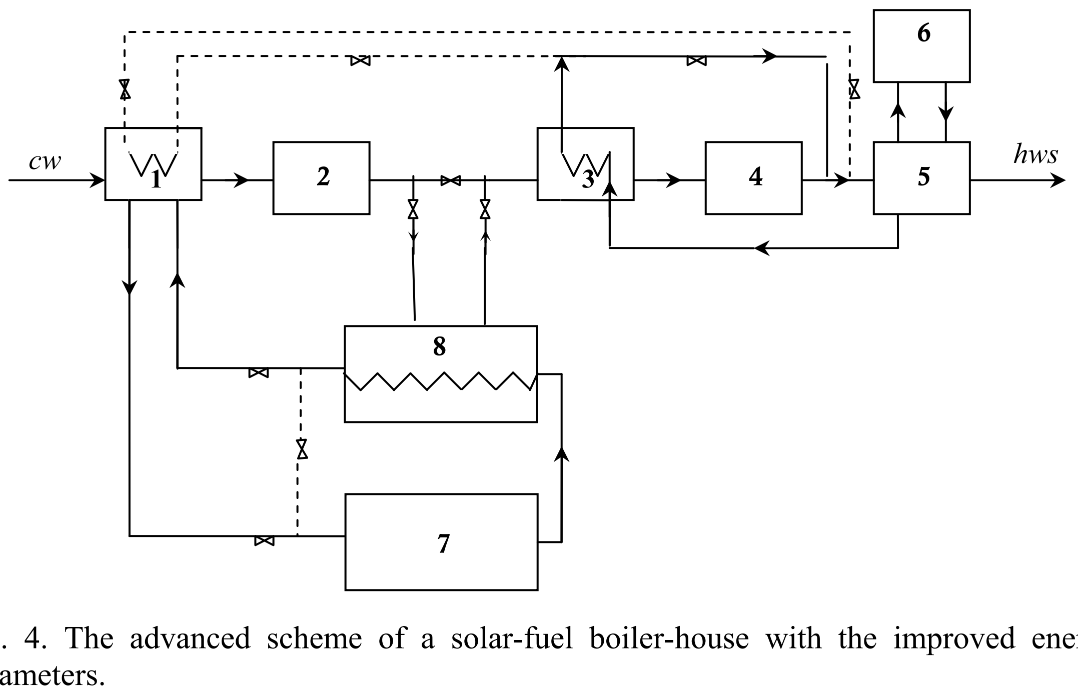

Fig. 4. The advanced scheme of a solar-fuel boiler-house with the improved energy parameters.

In view of equality G_{gelio} и G_{day}

$$F^1_{gelio} = \frac{\left(\frac{1}{\eta_c} + \frac{U_c}{k_{EX}} f_{onm}\right) G^1_{day} \rho C_o \overline{\Delta t}_{gelio}}{\left(\overline{\eta}_o - U_c \frac{0.5\overline{\Delta t}_{gelio} + t_c - t_a}{\overline{q}^{\Sigma}_s}\right) \overline{q}^{\Sigma}_s \cdot h_{day}}, \qquad (17)$$

G^1_{day} - daily norm of the using of hot water per one inhabitant.

$$F^1_{gelio} = \frac{F_{gelio}}{N} \qquad (18)$$

- the area of a solar attachment per inhabitant; N – the number of inhabitants, which thermal hot water supply's needs covered by a considered solar-fuel boiler-house.
On the basis of the developed technique the complex of programs in Mathcad is developed and effectively used on a preliminary design stage and scheme-parametrical optimization of solar-fuel boiler-houses.
Comparison of energy parameters different types of solar-fuel boiler-houses calculation by definition F^1_{gelio} is executed for following initial data G^1_{gelio}=100 *litres for 1 inhabitant per day*, t_h = 60°C, t_c=15°C, t^{inlet}_{gelio} = 20°C, $\bar{t}^{\,out}_{gelio}$ = 40°C, $\overline{\Delta t}_{gelio}$ = 20°C, η_2 = 0.86 (η_c=0.93, U_c=8.0 *W/(m²°C)*, k_{EX} = 900 *W/(m²°C)* и f_{onm}=10), $\overline{\eta}_o$ = 0.76, $\bar{t}_a$ = 30°C, $\overline{q}^{\Sigma}_S$=700 *W/m²* и h_{day} = 8 *hours* (28800 *sec.*).
On figure 3 the basic block diagram of a double-loop of solar-fuel boiler-house on a district "Vodnik" in Tashkent is presented. Consider in more details the basic scheme of this boiler-house.
It works under the open scheme, i.e. with direct consuming of hot water from a thermal network. The running cycle of a boiler-house provides serial processing feeding water: heating of initial water in the heat exchanger 1, chemical clearing – mitigation in the filters 2, heating in the heat exchanger 3, vacuum deaeration in installation 4, accumulation in tanks 5 and feeding by pumps to the return pipeline of a heating system. The mix of return and feeding waters by the pump moves to boiler units 6 and further to the submitting pipeline of a heating system and partially to accumulated tanks. In existing pipelines the insert for the heat exchanger 7 connected with a solar attachment 8 is executed. The heating feed water loop consists from the feeding pipeline of the chemically cleared water from a cycle of a boiler-house, intertrumpet space of high-speed heat exchangers 1, 3 and the pipeline heating water returned to a boiler-house.
The technical decision offered by authors is presented on fig. 4. Its novelty is that in solar loop seriously are connected with heat exchanger 1 of initial water. The given scheme considers a seasonal using of a solar attachment, if insufficient arrival of solar radiation the boiler-house works as the traditional scheme (it is shown in figure by a dotted line), i.e. the high-temperature heat-carrier of a water-heating boiler provides preliminary heating initial water.
The offered scheme allows also to increase duration of operation of solar attachment in a boiler-house which for the traditional scheme consist the period from April till October. At climatic conditions of March and November when it is possible to heat up the heat-carrier in solar collectors up to 20-25^0*C*, could switch to use solar loop only on heating of initial water in corresponding heat exchanger 1.
Besides efficiency of use solar collectors in a boiler-house increases because it is reducing temperature of the heat-carrier in input of solar collectors. Thus it is provided more thermo neutral operating mode of solar collectors in relation to an ambient temperature that carry out to decrease thermal losses in its.
In table 1 comparative results of calculations, according to above described technique are presented.

Table 1

Parameters	The traditional scheme	The developed scheme
Preheating water by a solar technical part	from 20÷25 ^{0}C to 40÷50^{0}C	from 5÷15 ^{0}C to 40÷50^{0}C
Thermal efficiency of the solar attachment ($\overline{\eta}_c$)	0.654	0,702
Hot water load replacement factor (φ) by the solar technical part in clear summer day	0.444	0,63
The demanded specific area of solar collectors F^1_{gelio}, m^2 per one inhibitant	0.665	0,619

The offered technique and the made complex of programs have the practical importance at a stage of predesign studies of solar-fuel boiler-houses. This is allows to optimize capital expenses for creation solar attachment with a reliable heat supply of consumers.

References

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