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REGIME AND STRUCTURAL FACTORS OF INFLUENCE ON PRODUCTIVITY OF THE SOIL ACCUMULATOR OF SOLAR PLANT SYSTEM

Abstract. *Non-stationary processes of heat exchange in a solar plant system with the thermal pump and the seasonal accumulator of heat with 9 soil vertical heat exchangers in the process of periodic charges of the accumulator during the summer period and discharges in winter for various regions of Ukraine are investigated. Recommendations about definition of a step of heat exchangers in a bush and their heights under condition of full maintenance of the consumer of heat during all winter period are offered.*

Key words: *the seasonal accumulator, solar plant system, the thermal pump.*

Анотація. *Досліджено нестаціонарні процеси теплообміну в геліосистемі з тепловим насосом і сезонним акумулятором тепла з 9 ґрунтовими вертикальними теплообмінниками в процесі періодичної зарядки акумулятора в літній період і розрядки в зимовий для різних регіонів України. Запропоновані рекомендації з визначення кроку зондів у кущі і їхньої глибини за умови повного забезпечення споживача тепла протягом усього зимового періоду.*

Ключові слова: *сезонний акумулятор, геліосистема, тепловий насос.*

Introduction. The structure of solar systems of heating is made by solar collectors, seasonal accumulators of heat and thermal pumps. The most widespread design of seasonal accumulators of heat are vertical soil designs from many heat exchangers [1,2], possessing convenient configuration and good operational indicators. Much individual (sectional) structures of accumulators differ with spatial placing, quantity and their sizes. The listed structural factors are defined by accumulator working conditions in a ground, and also the interfaced solar system. A variety of working conditions of systems of a heat supply demands the reliable substantiations considering of many factors of operation. For designers presence of methodical recommendations for choice constructive and operational parametres of the interfaced elements of system is important.

The analysis of last researches and publications. Usually the structure of the soil accumulator is offered to be carried out in the form of rectangular in respect of a bush with equal step between heat exchangers [2, 3, 4]. Such bushes differ with quantity of heat exchangers, their length and step. Data [2, 4, 5] shows that the step of an arrangement of heat exchangers to a bush and their length make essential impact on quantity of heat saved up in a ground. The step increase leads to growth of the thermal maintenance of a file. However the step increase leads to reduction of level of temperatures in a ground that is reflected in overall performance of the thermal pump. In [4] results of research on optimisation of a step and lengths of heat exchangers on the basis of the multifactorial mathematical model describing system of interfaced solar collectors, the soil accumulator and the thermal pump are resulted. However influence of a temperature mode of charging of the accumulator has not been considered. In [5] results of research on influence of a step on heat transfer conditions in a soil file proceeding from conditions of a discharge of the accumulator are resulted. Such data cannot be extended to various service conditions with optimisation regime and structural factors. In [6 - 7] techniques and results of calculations are offered according to heat accumulation in rock at interface of the accumulator to solar system. The tasks was solved in the simplified statement - at harmonious influences at system a ground-heat exchanger [6], and - at interaction of the soil heat exchanger with a file which temperature was accepted by a constant [7]. Such statement does not give possibility to extend results for wide practical realisation.

The aim. Definition of rational parametres of structure of the sectional soil accumulator of solar system - a step and length of the heat exchangers, working in an all-the-year-round cycle in various regions, and also loading characteristics of system on the basis of mathematical model with multifactorial criterion function.

Statement of the basic material. The architecture of modelling object included solar system with flat solar collectors (SC), the thermal pump (TP) and the soil accumulator consisting of 9 vertical in parallel included heat exchangers of coaxial type in height h and cross-section step S. The problem was solved in the adjoint the form with consideration of processes of absorption of radiant energy in SC, heat carrying over to the heat exchanger and a ground, and also energy transformations in TP. Heat exchange in the soil heat exchanger is described by system of the differential equations of power balance of all elements [1]: the heat-carrier of an internal pipe (submitting) and external (return), walls of pipes. Heat exchange in a ground is described by the equation of non-stationary heat conductivity in three-dimensional rectangular co-ordinates. Boundary conditions are formulated so that to capture process of carrying over and heat accumulation in a ground both in a zone of heat exchangers, and in the interfaced peripheral areas. The system of the equations was solved a certainly - difference method.

Material of pipes of the heat exchanger - plastic, heat conductivity of a wall λ_w= 0,28 W/(m·K). Diameter of external pipes of the heat exchanger according to [1] was accepted equal 180 mm. The heat-carrier - water. Therefore heat-carrier cooling in evaporator TP was limited to temperature 1ºC. At the analysis work TP with different temperatures of the heat-carrier circulating between heat exchangers and evaporator TP was modelled, and also at change of thermal loading. Mathematical model TP is developed on the basis of consideration thermodynamic and heat-massexchange processes in its elements. The model researches, allowed to offer the well-founded analytical method supplementing integrated models of systems of a heat supply of any configuration with use of heat pumps are conducted. The dependence of connecting coefficient transformation of heat energy in TP (COP) with key parametres, being conditions of formation of duty TP is found and described: temperatures in the evaporator, the condenser, and heat source in linking to other elements of integrated systems.

Working conditions of solar system were concretised by co-ordinates of various regions of Ukraine with latitude from 45 to 51 degrees during the period which began on April, 15th (the cold season termination) and came to an end in 6 months (180 days). For research are accepted modern flat SC with the resulted characteristic $U/(\tau\alpha)$ = 4,4 W/(m^{2}K), where U — warmth loss factor; ($\tau\alpha$)— optical characteristic SC. The heating season embraced 6 winter months.

At the solution of system of the equations of mathematical model temperature patterns in the heat exchanger and a soil file, heat content of a file of a ground, temperature and speed of heat-transfer agent circulating in solar system in development of daily and seasonal work of solar system were defined. Iterative calculation of process download heat defined total area SC which thermal productivity was limited by achievement of the maximum speed of heat-transfer agent (2 m/s) in soil heat exchangers at the fixed temperature of heat-transfer agent on an entry in the heat exchanger. Also iterative calculation defined settlement thermal loading of heating and matching settlement (nominal) thermal loading of evaporator TP. Heating load Q_h it was defined on a condition of satisfaction daily, depending on temperature of outdoor air, the schedule of thermal loading of a user during all period of heating in various regions. The algorithm of model allowed to release warmth to a user in a regime of droppings depending on heat-transfer agent temperature on an exit from the soil heat exchanger. The bottom criteria of definition Q_h were or a daily deficiency of warmth of a current of any days of the heating period, or achievement of the minimum temperature of a ground (background) on average distance between heat exchangers and on depth to equal semialtitude of a one (ground super-cooling).

On fig. 1 dependence of optimum depth of the heat exchanger on a settlement heating load of a user is presented at different temperatures of heat-transfer agent on an entry to the heat exchanger (t_{in}), and also thermal diffusivity of a ground (a). Locality latitude φ = 46,5 deg. The heating load was defined on all bush consisting of nine heat exchangers. It is visible that at the same loading depth of the heat exchanger depends on physical properties of a ground (a) and heat-transfer agent temperatures. Thermal diffusivity growth leads to decrease of demanded depth of the heat exchanger. However for depth decrease it is necessary to reduce at charging heat-transfer agent temperature on an entry in the heat exchanger. With growth of thermal diffusivity of a ground agency of temperature of charging decreases. It is connected with speed of rearrangement of temperature pattern in a ground in variable regimes download and heat selection.

The increase in latitude of locality reduces necessary depth of the heat exchanger. The analysis of this phenomenon shows that the greatest influence on overall performance of solar system in an annual cycle renders process of a discharge of the accumulator. At charging latitude influence is shown a little. Features of process of a discharge of the accumulator lead to that the residual, after full end of seasonal selection, the quantity of warmth in a ground decreases with latitude growth. These features are caused by a combination of some factors: a relationship of the periods of work and a pause interval of the TP in the conditions of satisfaction of daily thermal loading, speed of rearrangement of temperature pattern in a ground, the temperature of outdoor air influencing the schedule of thermal loading, etc.

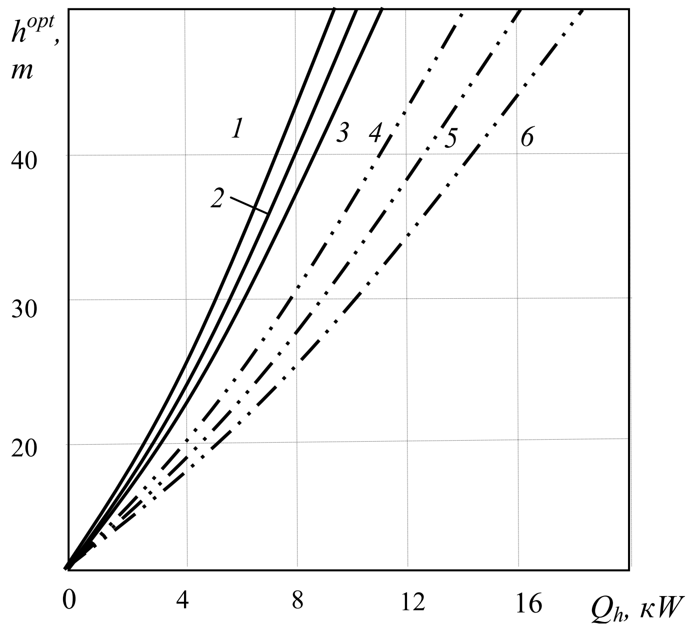

Fig. 1. **Dependence of optimum depth of the heat exchanger on a settlement heating load of a user, heat-transfer agent temperatures on an entry in the heat exchanger at download and thermal diffusivity of a ground**:
$a = 5{,}5 \cdot 10^{-7}$ m^2/s, temperature, ºC: 1 - 90; 2 – 70; 3 – 50; $a = 9{,}6 \cdot 10^{-7}$m^2/s, temperature, ºC: 4 - 90; 5 – 70; 6 – 50.

Generalisation of the presented data for optimum depth of the heat exchanger is optainad in an aspect, m

$$h^{opt} = 0{,}444(63{,}5 - \varphi) - 0{,}311 \cdot Q_h(51{,}3 - \varphi) + \frac{72 + 12{,}02 \cdot Q_h(31{,}14 - \varphi)}{a \cdot 10^7(41{,}4 - \varphi)},$$

$$B = 0{,}73 - 0{,}005 \cdot t_{in} + \frac{2{,}61 \cdot Q_h}{127{,}7 - t_{in}}.$$

Area of diagnostic variables Q_h=(0,5-25) кW; a = (2,8…9,6) 10^{-7} m^2/s; t_{in} = (50-90)ºC; φ = (45-51) deg.

Researches on revealing of an optimum step of heat exchangers in a bush have been spent at change of depth of one, latitudes of locality, physical properties of a ground and heat-transfer agent temperature on entry to the heat exchanger at injection heat. The optimum step was chosen proceeding from a condition of achievement of the greatest value of a settlement heating load at different productivity of the TP. The analysis of the gained data showed that naturally resistant to factors of agency are thermal diffusivity of a ground, temperature of heat-transfer agent and depth of a heat exchanger (h). Such three-factorial dependence in generalisation is presented on fig. 2. It is visible that growth of thermal diffusivity of a ground leads to increase in an optimum step. It is connected with dependence of storing up ability of a file of a ground on its physical properties. The increase in an optimum step means impovement of conditions of filling up of a ground by warmth. Growth of temperature of heat-transfer agent on an entry in the heat exchanger at download to return the influence - the step decreases. Thus the influence of depth of a heat exchanger decreases. The generalising settlement relationship is found in an aspect, m

$$S^{opt} = 4{,}4 - \frac{5{,}9}{h} + \frac{72{,}7}{t_{in}} + (5{,}47 - \ln t_{in})(7{,}3 \cdot 10^{12} a^2 - 6{,}03 \cdot 10^6 a).$$

Area of diagnostic variables: h = 10…100 m, a = (2,8…9,6) 10^{-7} m^2/s, t_{in}= (50…90)ºC.

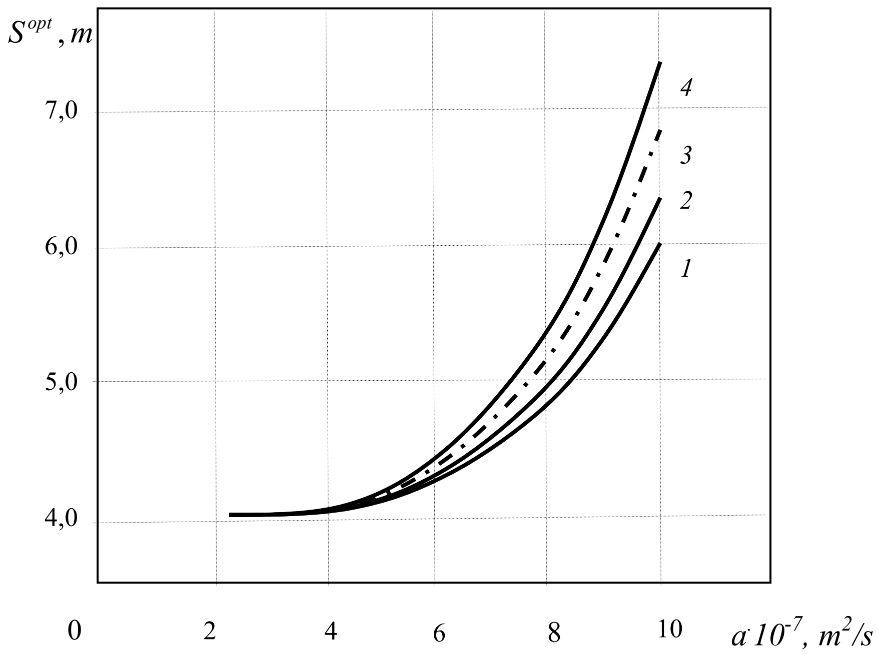

Fig. 2. **Dependence of an optimum step of heat exchangers on thermal diffusivity of a ground, depth of a one and heat-transfer agent temperature at charging, h, m/t_{in}, ºC** : 1 - 50 /90; 2 – 50/70; 3 -24/ 50; 4 – 50/50

Conclusions. For the seasonal soil accumulator with nine heat exchangers the basic influence on a step of heat exchangers on conditions of the greatest calculated load of heating is rendered the thermal diffusivity of a ground, temperature of heat-transfer agent and depth of a heat exchanger. With growth of thermal diffusivity the step of heat exchangers under condition of a full independent heat supply of a user on a heating load increases, and for soils, for example, with properties of limestone 6 m attain; in step increase results also growth of temperature of heat-transfer agent in summer download and growth of depth of a heat exchanger

Depth of heat exchangers should be defined taking into account a calculated load of heating, thermal diffusivity of a ground, temperature of heat-transfer agent and locality latitude. With growth of thermal diffusivity of a ground temperature influence becomes considerable, thus its decrease reduces necessary depth of the heat exchanger.

The generalising dependences allowing on a condition of a rational operating mode of solar system of heating in an all-the-year-round regime of charging and heat accumulator discharging to define a step of heat exchangers to a bush and their depth are offered.

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