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DEVELOPMENT OF A SOIL REGENERATOR WITH A GRANULAR NOZZLE FOR GREENHOUSES

I. Boshkova
Doctor of Technical Sciences, Professor*
E-mail: boshkova.irina@gmail.com

N. Volgusheva
PhD, Associate Professor*

A. Solodka
Senior Lecturer*

I. Mukminov
Postgraduate Student*

O. Bondarenko
Postgraduate Student*

*Department of Oil and Gas Technologies, Engineering and Power Engineering
V. S. Martynovsky Institute of Refrigeration, Cryotechnologies and Ecoenergetics
Odessa National Academy of Food Technologies
Dvoryanska str., 1/3, Odessa, Ukraine, 65082

The results of the development of a regenerative-type heat exchange unit for greenhouses are presented. The creation of a soil regenerator is conditioned by energy and economic expediency. In spring in the daytime, the air in greenhouses is intensely heated by solar radiation, and at night it can be cooled below the allowable temperature. Heat accumulation during the day and using this heat at night will reduce the need for heaters even to their complete exclusion. The soil regenerator contains a dense layer of granular material that is blown through by the air from the inner space of a greenhouse. This solution makes it possible to intensify significantly the heat exchange. To determine the mean intercomponent heat exchange factor, the empirical dependence, taking into consideration the effect of duration of the heat exchange process, was obtained. We developed the procedure of thermal design calculation of a regenerator, using which the main geometric characteristics of the heat exchange area are determined. The results of the calculation of the soil regenerator for a greenhouse with the surface area of 18 m^2 for the conditions of the warm continental climate were presented. The developed soil regenerator contains 5 channels that are 5.75 m long, filled with rubble. It was obtained that for the average solar radiation flow Q_c=2,160 W and the duration of operation of the soil regenerator τ_Σ=6 hours, the accumulated heat at night can be consumed for 2.6 hours at the average ambient temperature t_1=7 °C. As the ambient temperature rises, the time of regenerator operation will increase. The proposed soil regenerator is characterized by the design simplicity and its application will lead to an increase in energy costs to maintain the temperature mode in a greenhouse

Keywords: solar radiation, heat accumulation, heat calculation procedure, factor of intercomponent heat exchange

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1. Introduction

The need to develop energy-efficient methods for heating and cooling the premises increases every year. The efforts of many researchers are aimed at finding effective solar energy batteries to heat the premises under conditions of a significant daily temperature difference. It is advisable to use a dense layer of granular materials as an accumulating body. Due to the developed heat exchange surface, which is the cumulative surface of all particles in the apparatus, the heat exchange intensity increases significantly. A regenerator for maintaining the required temperature level in greenhouses is one of the applications of using a regenerative device with a granular nozzle in the form of a dense layer, for which the source of heat is solar radiation. The temperature in a greenhouse should be on average from +16 to +25 degrees, and at night should fall not more than by 5–8 degrees. The temperatures below and above the norm are undesirable for plants. It is known that the air in greenhouses in the spring period in the regions with moderate climate is intensively heated from solar radiation during the day time, and is significantly cooled at night due to temperature changes. This determines the rationality of the development of a regenerator that can accumulate heat during the day and use it to heat the internal volume of a greenhouse at night. The relevance of the research is determined by the need to save energy resources for heating premises, in particular, greenhouses. The development of effective soil regenerators requires a calculation procedure, which is used to obtain the data on the basic geometric characteristics of the regenerator and physical conditions of its operation.

2. Literature review and problem statement

The results of studying the influence of the heating method on greenhouse microclimate and energy consumption are presented in paper [1]. The data were obtained by analyzing three methods for heating greenhouses: using heating pipes in the soil, using air heaters, and the combined method based on them. It was shown that the use of a combined system is beneficial since the microclimate of a greenhouse is improved and the appearance of condensation on plastic films is prevented. However, the use of these methods requires a lot of energy consumption for heating. In paper [2], it is proposed to use a system of solar collectors to reduce energy consumption. The studies have shown that the appropriate modernization of traditional greenhouses can save up to 70 % of energy. The authors argue that the research into mathematical modeling and design of the best solar greenhouse shape for all agricultural areas is required. This will make it possible to obtain maximum solar radiation and decrease the need for fossil fuels. The results of the experimental study of the energy balance of a greenhouse without heating in hot and dry climates are presented in paper [3]. It was shown that greenhouse soil is an important heat source at night and can provide up to about 44.03 W/m^2 at significant daily isolation. Compared to the artificial heating system, which requires approximately 78 W/m^2, such heat source will be sufficient to maintain the temperature of the air in a greenhouse between 15 and 18 °C. However, these calculation results apply to the conditions of the experiments, that is, in the Mediterranean basin region. At the same time, the results indicate that heat accumulation by the greenhouse soil can significantly reduce energy costs. The authors of paper [4] prove that the main energy resource is solar energy. The direction of their research is related to the search for a method to increase the use of heat from the sun in the vapor generation. The authors explored the optical properties of solar absorbers and gave a description of nanophotonic structures. However, the proposed applications are not suitable for greenhouse farms. Article [5] deals with the major problem that inhibits the use of the full potential of natural and renewable energy sources. The use of solar energy in heating and cooling systems is impossible without the development of economically competitive and reliable means for heat accumulation. Article 6 explores various methods for accumulating solar thermal energy with the focus on bulk and boiling layers. Dense layers were found to have the main advantage in low-temperature systems of energy accumulation. Due to the feasibility of using dense layers as thermal batteries, the effectiveness of their use under different conditions is studied. In paper [7], based on a three-dimensional analysis of gas flows in a layer of aluminum balls, it was established that a decrease in the diameter of balls significantly increases the gradient of pressure and the flow rate decreases. The resulting data makes it possible to optimize the dimensions of the regenerator with a dense layer of particles. Studies of heat transfer in dense layers [8] led to the conclusion that when designing a layer for the accumulation of thermal energy, the Bio number should be as low as possible. In this case, thermal resistance inside a solid body is not decisive. When choosing the material for a nozzle, it is advisable to take this condition into consideration. It is also important to create conditions for the intensification of heat exchange. In paper [9], various modifications of contact points were studied to analyze forced convective heat exchange in a structured compacted layer of spheres. The effect of the contact shape on the pressure economy was found to be significant, and the Nusselt number is relatively small. However, the data are related to a layer of spherical particles, which prevents their propagation to a layer of particles with an arbitrary shape of the surface.

The process of a greenhouse heating and cooling is non-stationary, which significantly complicates mathematical modeling and obtaining dependences for calculating temperatures and heat flows. This issue can be solved by using the approximation used by the authors of article [10]. As shown in the article, to make estimating calculations, it is rational to use the approximation of stationary conditions at assigned mean values of temperatures and heat flows. Another problem is the uncertainty of the factor of heat output from the surface of the particle to the gas flow. Study [11] presents the dependence to determine the heat output factor, or intercomponent heat exchange factor, from the dense layer of spherical particles to the gas flow. However, the proposed dependence is applicable for a stationary mode of heat exchange between a moving layer of particles and a gas flow. The authors of paper [12] presented the results of an experimental study of heat output in a cylindrical nozzle layer of spherical porous particles of aluminum oxide. A procedure for processing experimental data and a semi-empirical model for prediction of the factor of heat output from gas to particles when modeling drying and combustion processes were proposed. The authors provide the results of the comparison of different correlations for heat output factors. It should be concluded that there is no general dependence for calculating heat output factor between the layer of particles and the gas flow. Each particular case of heat exchange needs appropriate correlation dependence. It should be noted that the literature uses two terms: heat output factor or intercomponent heat exchange factor. The latter seems preferable because it specifies the features of the heat exchange process, in which solid and gas heat transfer agents are in direct contact with each other. As noted in [13], in heat exchange with a fixed granular layer, the intercomponent heat exchange factor is significantly dependent on time, and this dependence has a sigmoid shape. Additional research is needed to obtain the calculation formula. Analysis of the data in the literature [6–9] shows that the development of regenerators with dense layers of granular materials is promising in terms of the development of energy-saving heating and cooling systems. At the same time, more knowledge is needed about the specific feature of designing of the soil regenerator, taking into consideration the heat exchange between the gas flow and solid particles. Research in this area is intended to create cost-effective and technically rational heat exchange devices to maintain the required temperature level in greenhouses.

3. The aim and objectives of the study

The aim of this study is to develop a soil regenerator with a granular nozzle in the form of a dense layer of material to maintain the required temperature level in greenhouses during the day and at night.

To achieve the aim, the following tasks were set:

– to establish experimentally the dependence of heat output factor on the airflow to a dense layer of granular materials;

– to develop the procedure for calculating the regenerator for the period of accumulation of excess air heat in a greenhouse in the daytime;

– to perform a thermal design calculation of the regenerator, the main element of which is the blown-through channels filled with rubble.

4. Materials and methods for studying the heat exchange of a dense layer of granular material with the airflow

An experimental plant simulating the actual heat exchange channel of the regenerator was designed and manufactured for the research. The plant provides heating of a dense layer of material and makes it possible to measure air temperature at the inlet and outlet of the channel, the temperature of the material at selected control points, and the flow rate. The channel was filled with granular material when it was mounted in an upright position, for which the possibility of channel disconnecting from the duct is envisaged. Mesh plugs with rubber seals are provided to fix the layer in the channel. The circuit of the experimental plant is shown in Fig. 1.

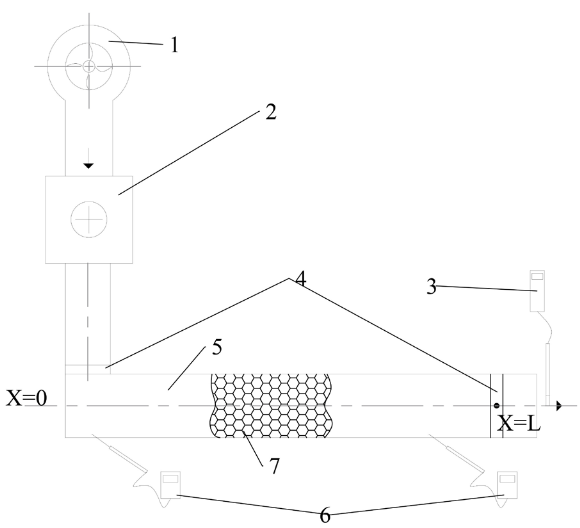

Fig. 1. Circuit of the experimental plant for studying heat exchange between the air and a dense layer of granular material: 1 – fan, 2 – heater, 3 – anemometer, 4 – mesh, 5 – heat exchange channel, 6 – temperature sensors, 7 – a layer of granular material

The procedure of the experiment involved the following. The assigned air temperature was set on the regulator, the fan 1 and the heater 2 were turned on. The air consumption was regulated by a gate valve at the inlet of the fan. The mesh plugs 4 at the ends of the channel allowed fixing material in the form of a dense layer, evenly distributed by cross-section. Anemometer 3 was used to measure air velocity. The maximum length of the layer was 0.6 m, the diameter of the channel was 0.1 m. Temperature measurements were carried out at the interval of 30 s. The air temperature at the inlet ranged from 30 °C to 50 °C. The weight of the material was determined before filling. When using claydite, the weight of the layer was 2.0 kg and 1.7 kg, with the use of rubble, the weight was 6.4 kg and 5.4 kg. At the same time, the length of channel L, filled with granular material, corresponded to 0.6 m for a larger weight of claydite and rubble, and 0.52 m for a smaller weight. During the experiment, the temperatures of the air and particles were determined at the level of $x=L$.

Based on the obtained results, the influence of heating duration, the weight of filling, input temperatures, and gas medium consumption on the temperature of the solid and gas components was analyzed. The obtained data were used to compute transferred heat Q and mean heat output factors.

5. Development of a soil regenerator with a fixed dense layer of granular material

5. 1. Empirical dependence for the calculation of an intercomponent heat exchange factor

The developed and tested calculation procedure is the basis of the creation of a soil regenerator, realizing the idea of heat accumulation by a layer of particles in the daytime and its use to heat the air in a greenhouse at night. The necessary component of the procedure of thermal design calculation of a soil regenerator with a fixed dense layer is the dependence for calculation of heat output factor. It was not possible to find in literary sources the dependence applicable to the explored particular case of heat exchange between a fixed dense layer and a gas flow. That is why the ultimate goal of the experiments was to obtain an empirical dependence for the intercomponent heat exchange factor. The duration of each experiment was determined by the condition of reaching a stationary mode, in which the temperature of the layer of material at all control points was set constant in time. The obtained empirical data determined the mean heat output factor:

$$\alpha_{av} = \frac{Q}{F_{int} \cdot \Delta t_{log}}, \quad (1)$$

where F_{int} is the area of the surface of particles taking part in intercomponent heat exchange, Δt_{log} is the logarithmic mean pressure between the temperatures of gas medium and particles. The area of the intercomponent heat exchange surface is the area of the surface of all particles in the heat exchange channel. As a result of generalization of the experimental data, using Origin 9 program, we obtained the dependence in a dimensionless form for calculation of intercomponent heat exchange factor that is average by channel length (2):

$$Nu = \left(0.39 - \frac{4.83}{1+10^{-1.63\left(0.23-\frac{G_g \cdot c_{p.g} \cdot \tau}{m \cdot c_s}\right)}} + \frac{5.37}{1+10^{-1.32\left(1.47-\frac{G_g \cdot c_{p.g} \cdot \tau}{m \cdot c_s}\right)}} \right) \cdot \mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.43}, \quad (2)$$

where $c_{p.g}$ is the thermal capacity of the air, c_s is the thermal capacity of particles, m is the weight of loaded material, τ is the time, Nusselt number

$$Nu = \frac{\alpha_{av} \cdot \phi \cdot d_e}{\lambda_g},$$

φ is the coefficient of particles' shape, determined according to recommendations [13], Reynolds number

$$\mathrm{Re} = \frac{w_f \cdot d_e}{\nu_g}$$

includes filtration rate w_f, that is, air velocity in relation to the hollow cross-section of the channel. The equivalent diameter of particles d_e, was chosen as determining because this magnitude determines the gas flow distribution between particles and heat exchange intensity. Equivalent diameter is determined in accordance with data [13]. It was found that average for fractions equivalent diameter of claydite d_e=0.019 m, for rubble d_e=0.035 m.

The dependence allows calculating α_{av} at assigned moment τ during heat exchange between gas medium and granular material in the channel. Conditions of application of dependence (2) are the following: granular material – rubble and claydite with thermal capacity c_s=750 J/(kg·K) for rubble and c_s=840 J/(kg·K) for claydite, the gas temperature at the inlet of the device $t_s' = 30-50$ °C, consumption G_g=0.010–0.06 kg/s. The relative error of the formula is 12.5 %.

5. 2. The procedure of thermal design calculation of a soil regenerator with an unmoving layer of granular material

The layout of the soil regenerator in a greenhouse is presented in Fig. 2. In the development of the regenerator's schematic solution, it was taken into consideration that the highest temperature in a greenhouse was at the top. That is why the air intake should be carried out under the roof of a greenhouse. During the heating period, the air is pumped by fan 4 through duct 3 into heat exchange channel 2 with granular material 1, heating it. To reduce heat losses, the heat exchange channel is covered by insulation 5. The heat exchange channel is located under the soil of greenhouse 6. During the cooling period, the heat from the heated granular material is transmitted to the air passing through the channel. Heated air arrives into the inner volume of a greenhouse, heating it.

The calculation is carried out by the method of successive approximations. To make the calculation, it is necessary to select granular material with the equivalent diameter of particles d_e. The following magnitudes must be assigned:

– duration of heating a heat exchange area τ;

– shape and dimensions of the channel;

– air temperature at the inlet of the channel t_g';

– air temperature at the outlet of the channel at the beginning of the heating period t_{0g}'';

– air temperature at the outlet of the channel at the end of the heating period $t_{\tau g}''$;

– the initial temperature of the layer of material t_s' and its final temperature t_g'';

– the average flow of solar radiation Q_c;

– duration of the process of heating the layer of material τ_Σ;

– a number of channels of the regenerator n.

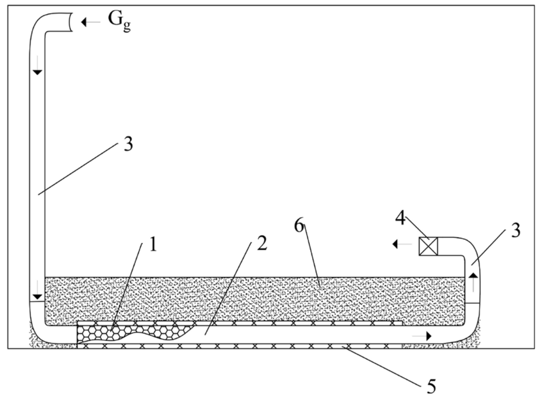

Fig. 2. The layout of a soil regenerator in a greenhouse: 1 — granular material, 2 — heat exchange channel, 3 — air duct, 4 — exhaust fan, 5 — insulation, 6 — soil in a greenhouse

The calculation of heat from solar radiation arriving at a greenhouse is carried out (3), (4):

– heat Q_c arriving from direct and scattered solar radiation is computed from the formula:

$$Q_c = Q_{0c} \cdot k + Q_{\Delta t}, \quad (3)$$

where Q_{0c} is the heat flow from direct solar radiation, $Q_{\Delta t}$ is the heat flow from scattered solar radiation, determined by heat transfer from the environment, k is the indicator of absorption of heat flow of solar radiation.

True solar time τ is approximately related to zone time by the ratio:

$$\tau = \tau_s + 4 \cdot (\lambda_{re} - 0{,}15 \cdot N), \quad (4)$$

where λ_{re} is the geographical longitude of the construction site in degrees, N is the number of time zones, N is the established deviation from solar time, τ_s is the zone time. After the density of heat flow for the desired period is determined, it is possible to transfer to design heat calculation.

The calculation is implemented by the method of successive approximations using the following algorithm:

1. Determine mean values of temperatures of gas and solid components:

$$t_{av.g} = \frac{t_g' + \overline{t}_g''}{2}, \ ^\circ\mathrm{C}; \quad (5)$$

$$t_{av.s} = \frac{t_s' + t_s''}{2}, \ ^\circ\mathrm{C}. \quad (6)$$

Using values $t_{av.g}$, determine thermal-physical characteristics of the air: ν_g, c_p, λ_g, ρ_g, Pr.

2. Determine average heat, withdrawn from the air in a greenhouse to the layer of material in one channel:

$$Q = Q_c / n, \quad (7)$$

where n is the number of channels.

3. Compute air consumption in one channel:

$$G_g = \frac{Q}{c_{p.g} \cdot \left(t'_g - \frac{t''_{0g} + t''_{\tau g}}{2} \right)}. \quad (8)$$

4. Compute air filtration rate:

$$w_f = \frac{G}{\rho_g \cdot S}, \text{ m/s.} \quad (9)$$

5. Determine Reynolds number:

$$\mathrm{Re}_g = \frac{w_f \cdot l}{\nu_g}. \quad (10)$$

6. Compute Nusselt number by dependence (2) and intercomponent heat exchange factor α_{av}:

$$\alpha_{av} = \frac{Nu \cdot \lambda_g}{\phi \cdot d_e}. \quad (11)$$

7. Determine the area of the surface of particles, taking part in heat exchange F_{int}:

$$F_{int} = \frac{Q}{\alpha_{av} \cdot \Delta t_{log}}, \quad (12)$$

where mean logarithmic temperature pressure is:

$$\Delta t_{log} = \frac{\left(t'_g - t'_s\right) - \left(\overline{t}''_g - t''_g\right)}{\ln \frac{\left(t'_g - t'_s\right)}{\left(\overline{t}''_g - \overline{t}''_s\right)}}. \quad (13)$$

8. Determine the value of the specific surface of particles:

$$a_{sp} = \frac{6 \cdot (1 - \varepsilon)}{\phi \cdot d_e}, \quad (14)$$

where ε is the layer porosity; the values of porosity for studied materials are given in [13].

9. Compute the volume of the heat exchange area:

$$V = \frac{F_{int}}{a_{sp}}. \quad (15)$$

10. Calculate the length of the heat exchange area for the considered time period:

$$l = \frac{V}{S}. \quad (16)$$

11. Calculate the weight of material loading for the heat exchange area:

$$m = \rho_s \cdot \frac{F_{int}}{a_{sp}}. \quad (17)$$

12. Calculate the heating duration of the heat exchange area:

$$\tau = \frac{c_s \cdot \delta t_s \cdot m_s}{Q}. \quad (18)$$

13. Determine the deviation of value τ calculated in the first approximation from the accepted one. If the deviation of values τ is more than 5 %, we should accept τ from p. 13 and perform the calculation in the second approximation. Calculations are repeated till satisfactory agreement of values τ.

14. The number of heat exchange areas along the length of the channel:

$$N = \frac{\tau_\Sigma}{\tau}. \quad (19)$$

15. The length of the channel of the regenerator:

$$L = N \cdot l. \quad (20)$$

The developed procedure takes into consideration a change in the intercomponent heat exchange factor over time. This makes it possible to obtain more accurate data about the value of the area of heat exchange surface, respectively, the volume of the heat exchange apparatus and the duration of accumulation and regeneration periods.

5. 3. Thermal design calculation of a soil regenerator for a greenhouse

The calculation was performed for a greenhouse with dimensions of 6×3 m, the height of the walls – 2.5 m, located in the zone of a warm continental climate. The mean magnitude of the thermal flow of solar radiation in April for the area of the greenhouse base is 18 m^2: Q_{0c}=5,840 W. At the average daylight of 13.5 hours, we take k=0.37. Under these conditions, Q_c=2160 W. Scattered sunlight is neglected.

We accept that the duration of rubble heating is 6 hours. It is recommended to start heating the battery after the temperature at the top of the greenhouse reaches 30 °C.

We take rubble with the equivalent diameter of particles d_e=3.5 cm as a granular material.

The original data for calculations are the following.

Duration of thermal layer heating – τ=1,800 s. Heat exchange channel of the square cross-section with the side of 40 cm. Air temperature at the inlet $t'_g = 30\,°\mathrm{C}$, at the outlet at the beginning of the heating process $t''_{0g} = 18\,°\mathrm{C}$ and the end $t''_{\tau g} = 29\,°\mathrm{C}$. The initial temperature of the layer of material $t'_s = 16\,°\mathrm{C}$, final temperature $t''_s = 26\,°\mathrm{C}$. Mean value of the solar radiation flow Q_c=2160 W, duration of the process of heating the layer of material τ_Σ=6 hours. The number of channels of the regenerator n=5.

One channel withdraws average heat.

$$Q = Q_c / n = 2160 / 5 = 432 \text{ W}.$$

The results of calculations according to the above procedure are shown in Table 1.

In the calculations, it was accepted that the shape factor in accordance with the studies [13], φ=1.43. In this case, the value of the specific surface of particles a_{sp}=60.

Since there are 5 channels in a greenhouse, the amount of heat accumulated by rubble will equal:

$$Q_J = Q_c \cdot \tau_\Sigma = 2{,}161 \cdot 6 \cdot 3{,}600 = 46.68 \text{ MJ}.$$

Table 1

Results of calculations of the soil generator for a greenhouse

Results of calculations of the soil generator for a greenhouse Air consumption in one channel G_g, kg/s	Air filtration rate w_f, m/s	Average intercomponent heat exchange factor α_{av}, V/(m^{2}K)	Length of channel L, m	Weight of rubble in channel m, kg
0.066	0.34	17	5.75	1,265

Accumulated heat is supposed to be used at night. Estimation calculation of heat losses at night should be performed. For the considered greenhouse, the area of the heat transfer surface is F=70.4 m^2.

In accordance with [14], the maximum factor of heat output from the surface of a greenhouse is α=8.0 W/(m^{2}K). The process of greenhouse cooling is non-stationary, and the temperature of both the ambient air and the air in greenhouse changes. However, the Newton-Richman law is used to estimate heat losses in the approximation of average temperatures:

$$Q_{loss} = \alpha \cdot F \cdot \Delta t. \quad (21)$$

Accepting that average temperature of the environment at night t_1=7 °C, and the average temperature on the surface of the greenhouse film t_2=16 °C, Q_{loss}=5,069 W. Then the heat accumulated will be sufficient for τ_n=9,209 s, or 2.56 hours.

The thermal design calculation makes it possible to determine the basic geometric characteristics of the regenerator and the weight of its filling. Turning on/off the regenerator fans should be monitored by air temperature sensors in a greenhouse and at the outlet of the regenerator. This will allow efficient use of the ground regenerator under different temperature conditions.

6. Discussion of results of the thermal design calculation of the regenerator with a dense layer

The idea of creating a soil regenerator is based on the information about the intensity of air heating in a greenhouse from solar radiation in the daytime and the effectiveness of contact heat exchange between the air and the layer of particles. The schematic solution involves the withdrawal of air from the top part of a greenhouse, which ensures feeding the airflow into the channel at maximum temperature. Thus, both rubble heating in the channel and the reduction of air temperature in a greenhouse take place, which protects plants from overheating. The proposed scheme (Fig. 2) provides direct contact between the air and the heat accumulating material. In this case, there is no need for an intermediate heat carrier and there is no additional thermal resistance. In addition, the use of granular material ensures a developed heat exchange surface. All this contributes to the efficient flow of heat exchange processes.

The developed procedure makes it possible to carry out thermal design calculations of the soil regenerator. Calculations allow determining the length of the regenerator channels, their number and weight of loaded material, as well as the duration of its effective operation at night for the assigned dimensions of a greenhouse and climatic conditions. The procedure was tested on a greenhouse with an area of 18 m^2, located in the warm continental climate zone, for April as the basic month for calculations. The method is based on empirical formula (2) to determine the intercomponent heat exchange factor. Calculations showed that the soil generator with 5 channels of square cross-section with the side of 0.4 m must have a length of 5.75 m, which allows placing it along the length of a greenhouse. The weight of rubble makes up 1,265 kg. The amount of accumulated heat Q_J=46.68 MJ enables maintaining the temperature in a greenhouse at the level not lower than 16 °C for 2.6 hours at the temperature of the environment of 7 °C. At the higher temperatures of the environment, the duration of regenerator operation in the cooling period will be increased until full compensation of heat losses.

The limitation of calculations is that they are of an estimating nature, as the cooling and heating processes in a greenhouse, ambient air, and the layer of material occur in non-stationary modes. The non-stationarity of the processes is taken into consideration by the introduction of average by period air temperatures and granular material. To clarify the procedure, it is possible to include dependences for the calculation of the non-stationary process of heating and cooling separate particles in a layer. This is possible with the use of particles of the classical shape, for example, a ball shape.

7. Conclusions

1. The formula for the calculation of the average factor of heat output from the airflow to a dense layer of granular materials, claydite, and rubble, was established experimentally. The formula makes it possible to calculate α_{av} at a given moment of time during heat exchange between the gas medium and granular material in the channel. For calculations, it is necessary to assign gas flow rate G_g and the weight of the load of granular material m. The formula is true with the margin of error of 12.5 % at the gas temperature at the inlet to the device $t'_g = 30-50\,°C$, consumption G_g=0.010–0.06 kg/s.

2. The procedure for calculating the regenerator for the period of excess air heat accumulation in a greenhouse in the daytime was developed. The procedure is meant to carry out thermal design calculations of the soil regenerator. Calculations make it possible to determine the length of the regenerator channels, their number, and the weight of loaded material, as well as the duration of its effective operation at night, for the specified greenhouse dimensions and climatic conditions.

3. The heat design calculations of the regenerator with the channels of square cross-sections, filled with rubble with equivalent dimensions of particles of 3.5 cm, was performed. It was found that at the average heat flow in day time Q_c=2,160 W, airflow rate in one channel G_g=0.066, kg/s, air filtration rate w_f=0.34, m/s, average intercomponent heat exchange factor α_{av}=17 W/(m^{2}K), length of the channel L=5.75 m. The amount of heat accumulated by a layer of rubble is Q_J=46.68 MJ. For the considered greenhouse with the area of heat transfer surface, F=70.4 m^2 at an average temperature of the environment at night t_1=7 °C and the average temperature on the greenhouse surface t_2=16 °C, accumulated heat can be consumed not less than for τ_n=9209 s. At an increase in the temperature of the environment during the regenerator operation, the duration of the regenerator operation will increase.

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