A MODEL FOR CONTROLLING A HYBRID-TYPE HOT WATER HEATING UNIT BY MEANS OF AN ELECTRONIC SYSTEM

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***Abstract*:** It is necessary for the reduction of energy consumption in a hybrid-type hot water heating unit to estimate the hot process energy state. A model of the process has been suggested, which takes into account both the water consumption and the hourly solar radiation diagrams. The underlying dependences and approximations applied to the modeling have been grounded. The main advantage of the model is in its capability to estimate the current state of the process according to the on-line data provided by sensors, as well as to assess it based on the water consumption diagrams and hourly solar radiation values.

***Keywords*:** model, hybrid-type hot water heating unit, electronic system.

1. INTRODUCTION

The climate conditions in Bulgaria require additional heating of water when using solar collectors for water heating. Therefore, the hybrid-type hot water heating units have become widespread. They consist of a solar collector, a conventional energy source and a hot water tank [1, 2]. Systems for controlling such installations are currently in use, which enhance the process through sustaining the set water temperature in the tank [3]. The main disadvantage of this approach is that the energy losses, the water consumption diagrams and the hourly solar radiation values are not accounted for.

2. METHODOLOGY

2.1. The aim of this research is to model the water temperature regime during the heating process in a hybrid-type hot water heating unit complete with a solar collector considering the water consumption diagrams and the hourly solar radiation values.

2.2. The object of control is the water temperature regime in a hybrid-type hot water heating unit (Fig.1). The installation is provided with a loop for water heating consisting of a solar collector 1, a heat exchanger 2 and a circulation pump 3. The unit also includes a hot water tank 4, a heat exchanger 5 powered by a conventional energy source 6, a valve 7, a flap 8 and a flow-rate indicator 9.

2.3. Justification of the applied approximations and dependences.

The energy production depends on the solar collector efficiency coefficient and, at a given time, is determined by the formula [3].

$$Q_S(\tau) = \eta I_S(\tau),\ \mathrm{W.m^{-2}}\ , \qquad (1)$$

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where:

$Q_S(\tau)$ - useful heat flow, $W.m^{-2}$;

τ - current time, s;

η - solar collector efficiency coefficient ;

$I_S(\tau)$ - solar radiation intensity, $W.m^{-2}$.

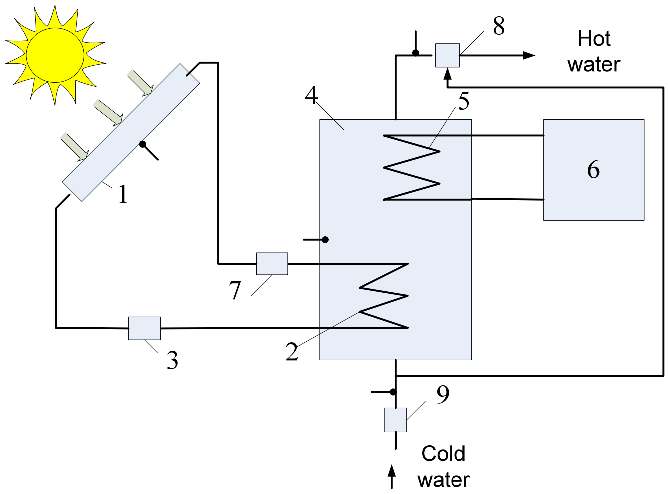

Fig. 1. Structural scheme of a hybrid installation for heated water production.

The efficiency coefficient for flat collectors varies depending on the temperature difference between the fluid and the environment [3].

$$\eta = \frac{Q_S(\tau)}{I_S(\tau)} = \frac{I_S(\tau)\upsilon a - k[t_F(\tau) - t_E(\tau)]}{I_S(\tau)}, \tag{2}$$

where:

υ - transmission coefficient;

a - absorption coefficient;

k - heat transfer coefficient, $W.m^{-2}.K^{-1}$;

$t_F(\tau)$ - fluid temperature, K;

$t_E(\tau)$ - environment temperature, K.

It is assumed that the fluid temperature is the same throughout the inside of the solar collector. In order to describe the temperature regime of the accumulating water tank, a number of dependences are used such as those for convective heat transfer, thermal conductivity and water energy balance. It is presumed that the temperature of the walls inside the tank equals the temperature of the water, which is possible because of the protecting insulation. The Nusselt number, used to calculate the mean heat transfer coefficient, is [4]:

$$Nu_m = C(Gr.Pr)_m^n, \tag{3}$$

where:

Nu_m - the Nusselt number;

C, n - coefficients;

Gr - the Grashof number;

Pr - the Prandtl number.

The coefficients C and n depend on the fluid movement ($Gr.Pr$). This flat-surface dependence can be applied to a cylindrical surface because of the relatively large value of its diameter. The Grashof number is defined by the formula [4]:

$$Gr = Ga.\beta.\Delta t \,, \tag{4}$$

where:

Ga - the Galilean number;

β - thermal expansion coefficient, K^{-1};

Δt - temperature gradients of the wall and the air K.

The Galilean number is determined by the formula [4]

$$Ga = \frac{gl^3}{\nu^2} \,, \tag{5}$$

where:

g - the earth acceleration, $m.s^{-2}$;

l - linear size, m;

ν - coefficient of the air cinematic viscosity, $m^2.s^{-1}$.

Considering formula (3), the coefficient of natural heat transfer is [4]:

$$\alpha(\tau) = \frac{\lambda.Nu_m}{l} \,, \; W.m^{-2}.K^{-1} \,, \tag{6}$$

where:

$\alpha(\tau)$ - coefficient of natural heat transfer between the external surface of the wall and the environment, $W.m^{-2}.K^{-1}$;

λ - thermal conductivity of the fluid, $W.m^{-1}.K^{-1}$.

The heat power loss resulting from the water tank natural convection is calculated with [4]:

$$N_{CONV}(\tau) = k_T(\tau)F\Delta T \,, \; W \,, \tag{7}$$

$$k_T(\tau) = \frac{1}{\frac{\delta_{WALL}}{\lambda_{WALL}} + \frac{\delta_{INS}}{\lambda_{INS}} + \frac{1}{\alpha(\tau)}} \,, \; W.m^{-2}.K^{-1} \,, \tag{8}$$

where:

$N_{CONV}(\tau)$ - heat power loss due to the natural convection to the environment, W;

$k_T(\tau)$- thermal conductivity, $W.m^{-2}.K^{-1}$;

F - tank surface, m^2;

ΔT - temperature gradient between the wall and the air, K;

δ_{WALL}, δ_{INS} - the width of the wall and the insulation, m;

λ_{WALL}, λ_{INS} - the thermal conductivity of the wall and the isolation, $W.m^{-1}.K^{-1}$.

3. PROCESS MODELLING

In order to estimate the energy gained from the sun, the estimated solar radiation and the efficiency coefficient of the collector are used. The solar energy received within a period of time [$0...\tau$] is:

$$E_S = \int_0^\tau N_S(\tau)d\tau\,, J\,, \tag{9}$$

in which: $N_S(\tau)$ - the particular heat power gains value received through solar radiation, W .

$$N_S(\tau) = \eta F_c I_S(\tau)\,, W\ , \tag{10}$$

in which: F_c - the collector surface, m^2 .

The hourly water consumption diagram is calculated as reduced energy consumption. The energy consumption E_{CONS} for the time period [$0...\tau$] is determined analogously to the formula (9), where the current heat power value is [4]:

$$N_{CONS}(\tau) = B_W(\tau)\rho_W c_W\left[T_T(\tau) - T_{IN}\right], W\,, \tag{11}$$

where:

$B_W(\tau)$ - flow rate of the consumed heated water outflow, $m^3.s^{-1}$;

ρ_W - water density, $kg.m^{-3}$;

c_W - specific heat capacity, $J.kg^{-1}.K^{-1}$;

$T_T(\tau)$, T_{IN} - temperature values of the water inside the tank and of the cold water at the inflow, K .

The heat water production model in hybrid installations complete with a solar collector and a conventional energy source is to consider the accumulated energy inside the tank, the energy loss from radiation and the heated water consumption. These components of the energy balance depend on the process parameters

$$E_S + E_P + E_T + E_{IN} - E_{CONV} - E_{CONS} = 0\,,\ J\,, \tag{12}$$

where:

E_S - solar energy gains, J ;

E_P - conventional energy gains, J ;

E_T - energy accumulated by the water inside the tank, J ;

E_{IN} - energy of the cold water, J ;

E_{CONV} - heat transfer loss, J ;

E_{CONS} - energy consumption within a period of time, J .

The modelling is based on the finite difference method. The time is divided into small intervals and the energy gains and losses are calculated for each. As a result, the water temperature inside the tank is assessed as a function of time. The algorithm is shown in Figure 2 a) and Figure 2 b).

The initial conditions are set in Block 1. Blocks 2 and 15 organize the time variations. Block 3 determines the method of collecting information about the process state. When operating in a simulation regime, the information is obtained from the assumed hourly diagrams of the solar radiation and the heated water consumption.

It is taken from the sensor readings in Blocks 5 and 6. These are followed by assessing the obtained solar energy (block 7) and determining the energy values of the heated water consumption (block 8). The similarity criteria are determined in block 9 so as to assess the energy loss to the environment (block 10). By virtue of the energy balance, the energy value needed to receive from the conventional source and its current power are calculated in blocks 11 and 12 accordingly.

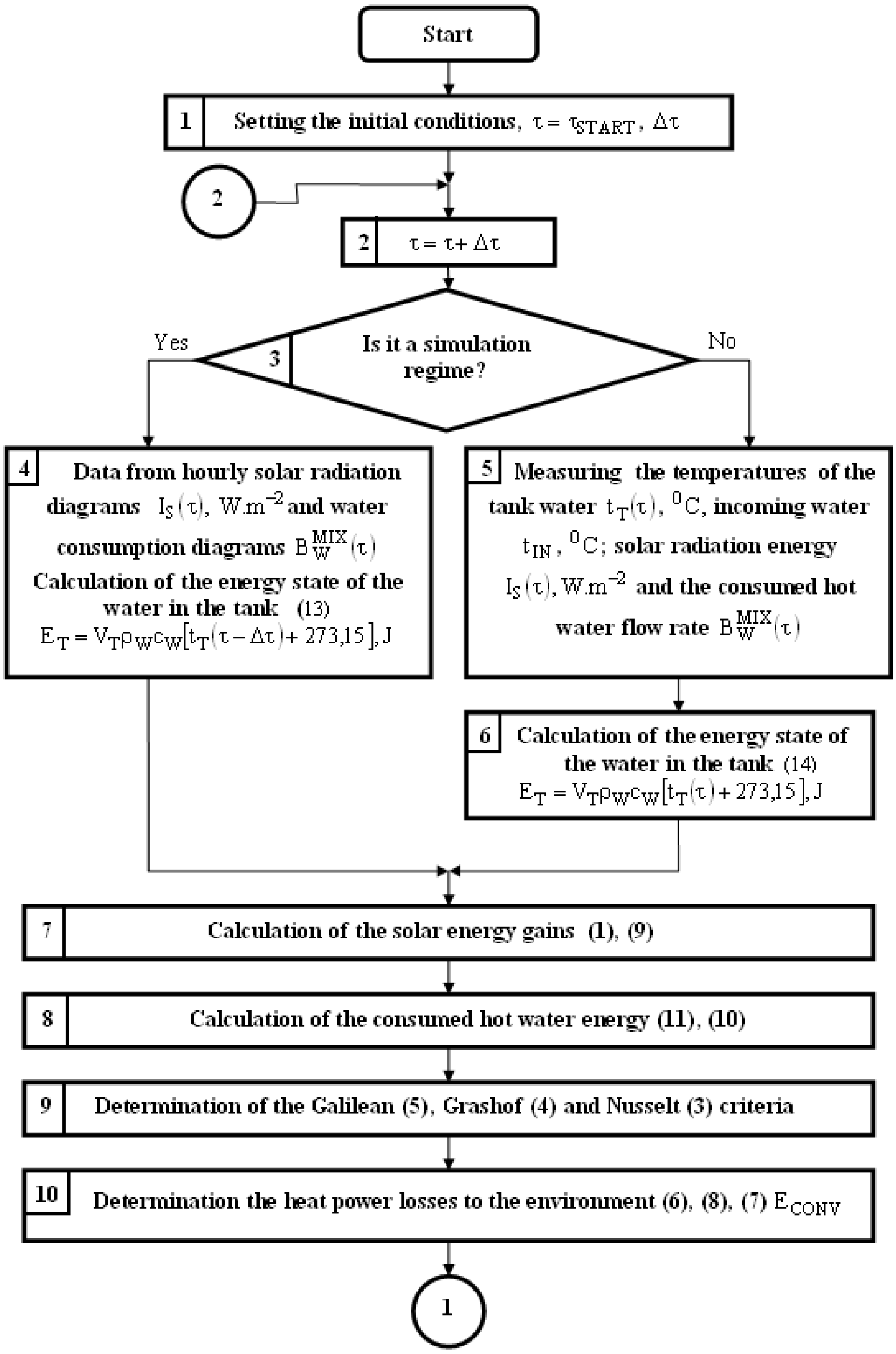

Fig. 2. a) Algorithm of the hot water production model.

The installation energy condition, which is, actually, the water temperature, is determined when operating in a simulation regime (block 14). After the calculation process is completed, the information about parameters variations as functions of time is presented on the screen.

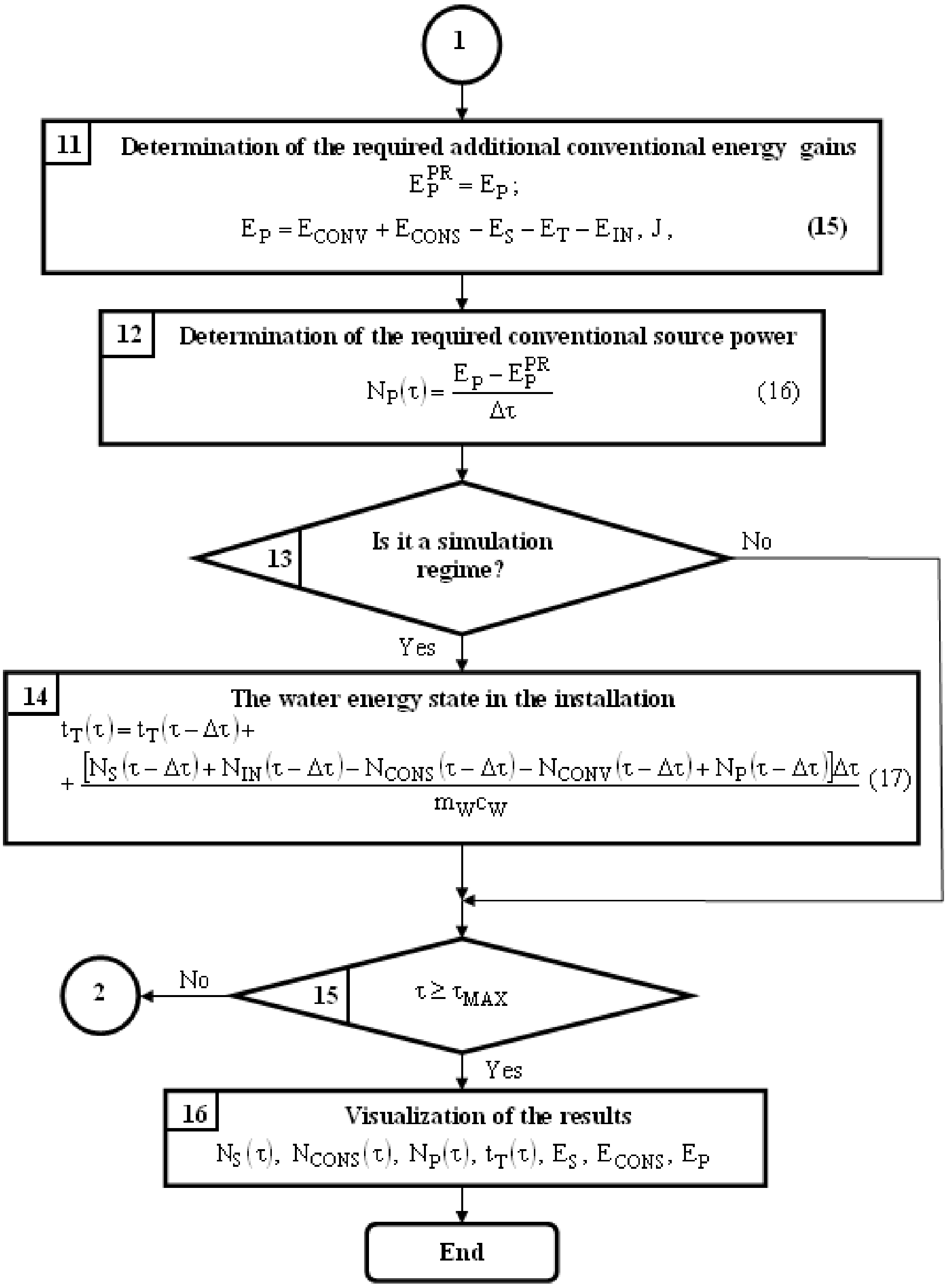

Fig. 2. b) Continuation of an algorithm of the hot water production model.

Figure 3 illustrates the graphical dependences of both the heat power values and the energy streams presented as functions of time. These have been assessed applying the model.

The model is applicable when estimating the energy efficiency of an available installation. The measured process parameters are used in the real time regime, while for simulation are applied the hot water consumption diagrams and the hourly solar radiation values [5, 6]. This information can be used to estimate the required minimal additional energy from conventional sources needed to sustain the water temperature.

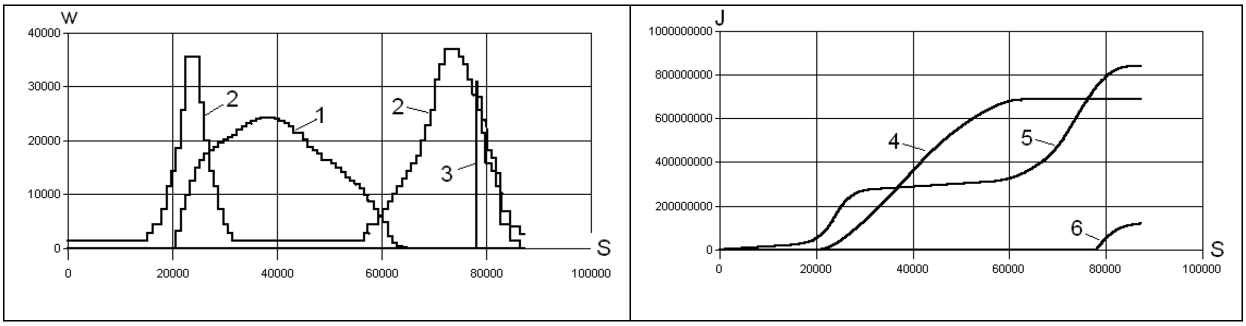

Fig. 3. Graphical dependences of the heat power values and the energy streams presented as functions of time assessed on the basis of the model application:
1 – the particular heat power gains value received through solar radiation, W ; 2 - the heat power loss due to hot water consumption, W ; 3 –the power of a conventional energy source, W ; 4 – solar energy gains, J ; 5 – energy loss due to water consumption, J ; 6 – conventional energy gains, J .

4. RESULTS

The specific of the heated water production in hybrid installations complete with solar collectors have been analyzed. The necessity for process modelling which takes into account the probable solar energy gains and the hourly hot water consumption diagrams has been reasoned.

The main approximations applied in the process modelling have been grounded.

A model which describes the energy state of the process has been developed, considering either the on-line data provided by sensors, or the data simulated based on the water consumption diagrams and the hourly solar radiation values.

5. CONCLUSIONS

The developed model can be used to estimate the current condition of the process and to simulate it with the aid of both the hot water consumption and the hourly solar radiation diagrams. This makes it appropriate for application in electronic control systems used for reducing the energy consumption in conventional sources.

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