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THERMAL EFFICIENCY OF A COMBINED CRADLE-CONVEYER TYPE OF SOLAR-FUEL DRYING INSTALLATION

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Abstract. *In this study, a thermal efficiency of drying chamber of combined cradle-conveyor type solar-fuel drying installation heated by the direct passing of solar radiation and an additional source of heat (an electric heating coil) has been investigated and estimated. According to the obtained results, the main growth of thermal efficiency falls on 25 to 250 m3/h range of volumetric rate of agent flow (fan’s performance). A growth of the thermal efficiency has been increased up to 3.9 times at the average during a rising of volumetric rate of agent flow from 25 to 250 m3/h and air flow temperature from 40 to 60˚C. At the temperatures the further growths of volumetric rate of agent flow have not produced a significant increasing of thermal efficiency of the solar-fuel drying chamber. Therefore, an optimal volumetric rate of agent flow for the combined cradle-conveyor type solar-fuel drying chamber has been studied and estimated to increase an energy efficiency of the dryer.*

Key words: combined solar-fuel dryer; solar air collector; cradle-conveyor type drying chamber.

INTRODUCTION

One of the basic ways of processing of agricultural products is drying, however, it is considered as an energy-intensive process. In turn, it requires a development of energy-efficiency technologies. The main problem of drying processes is in their energy-intensity, which consists 20% of total fuel and energy balances of agricultural sector [1]. According to the design, the intent dryers for a drying of agricultural products are divided to fuel and solar. Each of them has its advantages and disadvantages. The advantages of fuel dryers are: high performance and transfer possibility into an industry.

In the turn, their disadvantages are: the existing machineries for an artificial drying are very energy-intensive and unproductive for the fruits and vegetables, which grown in Uzbekistan, so that they differ with the high sugar content and solids [1-2]. In the conditions of Uzbekistan, the using of solar drying systems is the most perspective in order to solve the problem. The advantages of solar drying systems are: firstly, the fuel and energy resources saving and an enhancement of ecological compatibility of production; secondly, the season of ripening and processing of agricultural products coincide with the period of most gain of solar radiation; To disadvantages of solar drying systems might be referred: development of individual farm and autonomous facilities for processing the products requires an autonomy of energy source; depending on weather conditions, the high duration of drying process and reducing of system efficiency at absence of solar insolation (at night time and rainy days) [2]. In connection of solution for the above indicated disadvantages of solar drying systems, it is tasking on developing the combined fuel and solar drying systems. High solar insolation is typical for the south regions of Uzbekistan where it is reasonable to use the combined solar and fuel dryers. The investigations have proved against possibility of integration of artificial and natural drying by creating the combined (by energy) solar and fuel systems which can solve the problem of using the efficiency increasing of generated solar energy and waste heat that allowing to develop the energy-effective technologies and technical facilities for the drying.

The hybrid solar dryers combine the features of a solar energy with a conventional or some auxiliary source of energy and can be operated either in combination or in single mode with either source of energy. These dryers generally are medium to large installations operating in the range of 50-60%, and compensate the temperature fluctuations induced by the climatic uncertainties [3]. Bena and Fuller (2002) described a direct-type natural convection solar dryer combined with a simple biomass burner suitable for drying fruits and vegetables in regions without electricity [4].

The ambient air flows through a heat exchanger where it is heated to the desired temperature, by combustion gas. Part of the used air is exhausted from the north wall of the dryer and the rest is recycled through the recycling tube and the cooled gas exits through the chimney to the ambient (Condori et al., 2001) [5]. Amer et al. (2011) has recently designed and evaluated a hybrid solar dryer for drying of banana, consisting of a heat exchanger and heat storage facility [6].

PROBLEM INVESTIGATED

Based on the theoretical and experimental investigations the authors have proposed a vertical cradle-conveyer type

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combined solar and fuel drying installation is operated in closed movement mode (see Fig 1). The task of researchers includes the carry out the heat engineering calculation for the dryer, taking into account the heat-accumulating surface which leads to determination of additional energy quantity due to solar energy that is generated in an air interlayer is formed between the transparent cover and blacken surface of drying chamber.

PROPOSED MODEL DESCRIPTION OF THE SYSTEM

The drying installation consists of a vertical installed closed metallic chamber (1), O-shaped frame which has a rectangular cross section is installed on hauling chain (2) of loading mesh basket (3), transmission (4), loading-unloading hatch with a door (5), a branch pipe (6) for suction of waste drying agent, an electric heating coil (7), fan (8) and circular regenerator (9). The branch pipe is interconnected with a collector (10) with an exhaust bell-shaped of regenerator (9) (fig 1.).

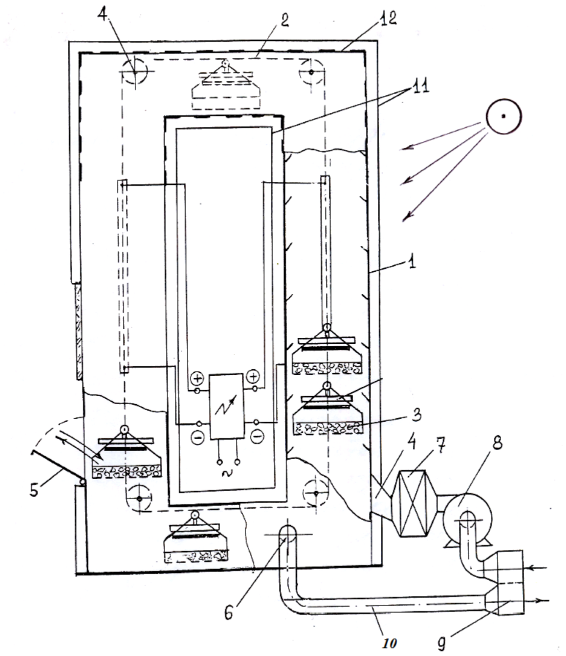

Fig. 1. *Principle scheme of vertical cradle-conveyer type solar-fuel drying installation*

A transparent layer (11) has been covered with a gap 50 mm over the drying chamber formatting the circuit of drying agent recirculation. The leak channels (12) are provided upon the top part of the chamber. The case frame made of angle 50×50×5 mm, and a covering is made of iron sheets with 1.2 mm thickness and the sheets have been processed with “black nickel” which absorptivity is 0.89-0.94.

OPERATING MODE OF THE UNIT

The dryer operates in the following way: at discretely-intermitted movement of hauling chain (2) along the closed circuit of the chamber (1) and by approaching of the mesh baskets (3) to the loading hatch (5), the dryable products are loaded or unloaded by turn. By loading or unloading all baskets and closing the door of the hatch (5), the transmission (4) will be switched on for an operating mode. At the same time, the fan (8), the electric heating coil (7) and the regenerator (9) also will be switched on to operating mode. The flowed hot air with temperature 60÷90˚C blows the laying products on the mesh baskets (3) where the heat and mass exchange occurs between the products and heat-transfer (drying) agent.

The saturated air by evaporating moisture comes to recirculating circuit, via the leak channels (12) are formed between the chamber (1) and transparent cover (11). The passed drying agent via the closed recirculating circuit additionally is heated by surrounding the blacken surface of chamber which carries out the role of heat-absorbing panels. The outlet temperature of drying agent in the recirculating circuit was 36÷40˚C at average when solar insolation has not been able. However, when the dryer was exposed by solar insolation, then the outlet temperature of the drying agent at the recirculating circuit has been increased up to 56÷60˚C. Therefore, the additionally heated drying agent by solar energy at outlet comes to the regenerator (9) to heat up a new air flow portion is in hausted by the fan (8). Finally, the additionally heated new air flow portion by waste energy will be heated up to the requirement temperature by the electric heating coil (7).

MATHEMATICAL DESCRIPTION

The heat gain occurs on a heat exchanging surface from two sides: as results of absorbing of passed solar energy through the transparent cover and the heat transfer through the wall of solar drying chamber due to the drying agent.

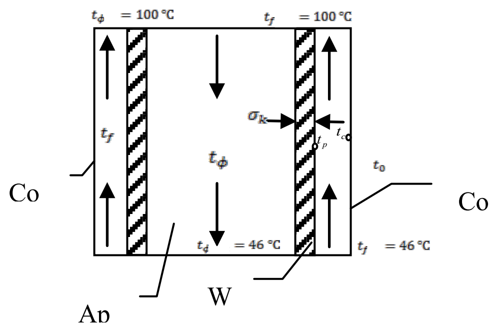

Fig.2. *A principal scheme of thermal balance components of solar collector*

According to [1], an equation for useful energy flow has the following form:

$$q_{uf} = \alpha_{\rho}\left(t_p - t_f\right) + \alpha_c\left(t_c - t_f\right) \qquad (1)$$

Besides the quantity of absorbed radiant energy by surface of drying chamber and the received heat by convection of drying agent is expressed as following

$$q_{ab} + K_{\phi}\left(t_{\phi} - t_p\right) = \alpha_{\rho}\left(t_p - t_f\right) + \alpha_r\left(t_p - t_c\right) \qquad (2)$$

The volume of K_{ϕ} is determined from the condition of equality of heat flows onto the conjugated surfaces, i.e.

$$K_{\phi} = \alpha_{\phi}\left(1 + \alpha_{\phi}\frac{\lambda_k}{\delta_k}\right)^{-1} \qquad (3)$$

The received heat by internal surface of transparent cover is transferred to drying agent and partially is loss to environment

$$\alpha_r\left(t_p - t_c\right) = \alpha_k\left(t_c - t_f\right) + \alpha_o\left(t_c - t_0\right) \qquad (4)$$

To represent the flow density of useful energy in the form of functions are depending on α_o, α_ρ, α_c, K_ϕ, t_ϕ, t_f, and t_0 it is necessary to eliminate the temperatures of heat receiver's surface (t_p) and transparent cover (t_c) from the equations (1), (3) and (4).
According to the combined solving (2), (4) and (1), after some algebraic conversions, it is obtained

$$q_{uf} = \eta_{te}\left[q_{ab} + K_\phi\left(t_\phi - t_f\right) - K_l\left(t_f - t_0\right)\right] \quad (5)$$

In the absence thereof solar radiation or at night operating mode of solar dryer, the equation (5) takes the following form

$$q_{uf} = \eta_{te}\left[K_\phi\left(t_\phi - t_f\right) - K_l\left(t_f - t_0\right)\right] \quad (6)$$

It is followed from the equation (5) that an economy of traditional energy source (electrical or steam heating of drying agent) depends on thermal efficiency of ventilated air interlayer (solar collector), which by turn depends on the velocity v_f and temperature t_f of waste heat-transfer agent that is circulated in the interlayer. The velocity of waste heat-transfer agent is defined by $v_f = \frac{L}{S}$, where, L – volumetric rate of agent flow (fan's performance); S – an area of circular gap around the chamber section. By expressing S via an equivalent diameter $d_{eq} = \frac{4S}{P}$, one can to determine the movement mode of heat-transfer agent.

Nusselt's number is acceptably for $1/d_{eq} > 50$

$$Nu = 0.21\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.43} \quad (7)$$

Taking into account the dependence of λ_k, v_f and Pr_f, on t_f, criterion equation (7) might be transformed into the form:

$$\alpha_k = A_f \cdot L^{0.8} \quad (8)$$

It has been experimentally determined that at various velocities of agent flow by increasing of its temperature from 40˚C to 60˚C, A_f became 0.0876. At same time, $K_\phi = 11.75\frac{W}{m^2 \cdot °C}$, $\alpha_r = 1.97\frac{W}{m^2 \cdot °C}$, $\alpha_o = 9.44\frac{W}{m^2 \cdot °C}$, and the equation for thermal efficiency of solar air collector takes the following form

$$\eta_{te} = \left\{1 + \frac{152.7 + 1.5\left(1 - 0.0019t_f\right)L^{0.8}}{\left[1.7 + 1.5\left(1 - 0.0019t_f\right)L^{0.8}\right]\left(1 - 0.0019t_f\right)L^{0.8}}\right\}^{-1} \quad (9)$$

RESULTS AND DISCUSSION

The obtained results of $\eta_{te} = f(L)$ dependence at $t_f = 40°C$, $50°C$ and $60°C$ are shown on fig. 3.

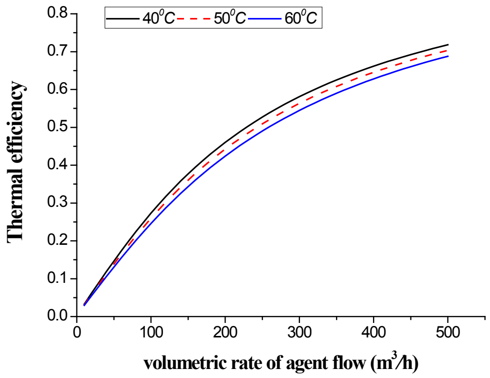

Fig. 3. *The dependence of thermal efficiency of $\eta_{te} = f(L)$ on L – volumetric rate of agent flow*

It is seen that, the main growth of thermal efficiency falls on 25 to 250 m^3/h range of volumetric rate of agent flow. A growth of the thermal efficiency has been increased up to 3.9 times at the average during a rising of volumetric rate of agent flow from 25 to 250 m3/h and air flow temperature from 40 to 60˚C. At the temperatures, the further growths of volumetric rate of agent flow have not produced a significant increasing of thermal efficiency of the solar-fuel drying chamber.

CONCLUSION

Based on the theoretical and experimental investigations the authors have proposed a vertical cradle-conveyer type combined solar and fuel drying installation is operated in closed movement mode. The task of researchers is to carry out the heat engineering calculation for the dryer, taking into account the heat-accumulating surface which leads to determination of additional energy quantity due to solar energy that is generated in an air interlayer is formed between the transparent cover and blacken surface of drying chamber. The thermal efficiency of drying chamber of combined cradle-conveyor type solar-fuel drying installation heated by the direct passing of solar radiation and an additional source of heat (an electric heating coil) has been investigated and estimated.

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