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THERMAL PROCESSES IN SOLAR DOMESTIC HOT-WATER SYSTEM

The heating of working medium in the core elements of a solar domestic hot water (SDHW) system depending on weather and operating conditions and using the Exodus procedure is analysed. We made the suggestion about how we could use a theoretical method of testing the dynamics of heating medium, based on our original probabilistic models of a liquid-heating flat plate solar energy collector and a storage tank with thermal stratification. The time-constants of collector were determined. A momentary distribution of water temperature along the tank axis was simulated for selected cases. Theoretical and real characteristics of the heating medium in the SDHW system were presented in comparison with external inputs. A study of heating dynamics in the solar system allows formulation of certain operating recommendations.

1. INTRODUCTION

In order to analyse the operation of a solar hot-water system it is necessary to understand the heating dynamics of working medium. In real conditions of experiments, a continuous recording and collecting the parameters measured are absolutely essential. The results of this research allow us to verify a simulation program. In model testing, the *f-chart* method being developed in the 1970s [1], [2] was repeatedly used. Many researchers used the TRNSYS software to simulate the system work in non-steady conditions and to establish the effect of thermal stratification in the storage tank on the operation of the whole solar hot-water system [3], [4]. Some experiments as well as theoretical research were performed by CHOCHOWSKI and CZEKALSKI [5] in order to suggest the methods for controlling the medium flow through collectors. PLUTA and WNUK [6] presented the results of numerical analysis of the operation of a solar hot-water system with double-medium storage tank. A mathematical description of a simplified model of storage of thermal energy in phase-changing materials was provided by GUMKOWSKI [7]. A one-dimensional model of the solar collector in equivalent thermal network has been presented

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in [8].

This paper presents the possibility of using the Exodus procedure for modelling and simulating the operation of a system consisting of a liquid heating flat plate solar collector and a water storage tank with thermal stratification. An indisputable advantage of this method is determining the temperature of the medium flowing out of the collectors and the temperature of water in the tank as a time function, taking into account the stochastic character of external inputs.

2. DESCRIPTION OF THE SOLAR DOMESTIC HOT-WATER SYSTEM

A small solar domestic hot-water (SDHW) system in a detached house inhabited by four people was tested. In such a family, a mean daily hot water consumption was estimated at 155 dm^3/d. The core elements of the system are two solar collectors with an absorber area of 2.4 m^2 and a storage tank of 200 dm^3 capacity that supplies water to an electrical boiler of 150 dm^3 capacity. The technical parameters of the collectors are given in the table.

Table

Construction and material parameters of a collector in the solar hot-water system

Parameter	Description
Dimensions: length×width×depth, mm	1920×830×95
Gross area of the collector, m^2	1.58
Aperture area of collector, m^2	1.43
Absorber area of collector, m^2	1.20
Glass cover thickness, mm	4
Absorber plate thickness, mm	3
Insulation thickness, mm	50
Collector box thickness, mm	1
Flow channel diameter, mm	10
Collective fluid conduits diameter, mm	20
Water capacity, dm^3	3
Front cover material	solar tempered glass
Absorber plate / flow channel material	steel / copper
Covering layers on absorbers	black galvanic chromium on a nickel-plated surface
Insulation material	polyurethane foam + Al film
Collector box material	aluminium
Number of transparent covers	1
Glass transmittance	0.80
Absorber plate absorptance	0.95
Maximum efficiency of the collector related to absorber surface	0.79

The solar energy collectors were held by special stands. A tilt angle of the collectors with respect to horizon was adjusted. The surfaces of the collectors were oriented south-west. A heat storage in a tank is of short-term character. The steel tank has a diameter of 400 mm and the height of 1.5 m and is heat-insulated by covering it with 50 mm thick foamed polystyrene. There is no heat exchanger in the tank. The height to diameter ratio of the storage tank is 3.75. A flow rate of the heat transferring medium in collectors was controlled by a circulating pump and a time programmer. The experimental SDHW system was fitted with a measuring apparatus for monitoring. Measurements were recorded as mean values for each hour. PT 100 temperature sensors were located in such places as: medium from the outlets of collectors, the surface of the storage tank at 1/3, 1/2 and 2/3 of its height, on the pipeline connecting the tank with the boiler; an outside air temperature sensor was also installed.

3. SIMULATION METHOD

In the simulation studies of the heating dynamics of working medium in the SDHW system, the co-operation of the flat plate solar collectors with the water storage tank was carried out. Thermal and probabilistic models of those two elements of the system have been presented in detail in [9], [10]. The mathematical description of the collector model, using the Exodus procedure, allowed determination of the temperature of three collector elements (i.e., glass cover (T_g), absorber plate (T_p) and working medium (T_f)) at any time [9]. A four-node storage model was accepted. Temporary energy-balance equations representing four sections of the tank in the case of loading and unloading have been derived in [10]. The systems of equations were solved by Exodus method.

The simulations were performed using the CollSt.PAS. program. The changes in the temperature of fluid flowing out of the collectors as well as the temperature of the water stored in the tank were investigated. The average values of meteorological and exploitation parameters (measured for one hour) such as a global solar irradiance on collector plane I, an ambient temperature T_a, the wind speed v_w, a medium volume flux through collectors Q_c, the collector inlet fluid temperature $T_{f,i}$, a domestic hot-water flow rate Q obtained on the basis of the measurements recorded, were introduced into the program. An assumption was made that the physical properties of the glass cover and the absorber plate are independent of the temperature. During calculations the temperatures of a glass cover, the absorber plate and the working fluid were determined for each one-second time step. This enabled correction, after each time step, of all physical properties dependent on the temperature as well as the convective heat transfer coefficients, the particular thermal resistances of the collector and the capacity of the internal thermal sources. It was assumed that the temperature of the tank supply water is approximately the same as the temperature of the water flowing out of the collectors. Heat losses from the tank bottom and its upper surface were neglected. The temperature gradient in a radial direction was also omitted.

4. EXPERIMENTAL AND SIMULATION RESULTS

The heating characteristics of a three-nodal model of the solar collector allowed the heating curves representing all distinguished elements to be drawn (figure 1).

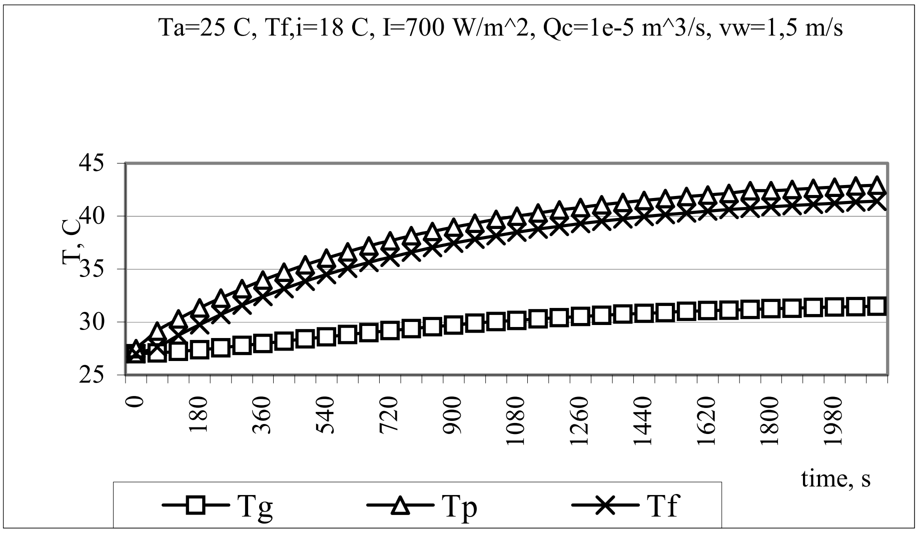

Fig. 1. Heating characteristics of the solar collector as a function of time

These curves make the determination of the three time constants of the collector possible. The collector time constant is a basic dynamic parameter of the system. Figure 2 presents an example of the results of the simulation of loading the storage tank with water at a constant temperature of 55 °C ($T_{f,o}$) and 10^{-5} m^3/s volume flow rate (Q_c). It was assumed that at the initial moment the temperature in the storage tank was constant and equal to 22 °C. The changes of the water temperature in the tank at four distinguished levels were recorded every half-hour for the first 5.5 hours of loading.

The ambient temperature of the tank was assumed to be 18 °C. Mean hour values of input parameters, the temperature distribution in the system and a domestic hot-water consumption in selected days are presented in figures 3 and 4. Based on the analysis of the curves plotted, the consistence of the simulated and measured values may be called satisfactory.

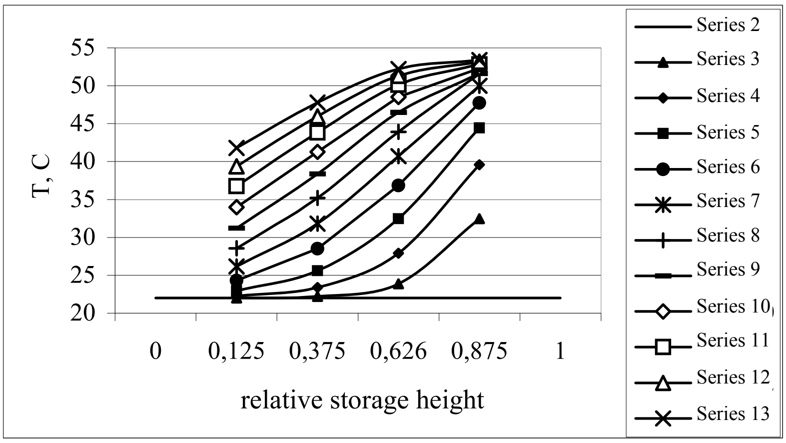

Fig. 2. Distribution of temperature
in the storage tank during loading phase

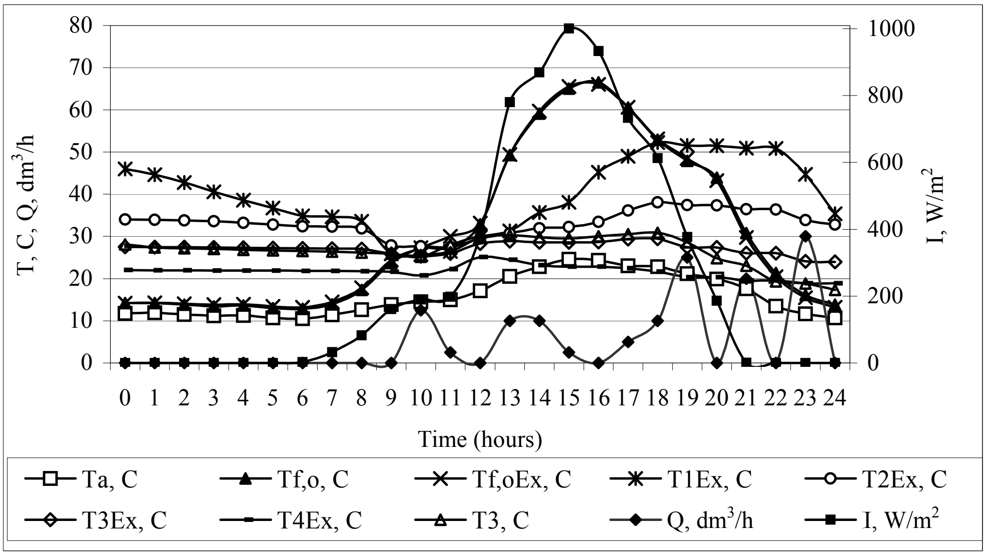

Fig. 3. Heating the working medium in the SDHW system

in comparison with external inputs

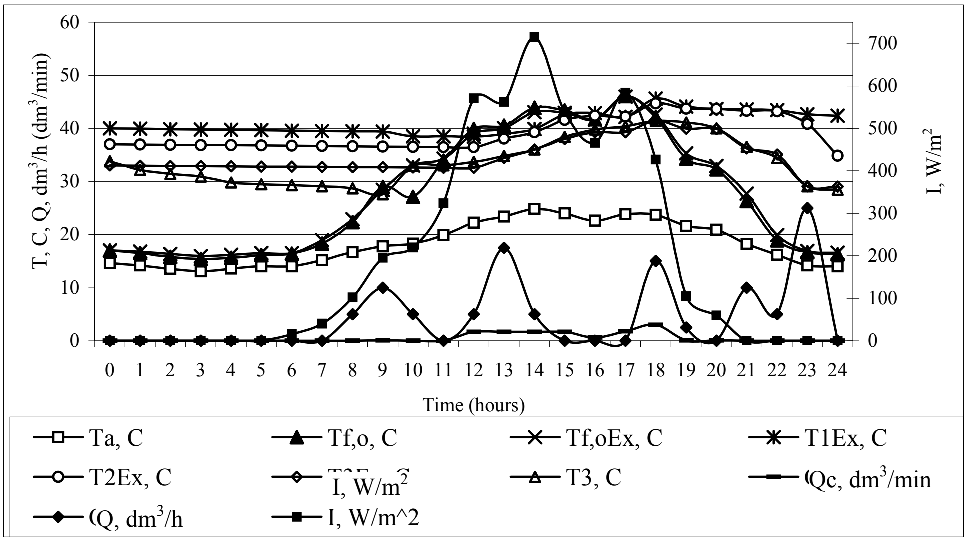

Fig. 4. Heating the working medium in the SDHW system
in comparison with external inputs

5. CONCLUSIONS

In order to determine a thermal field in the flat plate solar collector and in the storage tank, the Exodus procedure has been applied. It allowed us to simulate the dynamics of SDHW system, taking into account the real weather and operating conditions changing with time. The results of the calculations were compared with the results of the measurements. The results calculated make it possible to analyze the SDHW system operation under any conditions, to evaluate the energetic efficiency of its operation and to check the heat dynamics of the system elements.

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DYNAMIKA NAGRZEWANIA CZYNNIKA ROBOCZEGO W INSTALACJI SŁONECZNEJ CIEPŁEJ WODY UŻYTKOWEJ

Opisano, korzystając z procedury Exodus, nagrzewanie medium roboczego w głównych elementach instalacji słonecznej ciepłej wody użytkowej w zależności od warunków klimatycznych oraz parametrów eksploatacyjnych. Zaproponowano teoretyczną metodę badania dynamiki nagrzewania czynnika na podstawie wcześniej opracowanych autorskich modeli probabilistycznych płaskiego cieczowego kolektora energii promieniowania słonecznego oraz zbiornika akumulacyjnego ze stratyfikacją termiczną. Określono stałe czasowe kolektora, które charakteryzują bezwładność cieplną układu. Dla wybranych przypadków eksploatacyjnych przeprowadzono symulacje chwilowego rozkładu temperatury wody wzdłuż osi zbiornika. Sporządzono oraz porównano teoretyczne i rzeczywiste charakterystyki nagrzewu czynnika w systemie słonecznym bezpośrednim w zestawieniu z wymuszeniami zewnętrznymi. Badania dynamiki nagrzewania w obiegu kolektorowym umożliwiają ocenę energetyczną danej instalacji słonecznej oraz sformułowanie pewnych zaleceń eksploatacyjnych.