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GRANITE HEAT ACCUMULATORS FOR AIR HEATERS

The article deals with one of the ways to improve the energy situation in agriculture of Ukraine, namely to increase the energy efficiency of solar air heaters through the use of granite heat accumulators.

In the world, in recent years, the share of energy produced by non-traditional sources has been steadily increasing. Unfortunately, in Ukraine this proportion is much smaller than in the first world countries. This problem is especially relevant for agriculture. The main renewable energy sources for Ukraine's agricultural sector are biofuels (solid, liquid, gaseous), wind and solar. The latter is the most attractive for widespread use in agriculture. After all, for the production of biofuels requires at least land, mechanization and chemistry, etc., for the production of wind energy requires appropriate weather conditions that are not available in most regions of the country. And only solar energy is everywhere and almost always. The difficulty of using solar energy at night is one of the main constraints on the widespread use of solar installations. The use of heat accumulators (in devices that accumulate heat during the day and give it away at night for production purposes) for solar heaters greatly enhances their technological capabilities. Battery material is a variety of materials - from soil to plastic water bottles. This article discusses the theoretical justification (confirmed by experimental studies) of the choice of rational size and shape of granite heat accumulator elements.

To simplify the task, it was assumed that the battery element has a spherical shape and its thermophysical characteristics remain constant throughout the process of heating and cooling. As a result of the solution of the differential equation of thermal conductivity for these conditions, the dependence of the liquid temperature distribution depending on the radius and time of heating was obtained. The battery element is fully charged when the liquid temperature in the center and on the surface is equal. The temperature distribution in the middle of the liquid was also determined when cooled. Theoretical calculations were confirmed by experimental studies. To determine the rational parameters of the battery cells, a criterion was proposed, the value of which depends on the ratio of heating and cooling time, heating and cooling temperatures, the location of thermocouples.

As a result of theoretical and experimental studies, it is established that the rational size of the granite element of the heat accumulator is an equivalent diameter of 0.3 m. The use of a heat accumulator of this type allows to evaporate more than 300 kg of moisture, which allows to reduce the hay ventilation period, to reduce nutrient losses.

Key words: *heat accumulator, solar air heater, energy efficiency, equivalent diameter, temperature, heat capacity.*

Formulation of the problem. Human life can be seen as a continuous process of energy consumption and transformation. It is the amount of energy consumed that is one of the most important characteristics of civilization. This statement can be confirmed, for example, by comparing per capita energy consumption in different regions of the world. The highest value in the United States is about 85,000 kWh. per capita per year, while in Africa it is just under 8000 kWh [1]. For Ukraine, this value is approximately 40,000 kWh [2]. To meet its ever-increasing needs, humanity needs more and more energy. And it can only meet these needs at the expense of the environment. All natural energy can be roughly divided into three main groups: fossil, nuclear and renewable. The fossil fuels include currently the main sources of energy - coal, oil, gas, etc. These sources account for about 82% of global energy production. Atomic sources account for about 6% of world production. And renewable energy accounts for just under 13% of energy production [3,4]. The structure of energy production in Ukraine differs significantly from the world average: nuclear energy accounts for 49.4% of total production, and the share of alternative sources is only 1.2% [5]. In addition, it should be noted that there are relatively few fossil energy sources in Ukraine, so the use of renewable (alternative) sources is currently a pressing issue.

In the agricultural production of Ukraine the main renewable sources are biogas, biofuels, wind and solar energy. Appropriate conditions are required for the production of biogas and biofuels (animals, land for the cultivation of bioenergy crops, special machinery and equipment, etc.). The use of wind energy on an industrial scale is constrained by the insignificant power and uneven geographical location of energy sources. And only solar energy in Ukraine is practically everywhere and always (usually in the daytime). This is (the work of solar heat generators only in the afternoon) and is the main disadvantage of various devices that use solar energy to heat air, water and other heat carriers, direct conversion of solar energy into electricity, and so on.

Heaters are used to increase the life of the heaters. The principle of their work is that in the daytime part of the solar energy is used to heat the substance that accumulates energy, and at night this energy is sent to fulfill technological goals. Of course, heat accumulators must have certain properties (thermophysical characteristics, material cost, etc.) and adapt to the conditions of use. This article deals with the selection of rational batteries based on the main indicators of heat accumulators that were used in the heat generators during hay drying, so its topic is, without doubt, relevant.

Analysis of recent research and publications. Rechargeable devices are widely used in “big” energy. Plugging them into the grid enhances the reliability and stability of consumers' energy supply, enables them to regulate the modes of operation of power plants by cutting the peaks of the battery discharge schedule and filling the battery dips. The main types of energy storage devices are presented in [6,7]: heat (cold) accumulators in which energy is stored at the expense of heat capacity, heat of phase transitions, and endothermic and exothermic reactions; batteries of electrochemical energy in which electricity is stored and supplied as a result of chemical reactions; mechanical accumulators in which energy is stored as potential and kinetic energy of physical bodies; electrical accumulators in which energy is stored in the form of electrical or electromagnetic energy.

The most important characteristics of heat accumulators are [8]: the operating temperature range, in the temperature of the coolant at the inlet and coutput of the system; thermal capacity per unit mass or volume; methods of heat supply and selection and corresponding temperature differences; temperature stratification in the battery; power required for heat supply and removal; means of regulation of thermal losses of the battery; cost of production and operation.

The design of the heat storage batteries and the choice of material for them depends on the temperature level, the scale (sizes) of the installation and the heat storage period. The higher the temperature of the accumulation, the more difficult it is to provide a long duration of accumulation due to considerable heat loss. Improving thermal insulation reduces heat loss and, accordingly, increases the shelf life of stored energy. Therefore, the required duration of heat storage technology affects the appearance, construction, cost of heat accumulators.

When choosing a material for a heat accumulator, it is necessary (as for other technological processes) to find a reasonable compromise between price and quality. In our case, the material must have satisfactory thermophysical characteristics (heat capacity, thermal conductivity) and acceptable price and technological and construction qualities. Recently, stones, water, gases and eutectic salts have been used as heat storage materials [9]. But the use of specific material depends on many factors. Quite often, fine gravel or even soil is used as the heat storage material [10, 11]. Large masses of water heaters require large capacities, compactly positioned, and protected from corrosion. The use of plastic beverage bottles can be an effective method of creating water heaters of any capacity and configuration [12]. Along the way, it helps to solve the problem of disposal of these products. Another interesting use of heat accumulators is to use them as regenerative installations [13].

However, some heat accumulators will not be able to significantly improve the efficiency of solar installations. The greatest effect is given by the harmonious combination of rational design of solar installation with heat accumulators [14, 15]. The rational design and technological parameters of solar installations allow to get the maximum effect not only from direct use of solar energy, but also to extend their operating time due to the use of heat accumulators.

When hay is actively ventilated, it is advisable to use solar air heaters with heat accumulators for nighttime operation. This paper investigates the question of the choice of rational characteristics for a granite heat accumulator when drying the hay by active ventilation with air heating in a solar installation.

Purpose of research. The aim of the research is to increase the energy efficiency of the active hay ventilation process by substantiating the rational design and technological parameters of an air heater with a heat accumulator.

Presenting main material. The use of unconventional energy sources (solar, wind, etc.) can reduce fuel consumption and reduce agricultural processing costs. The most widely used in agriculture are heat generators that use solar energy to heat the air, which they use to dry products, including hay.

However, solar heat generators can only be used for 8 ... 10 hours a day. For more efficient use of solar air heaters, it is advisable to use heat accumulators, in, elements that heat and accumulate energy in the daytime and give it away at night when cold air is blown through them. Granite is one of the best heat storage materials. This is cheap and affordable material. For efficient use of granite heat batteries it is necessary to know the time of their heating and the optimal size of stones.

When acting on the liquid of a coolant with constant temperature t_T, the surface of the liquid (temperature t_s) first warms up, and then the temperature of the center of the liquid t_c begins to rise. As the heating time increases, the temperatures t_s and t_c are leveled and, as $\tau \to \infty$ (τ is the heating time), they become equal to t_T. For practical purposes it is necessary to know the time τ_2, during which the whole liquid warms up, in when t_s=t_c. If we continue to purge the coolant after τ_2, the liquid temperature and its enthalpy will remain constant, and the energy used to heat and purge the coolant will be wasted.

In the process of heating, the liquid temperature changes only by 10 ... 20°, so it can be assumed that the thermophysical parameters of the liquid and the coolant remain constant. Let us also assume that the battery element is a sphere of radius r_0.

At the initial time ($\tau=0$), the temperature in a sphere of radius r_0 is uniformly divided and equal to t_0. The ball is in a medium with constant temperature $t_T>t_0$. The heat exchange between the surface of the liquid and the coolant occurs at a constant coefficient of heat exchange $\alpha=const$. It is necessary to determine the temperature distribution in the ball $t=f(r,\tau)$.

Introduce the concept of excessive liquid temperature:

$$\vartheta = t_T - t, \qquad (1)$$

where t is the current temperature of the liquid.

Differential equation of thermal conductivity of a sphere in spherical coordinates:

$$\frac{\partial\vartheta}{\partial r} = a\left(\frac{\partial^2\vartheta}{\partial r^2} + \frac{2}{r}\cdot\frac{\partial\vartheta}{\partial r}\right) \qquad (2)$$

where a is the coefficient of thermal conductivity of the liquid.

Initial conditions

$$\vartheta_0 = t_T - t_0 \text{ for } \tau=0 \qquad (3)$$

Boundary conditions

$$\left(\frac{\partial\vartheta}{\partial r}\right)_{r=r_s} = -\frac{a}{\lambda}\vartheta_{r=r_s} \qquad (4)$$

where a is the coefficient of heat exchange between the air and the liquid;

α is the coefficient of thermal conductivity.

$$\left(\frac{\partial\vartheta}{\partial r}\right)_{r=0} = 0 \qquad (5)$$

Equation (4) reflects the conditions of heat exchange on the surface of the ball, and equation (5) characterizes the symmetry of temperature distribution in the liquid.

The solution of equation (2) with boundary conditions (3-5) can be represented in the following form [16]:

$$\theta = \frac{\vartheta}{\vartheta_0} = \frac{t_T - t(r,\tau)}{t_T - t_0} = \sum_{n=1}^{\infty}\frac{2(\sin\mu_s - \mu_s\cos\mu_s)\sin(\mu_s R)}{(\mu_s - \sin\mu_s\cos\mu_s)\mu_s R}exp(-\mu_n^2 Fo), \qquad (6)$$

where $R = \frac{r}{r_0}$ – (r is the current radius, r_0 is the radius of the sphere);

$Fo = \frac{\alpha\tau}{r_0^2}$ – kryteriy Furie ;

μ_s are the roots of the characteristic equation.

$$tg\mu = -\frac{\mu}{(B_i - 1)}, \qquad (7)$$

where $Bi = \frac{\alpha\cdot r}{\lambda}$ is the Bio criterion.

As shown by the analysis of equation (6) at $Fo>0.25$ (and in our conditions it will be already at $\tau>20$ min), the series quickly coincides and can be replaced by the first term of the series.

If the thermophysical characteristics of the liquid and the coolant are known, as well as the conditions of heat exchange between them, then equation (6) can determine the temperature at any point in the liquid and at any time.

In this problem, we are most interested in the center of the ball, because it reaches the temperature t_T at maximum τ. For the center of the sphere $R = \frac{r}{r_0} = 0$, therefore:

$$\frac{\sin\mu_1 R}{\mu_1 R} = 1 \text{ (because } \lim_{x\to 0}\frac{\sin x}{x} = 1\text{)} \qquad (8)$$

Then for the center of the sphere expression (6) is simplified and will look like:

$$\theta_c = \frac{\vartheta_c}{\vartheta_{oc}} = \frac{2B_i\sqrt{\mu_1^2+(Bi-1)^2}}{\mu_1+Bi^2-Bi} exp(-\mu_1^2 Fo) \quad (9)$$

To test equation (6) and determine the optimal size of the battery cells, a series of experiments were carried out with stones of different sizes. The equivalent diameter of the stones was 0.112 m; 0.18 m; 0.20 m; 0.25 m; 0.30 m; 0.34 m. The stones were heated in a drying cabinet ShSS-80P with simultaneous fixation of temperature by thermocouples HC, which were placed at different depths.

The difference between the actual temperature and the one calculated by equation (6) did not exceed 10.5%.

As the heating time increases, the difference between the calculated and the actual temperature decreases and equation (9) can be used to determine the charging time of the battery. Charging time of stones with an equivalent diameter of d_e= 0.3 m is about 8 hours.

A series of experiments on heating and cooling stones of various sizes were carried out to determine the optimal stone sizes for heat storage batteries.

The general view of thermograms of heating and cooling of stones is shown in fig. 1.

The optimization criterion was chosen for the following reasons. The faster the battery element heats up and the slower it cools, the more suitable it is for the battery. Therefore, this criterion should include the ratio τ_{cool} / τ_{heat}.

For the same reasons, the criterion introduces the ratio Δt_{heat} / Δt_{cool}. We also introduced the value $(r_T / r_0)^3$ (where r_T is the thermocouple placement radius), which characterizes, firstly, the volume of stones (accordingly, the amount of heat accumulated in the stones) and, secondly, the location of the thermocouple because they were placed in different samples at different depths.

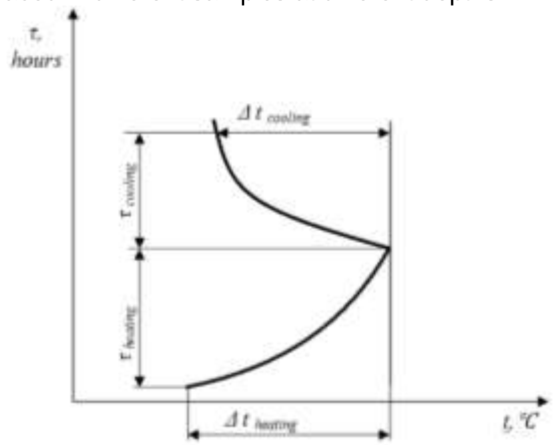

Fig. 1. Thermogram of heating and cooling of granite samples

Thus, the ratio was selected as the optimization criterion

$$K = \frac{\tau_{cool}}{\tau_{heat}} \cdot \frac{\Delta t_{heat}}{\Delta t_{cool}} \cdot \left(\frac{r_T}{r_0}\right)^3 \quad (10)$$

After conducting experiments on samples of different sizes, it was determined that stones with an equivalent diameter of 0.25…0.30 m are rational for use in heat storage (Fig. 2). A stone of about 30 kg corresponds to this equivalent diameter.

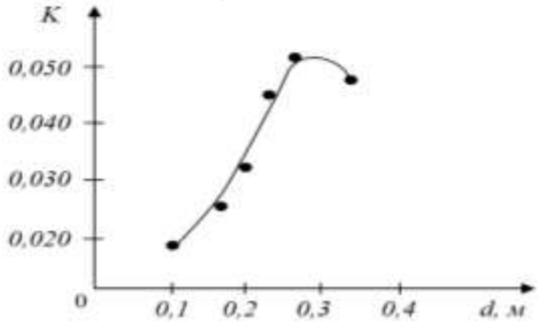

Fig. 2. The dependence of the criterion K on the equivalent diameter of the sample

In practice, two types of thermal accumulators were used. The first - the stones, located in a closed channel, is heated in the day by hot air coming out of the heat generator, and at night it is discharged when cold air is blown through it. The second is the stones located in the parabolic thermal accumulator, in the daytime it is heated by direct sunlight when the film of the thermal accumulator is raised and at night when the film is lowered it is cooled by cold air.

The example of calculations of the time of charging and discharging of heat accumulators, as well as the efficiency of their use are given.

The first option - charging the heat accumulator occurs by blowing hot air after the heat generator through a layer of stones (700 pieces of granite blocks with d_e = 0,3 m).

At the inlet to the solar heat generator, the air has a temperature $t_{in} = 22°C$, and at the coutput of the heat generator - $t_{out} = 22 + 10{,}9 = 32{,}9°C$. Determine the average air temperature in the heat generator - the temperature at which the heat exchange between the air and the stones.

$$\tilde{t}_n = \frac{t_{out}-t_{in}}{ln\left(\frac{t_{out}}{t_{in}}\right)} = \frac{32{,}9-22}{ln\left(\frac{32{,}9}{22}\right)} = 27{,}09°C$$

(11)

The heat exchange between the air and the stones will occur according to the law of external flow around the ball. Nusselt's criterion will then be determined by the expression:

$$Nu_{n-k} = 2 + 0{,}03Re^{0{,}54}Pr^{0{,}33} + 0{,}35Re^{0{,}58}Pr^{0{,}36}, \quad (12)$$

where Pr is the kryterii Prandtlia (for air, $Pr = 0.71$).

The Reynolds criterion in this case will be relevant:

$$Re = \frac{\vartheta_s d_e}{v} = \frac{0{,}423 \cdot 0{,}3}{15{,}61 \cdot 10^{-6}} = 8129{,}4 \quad (13)$$

Criterion Nuselta: $Nu_{s\text{-}k} = 62{,}79$.

Coefficient of heat exchange between hot air and heat generator stones:

$$a_{s-k} = \frac{Nu_{n-k} \cdot \lambda_n}{d_e} = 5{,}55 \ \frac{Vt}{m^2 K} \quad (14)$$

Next, determine how the temperature of the center of the stone will change after 10 hours of hot air heating. To do this, we determine the quantities that are included in equation (9).

Criterion Bio:

$$Bi = \frac{a_{s-k} \cdot r_e}{\lambda_k} = 0{,}0359, \quad (15)$$

where $\lambda_к = 23{,}2$ Vt/m·K is the thermal conductivity of granite.

Criterion Furie:

$$Fo = \frac{a \cdot \tau}{r_e^2} = 24{,}85, \quad (16)$$

where $a = 15{,}53 \cdot 10^{-6}$ m^2/c - thermal conductivity of granite;

$\tau = 36000$ c - time of stone heating.

The first root of the characteristic equation:

$$tg\mu = -\mu/(0.0359 - 1); \quad \mu_1 = 0{,}29 \quad (17)$$

Dimensional heating temperature:

$$\theta = \frac{\tilde{t}_s - t(0;10)}{\tilde{t}_s - t_0} = \frac{2Bi\sqrt{\mu_1^2 + (Bi-1)^2}}{\mu_1 + Bi^2 - Bi} exp(-\mu_1^2 F_0) = 0{,}0351, \quad (18)$$

where $\tilde{t}_s = 27{,}09°C$ – hot air temperature;

$t_0 = 22°C$ initial air temperature;

$t(0;10)$ – temperature of center of stone after 10 hours of heating;

$$t(0;10) = \tilde{t}_s - \theta(\tilde{t}_s - t_0) = 26{,}91°C \quad (19)$$

Within 10 hours of heating, the temperature of the center of the stone will be almost equal to that of hot air. This means that the battery is fully charged. In the evening, cold air was blown through the heat accumulator with $t_s^0 = 15°C$. We assume that the battery runs until its center temperature is $t(0;\tau) = 16°C$. The heat transfer conditions are the same as those of the heat accumulator.

Dimensional cooling temperature:

$$\theta = \frac{t_s^0 - t(0;\tau)}{t_s^0 - t_0} = \frac{15-16}{15-26{,}91} = 0{,}084 \quad (20)$$

The cooling time of the heat accumulator is from the expression:

$$exp(-\mu_1^2 Fo^0) = \theta \frac{\mu_1 + Bi^2 - Bi}{2Bi\sqrt{\mu_1^2 + (Bi-1)^2}} \quad (21)$$

$Fo^0 = 14{,}447$ and

$$\tau^0 = \frac{Fo^0 \cdot r_e^2}{a} = 20931\ c = 5{,}8\ \text{year}$$

This is the time of effective operation of the battery.

The amount of heat that the heat accumulator will give to cold air (we assume that the whole stone has cooled to a temperature of 16°C):

$$Q_{hc} = M_{hc} C_{gr}[t(0;10) - t(0;5{,}8)] \cdot (1-\eta) = 168{,}09\ MJ, \quad (22)$$

where

$M_{hc} = N_k \rho_{gr} \frac{3}{4} \pi \cdot r_e^3 = 26705{,}7\ kg$ - weight of stones of the heat accumulator;

ρ_{gr} = 2700 kg/m³ - density of granite;

C_{gr} = 641 J/kg·K - heat capacity of granite;

η = 0,1 is the fraction of heat lost to the environment;

$N_k = 700$ pcs. - the number of stones in the heat accumulator.

The amount of moisture that can be evaporated using the heat of the solar heat generator and the heat accumulator:

$$T_{moi} = \frac{Q + Q_{hc}}{Q_{exh}} = \frac{19{,}23 \cdot 10 \cdot 3600 + 168090}{2500} = 344{,}15\ kg, \quad (23)$$

where Q_{exh} = 2500 kJ/kg - the amount of heat required to evaporate 1 kg of moisture.

Quantity of conditional fuel saved by the operation of a solar heat generator with a heat accumulator:

$$M_{cf} = \frac{Q + Q_{hc}}{Q_{l.cf}^{W}} = \frac{19{,}23 \cdot 10 \cdot 3600 + 168090}{29300} = 29{,}37\ kg, \quad (24)$$

where $Q_{l.cf}^{W}$ = 29300 kJ/kg - the lower working heat of combustion of conventional fuel.

Let us now consider the second option, when the stones are heated by direct sunlight. The film in the solar heat generator is raised, the air through the stones is not supplied. We will assume that 25% of heat from stones through convection and thermal conductivity is lost to the environment. Some of the heat from the stones is also lost as a result of its own radiation.

To find the temperature of T stones after 10 hours of solar radiation, the following equation must be solved:

$$0{,}76Q_{hc}^{c} - Q_E = M_{hc} \cdot c_{gr}(T - T_0), \quad (25)$$

where Q_{hc}^{c} is the amount of heat that the heat accumulator receives from the Sun;

Q_E is the amount of heat emitted by the heat accumulator into the environment;

M_{hc} is the mass of stones of the heat accumulator;

c_{gr} - heat capacity of granite;

T_0 =*293 K* - initial temperature of granite.

Amount of heat received by the solar battery:

$$Q_{hc}^{c} = Q_c \cdot S \cdot \tau, \quad (26)$$

where Q_c is the average intensity of solar radiation during the day;

S is the area of the base of the heat generator;

τ - time of efficient operation of the heat generator.

Amount of heat emitted by the battery into the environment:

$$Q_E = E \cdot S \cdot \tau, \quad (27)$$

where E is the intrinsic flux density of the heat accumulator stones.

$$E = C\left(\frac{T}{100}\right)^4, \quad (28)$$

where $C = \varepsilon \cdot C_0$ is the radiation coefficient of the gray liquid;

$C_0 = 5{,}67\ \frac{Vt}{m^2 K}$ - radiation coefficient of absolute black liquid;

$\varepsilon = 0{,}93$ - the degree of blackness of granite;

T - stone temperature.

Substituting into equation (25) all known quantities and solving it, we obtain values *T = 305,1K* or t_{gr} *= 32,1°C*.

Similarly to the first variant, determine the cooling time of the battery with cold air from $t_s^0 = 15°C$ to the temperature in the center of the stone $t(0;\tau) = 16°C$.

Dimensionless temperature $\theta = \frac{15-16}{15-32{,}1} = 0{,}0585$.

To find the cooling time of stones, we first determine the Furie test and then the cooling time itself.

$$\exp(-0{,}29^2 Fo^0) = 0{,}0585 \frac{0{,}29+0{,}0359^2-0{,}0359}{2\cdot 0{,}0359\sqrt{0{,}29^2+(0{,}0359-1)^2}} = 0{,}206 \quad (29)$$

$Fo^0 = 18{,}77$, and

$$\tau^{cool} = \frac{Fo^0 \cdot r_e^2}{15{,}53\cdot 10^{-6}} = 7{,}55\ год. \quad (30)$$

The amount of heat that the battery will give the cold air:

$$Q_{hc} = M_{hc}C_{gr}[t(0;10) - t(0;4 - 7{,}55)] \cdot (1-\eta) = 248{,}04\ mJ \quad (31)$$

The amount of moisture that can be evaporated by the heat of the battery:

$$m_{moi} = \frac{248040}{2500} = 99{,}216\ kg \quad (32)$$

Quantity of conditional fuel that can be saved daily by the use of a battery:

$$M_{cf} = \frac{248040}{29300} = 8{,}47\ kg$$

The calculation data for determining the amount of heat produced by the heat generator were checked in practice. The difference between the calculated and practical data did not exceed ± 12%.

Comparing expressions (22) and (31), it can be seen that the open battery stores 1.48 times more heat than the closed battery. It should be noted that this figure does not take into account the energy for blowing hot air through the heat accumulator in the first embodiment.

The use of heat accumulators allows to increase the capacity of solar heat generators by almost 25%, to reduce the ventilation time of hay, to improve its quality.

Conclusion. As a result of theoretical and experimental studies, the dependence of the temperature distribution in the elements of the granite heat accumulator was obtained. Based on this, it was determined that the rational size for the elements of the heat accumulator are granite blocks with an equivalent diameter of 0.3 m.

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ГРАНІТНІ АКУМУЛЯТОРИ ТЕПЛА ДЛЯ ГЕЛІОПІДІГРІВАЧІВ ПОВІТРЯ

В статті розглянутий один із шляхів покращення енергетичної ситуації в сільському господарстві України, а саме підвищення енергетичної ефективності геліопідігрівачів повітря шляхом застосування гранітних акумуляторів теплоти.

У світі в останні роки постійно збільшується частка енергії що виробляється нетрадиційними джерелами. На жаль в Україні ця частка значно менша ніж в країнах першого світу. Особливо актуальна ця проблема для сільського господарства. Основні поновлювальні джерела енергії для аграрного сектору України – це біопаливо (тверде, рідке, газоподібне), вітрова та сонячна енергія. Саме остання є найбільш приваблива для широкого розповсюдження в сільському господарстві. Адже для виробництва біопалива потрібна, як мінімум земля, засоби механізації та хімізації тощо, для виробництва вітрової енергії потрібні відповідні погодні умови які відсутні в більшості регіонів країни. І тільки сонячна енергія є всюди і майже завжди. Саме труднощі з використанням сонячної енергії вночі є одним з головних стримуючих факторів в широкому використанні геліоустановок. Використання акумуляторів тепла (тобто пристроїв які вдень накопичують теплову енергію, а вночі віддають її для виробничих потреб) для геліопідігрівачів значно розширює їх технологічні можливості. Матеріалом для акумуляторів

служують різноманітні матеріали – від ґрунту до пластикових пляшок з водою. В даній статті розглядається теоретичне обґрунтування (підтверджене експериментальними дослідженнями) вибору раціональних розміру і форми елементів гранітних акумуляторів тепла.

Для спрощення вирішення поставленої задачі було зроблено припущення що елемент акумулятора має сферичну форму і його теплофізичні характеристики залишаються постійними протягом всього процесу нагріву та охолодження. В результаті розв'язку диференційного рівняння теплопровідності для даних умов була отримана залежність розподілу температури тіла залежно від радіусу і часу нагріву. Елемент акумулятору повністю зарядиться коли температура тіла в центрі і на поверхні будуть рівними. Також був визначений розподіл температури в середині тіла при його охолоджені. Теоретичні розрахунки були підтверджені експериментальними дослідженнями. Для визначення раціональних параметрів елементів акумулятора був запропонований критерій , величина якого залежить від співвідношення часу нагріву та охолодження, температур нагріву та охолодження, місця встановлення термопар.

В результаті теоретичних та експериментальних досліджень встановлено, що раціональним розміром гранітного елемента акумулятора тепла є еквівалентний діаметр 0,3 м. Використання акумулятора тепла даного типу дозволяє додатково випарувати більше 300 кг вологи, що дозволяє скоротити термін вентилювання сіна, зменшити втрати поживних речовин.

Ключові слова: *акумулятор тепла, геліопідігрівач повітря, енергетична ефективність, еквівалентний діаметр, температура, теплоємність.*

ГРАНИТНЫЕ АККУМУЛЯТОРЫ ТЕПЛА ДЛЯ ГЕЛИОПОДОГРЕВАТЕЛЕЙ ВОЗДУХА

В статье рассмотрен один из путей улучшения энергетической ситуации в сельском хозяйстве Украины, а именно повышение энергетической эффективности гелиоподогревателей воздуха путем применения гранитных аккумуляторов теплоты.

В мире в последние годы постоянно увеличивается доля энергии вырабатываемой нетрадиционными источниками. К сожалению в Украине эта доля значительно меньше, чем в странах первого мира. Особенно актуальна эта проблема для сельского хозяйства. Основные возобновляемые источники энергии для аграрного сектора Украины - это биотопливо (твердое, жидкое, газообразное), ветровая и солнечная энергия. Именно последнее является наиболее привлекательна для широкого распространения в сельском хозяйстве. Ведь для производства биотоплива нужна, как минимум земля, средства механизации и химизации и т.д., для производства ветровой энергии нужны соответствующие погодные условия, которые отсутствуют в большинстве регионов страны. И только солнечная энергия есть повсюду и почти всегда. Именно проблемы с использованием солнечной энергии ночью является одним из главных сдерживающих факторов в широком использовании гелиоустановок. Использование аккумуляторов тепла (то есть устройств которые днем накапливают тепловую энергию, а ночью отдают ее для производственных нужд) для гелиоподогревателей значительно расширяет их технологические возможности. Материалом для аккумуляторов служат различные материалы - от почвы до пластиковых бутылок с водой. В данной статье рассматривается теоретическое обоснование (подтвержденное экспериментальными исследованиями) выбора рациональных размера и формы элементов гранитных аккумуляторов тепла.

Для упрощения решения поставленной задачи было сделано предположение, что элемент аккумулятора имеет сферическую форму и его теплофизические характеристики остаются постоянными в течение всего процесса нагрева и охлаждения. В результате развязку дифференциального уравнения теплопроводности для данных условий была получена зависимость распределения температуры тела в зависимости от радиуса и времени нагрева. Элемент полной зарядки аккумулятора когда температура тела в центре и на поверхности будут равными. Также было определено распределение температуры внутри тела при его охлажденные. Теоретические расчеты были подтверждены экспериментальными исследованиями. Для определения рациональных параметров элементов аккумулятора был предложен критерий, величина которого зависит от соотношения времени нагрева и охлаждения, температуры нагрева и охлаждения, места установки термопар.

В результате теоретических и экспериментальных исследований установлено, что оптимальным размером гранитного элемента аккумулятора тепла является эквивалентный диаметр 0,3 м. Использование аккумулятора тепла данного типа позволяет дополнительно испарить более 300 кг влаги, что позволяет сократить срок вентилирования сена, уменьшить потери питательных веществ.

Ключевые слова: *аккумулятор тепла, гелиоподогреватель воздуха, энергетическая эффективность, эквивалентный диаметр, температура, теплоемкость.*

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