APPLICATION OF HEAT PIPES FOR BREAD BAKING AND GRAIN DRYING HEAT TECHNOLOGIES PERFECTING

* S. Gajda
** A.V. Zykov, O.G. Burdo

*Opole University, Opole Poland
**Odessa State Academy of Food Technologies , Odessa Ukraine

Abstract

In the report the outcomes of researches directed on a complex solution of ecological and energy-saving problems in bread baking and grain drying are represented. Effective way of a complex solution of ecological and energy-saving problems in bread baking and grain drying is the use of heat pipes (HP) in technologies. The expediency of such path of HP using is reasonable with the help of hierarchical model of transformation, transportation, losses and use of energy in baking furnaces and drying installations. The advantages HP in the traditional schemes of heat utilization are shown. On a basis of HP the scheme of in essence new devices designed. In the report the generalization of experimental data on a mechanics of a flow and heat exchange between a dense gravitational grain stratum and a HP surface, conducted in view of a flow velocity, diameter and arrangement of the HP is represented. The laminary grain preheater with HP and HP heat utilizator are practically tested on grain dryer DSP-32OT. In an outcome of a complex of analytical and experimental works, the high efficiency HP in heat technologies of bread baking and grain drying is proved.

KEYWORDS

Unused potency, heat utilization, bread baking, grain drying, heat losses, laminary preheater.

INTRODUCTION.

The problem of efficient energy using is one of major problems of Ukrainian industries. Even such branches of agroindustrial area as bread baking and grain drying is not exception. These branches have priority significance, as associated with bread, which is a main product of feed.

The basic customer of energy in bread baking is furnace, the most of which are continuous conveyor or tunnel type oven. It is considered, that the basic potential energy-saving consists in baking furnaces, and the recuperation of outgoing gases overflow heat can serve for a preheating of an article and air for combustion process, or for heating. The analysis of world grain drying practice displays, that 10% of all power inputs are necessary for a ventilators drive, and remaining 90% for drying. The thermal energy is spent so: 40% of it is expended on moisture evaporation, 10%-on grain heating, 20%-on heating of air and water vapors up to drying agent temperature, and 30% of heat is lost in an environment. A preheating of a grain before drying intensifies process in shaft dryers [1]. They consider the basic reserve of energy consumption lowering during grain drying is contained in a rational mode of a heat carrier recirculation [2,3]. Drying of all food articles intended for feeding is realized by preheated air. The exception is grain drying, where the drying agent is the mixture of furnace gases and air. The direct contact of combustion products to a grain impairs its quality concerning probable infiltration carcinogenic components into a product. The considerable reduction of fuel consumption in existing furnaces can be achieved, by using warm of combustion products in heat utilizators and it utilization for heating of outside cold air arriving on blast at a furnace and on heat in mixing chamber. However, for generation of the ecologically pure drying agent it is necessary to realize complete separation of high-temperature combustion products with a stream of outside pure air.

Effective way of a complex solution of the designated problems is use of thermal pipes in technologies.

THE METHODOLOGY OF ENERGY SAVING

In order to substantiate the common principles and estimate criterions of energy techniques and directions of their perfecting the concept "a energy-saving potential" (P) is used. The P is a difference between an actual power inputs level J_f and its idealized analog J_i. The total reserve of an economy (R) represents a difference between energy consumption on the base and perspective level. At transition from one technique to other the reserve of an energy saving both at time of substitution (τ_0), and at a perspective level (τ_1) is determined.

$$R_\tau = P_\tau - P_{\tau+\Delta\tau} = \left(\sum J\right)_\tau - \left(\sum J\right)_{\tau+\Delta\tau} \tag{1}$$

For the analysis of effectiveness of the multilevel schemes of energy transmission and transformations are offered transformation ratios of heat carrier consumption and its heat content: $(\psi_m ; \psi_i)$. The common energy effectiveness of the scheme consisting from n levels, will be defined by a ratio of total thermal losses to a fuel energy E_T:

$$\varepsilon = 1 - \frac{\sum_i^n Q_i}{E_T} = \prod_{i=1}^{n} \prod_{i=1}^{2} \psi_{ij} ; \quad \psi_m = \frac{M_i}{M_{i-1}} ; \; \psi_i = \frac{C_{P_i} t_i}{C_{P_{i-1}} t_{i-1}} . \tag{2}$$

The concept "the unused power" N_C is introduced. It is necessary to consider losses of the single-level scheme as limiting value N^τ_C. . If at a moment τ_1, the technique has N^1_C, and advanced corporations technique N^n_C it is possible to achieve a value N^n_C fast enough using their experience. More long-lived will be a path of lowering N^n_C up to a technically accessible level N^r_C requiring original engineering concepts. It is so-called pyramid law [4].

The convective dryer is represented by four levels of energy transformation (fig. 1). At the first level (furnace device) the energy of fuel is transformed to an energy of gases (E_g) in view of the relevant losses at combustion Q_1. At the second level in steam generator get a vapor (E_v) in view of losses with flue gases Q_2. Partially it is possible to return these losses in air-heater (q2). In heater, energy of the drying agent is E_A. The losses with a condensate Q3 are reduced at its recovery (q4) in steam generator. 40 % from E_A is spent for evaporation of a from a grain, 10 % - on grain heating, 20 % - on heating of water and air, and 30 % is lost in a environment (Q4). The preheating of air in heat utilizer (q4) reduces losses with the exhaust drying agent. From an available energy of fuel (40 ° MJ/kg) drying agent is delivered 0.15 MJ/kg. 7…8 MJ is spent for evaporation of a moisture. During grain drying by furnace gases, the scheme becomes three-level, and the specific energy input is reduced up to five MJ/kg of evaporated moisture. However, this is reached at the expense of reducing ecological safety of technique. For the baking furnace, it is possible to allocate two levels of transformation. The energy technologies perfecting is associated with reducing of losses Q_1,Q_2,Q_3,Q_4 and with a diminution of number of levels.

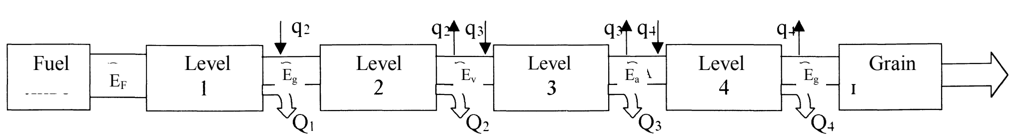

Fig. 1. The hierarchical model of energy transformation in grain dryer

ENGINEERING SOLUTIONS

Blast air preheater on heat pipes

The outgoing gases temperature span in baking furnaces is 150-360°C, and their flow is 0,02... 0,075 $м^3$/sec, that allows to utilize them for blast air preheating. It is propose the scheme of salvaging of heat of gases, leaving the baking furnace, with use of a heat exchanger on heat pipes. The blast air preheating from environment temperature t_C up to temperature t_r is realized at the expense of cooling the used heat carrier from temperature t^1_y up to t_y. Advantage of this type recuperator is the high heat transfer coefficient, low aerodynamic drag and ease clearing from dust deposits.

The steam boiler – oven gases utilizer on the basis of a HP heat transfer system

The temperature potential of outgoing oven gases is sufficient to generate steam by pressure 0,15...0,3 MPa. These parameters obey necessities of dough blanks humidifying technique. It is represented, that the perspective scheme will be a one of effective heat transfer from oven gases to boiling water establishing based on HP. Under the scheme, oven gases in duct wash evaporative sites of a bundle of HP. The condensation sites of the HP are located in water volume of the boiler. The flue gases is cooled, and the formed steam arrives in the baking furnace for humidifying an air quality and on other technological needs. Thus, the problems of ecology are solved (the thermal pollution of the environmental is reduced) and the plant necessity in steam is obeyed. Necessity for operation of boiler-house at the plant disappears.

HP utilizer of the used drying agent heat

Temperature of the drying agent, used in heating zones reaches 50... 75°C in different constructions. It is in essence possible to use this energy for heating of fresh air arriving in heat plant. The scheme of grain drying installation is proposed. On shaft dryers, the settling vessels are erected on all height of the shaft. Its upper windows are connected by flue to the hot heat carrier chamber of the heat utilizer. In the hot heat carrier cabinet, the bundle of evaporative sites of HP is located. The condensation sites of the HP through a tube plate are introduced in the chamber of the cold heat carrier. Here the fresh air is heated and moved in mixing chamber. Consequently, the consumption of fuel should be reduced. The ecological problems are at the same time solved: The degree of environmental by thermal effluents is reduced, partially, besides the gas ejections is dried in the hot streams chamber.

HP heat-generator of the ecologically pure drying agent

The development of the previous scheme is possible in a direction of a heightening of grain drying ecological safety. It is represented that with the help of HP it is possible to realize an effective transfer of heat from combustion products to air without their blending. In this case combustion products transit through a bundle of evaporative sites of the HP, and outside (or beforehand preheated in utilizer) air washes condensation sites of the HP. The separation of streams of combustion products and drying agent protects a grain from carcinogenic contamination in drying process. At that a world experimental performance of HP heat exchangers of a system "gas – air" allows to calculate on high heat engineering parameters of such heater.

The laminary grain preheater on the basis of HP

In essence, such devices represent by itself the cylindrical shafts with longitudinal flow of condensation sites of HP by a gravitation propellented grain layer. The evaporative sites are warmed with combustion products. The advantage of such scheme that is eliminated the intermediate heat carrier - air. More simple design is the scheme with rectangular shaft. One side-wall of shaft bounds with flue. In the scheme, the transversal flow of condensation sites of the HP by a layer promotes effective intermixing of a grain.

The HP regenerator of heat of grain streams

It is known that with a hot grain 20 % of burned fuel energy is lost. It is approximately spent as much on grain preheating up to drying temperature. The regenerator of a grain layer heat is represent in [5]. With reference to existing grain dryers, in the grain preheating chamber install the condensation sites of the HP, and in the grain cooling chamber - evaporative sites of the HP. The energy of a hot stream is transmitted by means of the HP to a cold stream. Using in the HP the transport sites with different length allows at sequential driving of a layer from the heating chamber through the drying chamber into the cooling chamber to receive effect of the scheme with countercurrent streams driving. Therefore, the coldest grain in the heating chamber inlet is bound by a series of the HP to the coldest grain in the cooling chamber outlet. In addition, the most heated grain of the chamber is bound by a series of the HP to the hottest layer of a grain of the chamber.

The autonomous HP system of granary cooling

In a procuring system, the increasing urgency is acquired by problems of grain storage. The virtues of HP (self-sufficiency, possibility of heat flux transformation, low thermal resistance etc.) guess expediency of HP using in techniques of a grain storage. In this case evaporators of the HP are disposed in a grain mass of a silo, a granary. The condensation sites of the HP is taken out of granary walls. The heat flux from a grain mass with the help of the HP bundle is abstracted in environment. As the HP have one-sided conductance, the effective using of daily temperature variations for temperature stabilization in a grain mass is possible.

Rotation device for heat treatment of grain streams on the base of the two-phase heat-transfer module

Self-sufficiency of the HP, possibility of heat flux transformation and shapes variety prompts to sentences to allot the heat-transfer module by subfunctions. For example, it is to organize a heat transfer from a power source to a grain through the HP with the ramified condenser. In addition, the condenser shape is able to provide not only heat emission surface development, but also to ensure necessary mechanical effect on a grain stratum. For example, to intermix, to transport. The heat-transfer module gyration in a grain stratum promotes fissile effect on a boundary layer in a band of contact « the grain - condenser of the HP ». It loosens and intermixes a stratum that is equivalent to magnification of an interfacial area of phases at drying. The practical embodying of technique on the basis reduced above than sentences requires development of scientific and engineering bases of projection and optimization of installations.

THEORETICAL INVESTIGATION

Problem of a grain stratum stationary thermal conduction with a series of HP

The thermal state of a grain stratum can be presented with assumptions, that the axes of the HP are located in one plane with an identical pitch y_o, and height of the HP is much more than width of a stratum ($h>>\delta$). In such statement, the problem is reduced to a known problem for n infinite cylinders located in one plane in an unlimited plate. The solution of such problem is obtained by way of temperature resistance per unit of cylinder length. The heat flux, which is abstracted by the HP, is possible to calculate on a relation:

$$Q_{TC} = \Re^{-1} h\left[t_2(\tau.) - t_H(\tau.)\right]N \; ; \quad \Re_h \approx \frac{1}{4 y_0 \lambda.(w)}\left(\delta + \frac{2y_0}{\pi}\ln\frac{y_0}{2\pi.r_H}\right). \qquad (3)$$

Thus, it is considered, that for given interval of time τ the process is quasistationary, and the values t_2 and $t_и$ are known.

Two-component model of heat transmission in layer devices

For a moving dense stratum, the discrete binary system «air - grain» is considered which washes a series of the HP. For each component, the description of heat emission will be carried out as for a continuum. On the shaft axis, the representative mesh with volume Vя and cross-section area Fя containing N HP is chosen. The assumptions are accepted, that the temperature gradient on coordinate Z is much more, than in cut of the representative mesh, and saturation temperature of a vapor in the HP - are identical. The thermal properties of gas, air and grain are considered as stationary values. Then, on condensation sections of the HP for a grain stream it is valid:

$$G_3 c_{P3}\frac{dt_3}{dz} - \alpha_{B3}(t_B - t_3)F_{\text{Я}}\varepsilon_V = \frac{N}{V_{\text{Я}}}F_{\text{Я}}F_K(t_{\text{н}} - t_3)\left(\frac{1}{\alpha_3}+\frac{1}{\alpha_K}\right)^{-1}. \quad (4)$$

If $t_a \approx t_g$, the intercomponent heat exchange is negligible and relation (4) becomes simpler. It is similarly possible to note relation for air and for gas on evaporators of the HP. The intensity of heat emission at stratum driving at the HP surface is largely determined by the mechanism of a flow.

EXPERIMENTAL RESEARCHES

Mechanics of grain stratum driving at the HP surface

The experiences were conducted in rectangular shaft with walls from an organic glass. Height of shaft is 1m, breadth and depth is 150mm each. A research technique is visual, with the help «of the marked stratum». The construction of an exhaust shutter allowed fast «to cut off» a stratum and to register a position of grains «of the marked stratum». The patterns of a flow were studied and were photographed. In experiences, the average speed of flow and local value of a velocity in the cylinder cut was measured. The single pipes series and bundles were investigated. The stable stratum driving was watched at a flow of HP series under condition of $S_1 > 4d_e$. This requirement has defined minimum values S1 / D. Because of visual examinations of a flow mechanics it is established next. The patterns of a grain stratum front warpage like a parabola with vertex in a frontal point of a pipe (γ=0). The flow velocity exerts considerably smaller influence on the shape of this front, than diameter of a pipe. The character of a flow along a pipe by a grain stratum essentially differs from the scheme of a flow by an inviscid fluid stream (fig. 2, line 1). Contact angle of a grain with a pipe grows with magnification of a pipe diameter; the degree of a flow velocity local value deviation from an average value on unrolled cut of a pipe is identical to all diameters at γ=45° (fig. 2). With D increasing the non-uniformity of local flow velocities is augmented, and it is most essential at 45°<γ<315°.The relative band of a stream perturbation is reduced with D increasing. All this does not allow drawing a one-valued conclusion about quality character of average and local heat emission on pipes. The experimental researches in established range of D, S1 /D, S2/D are required.

Local heat emission of cylindrical pipes to a grain stream

A working section was the experimental model of the HP by the diameter is 33мм, manufactured from a tree. On a surface of the cylinder there was an aperture by a size 6x11мм, depth 15мм for the block of a heater. After reaching steady state, the grain temperature t_g, the heater surface temperature t_K, the heater power (heat flux) Q, average stratum velocity is registered.

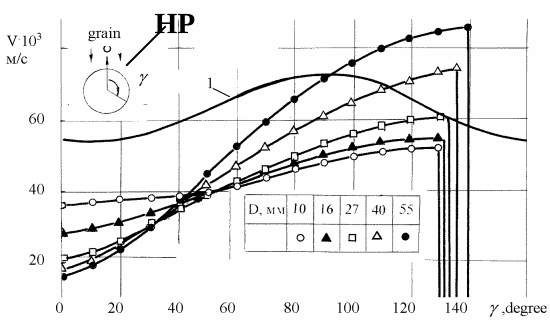

Fig. 2. Local values of a velocity of a grain stratum at a flow of a single pipe

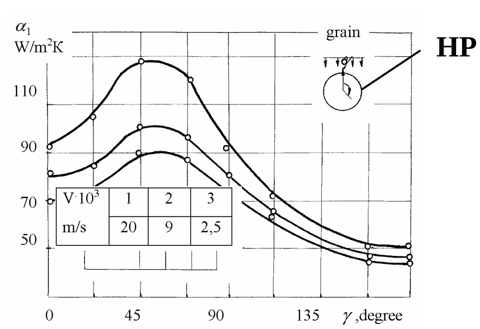

Fig. 3. Allocation of values of coefficients of heat emission on angular coordinate

The local heat emission at new angular coordinate was similarly defined by the calorimeter rotational displacement on 22,5°. The maximal heat emission is reached at angular coordinate 45... 60° (fig. 3). On sections of a surface with maximal values of local flow velocities (γ=120... 140°) the heat emission even is lower, than in a frontal point at γ=0. To explain it is possible by that, since γ> 60°, there is stratum rarefaction, parameter ρ (reduced density of a stratum) is reduced. In a stratum tear band (γ>130... 140°) the heat emission is carried out to air in general. At γ>150° values α stabilize and feebly depend on a velocity. It is interesting, that the maximal values of local heat emission grow with increasing V . An aberration of local from average values α is in limits ±30...50%. All dependencies of average values of single pipe heat emission coefficients on flow velocity for different pipes diameters have similar character. With average grain stream velocity increasing, the value average heat emission coefficient grows. It is explained by requirements of a flow along a pipe surface by the stream. On the one hand, the V increase leads to some stratum loosening, to r decreasing. It is the negative factor. On the other hand, the V increase leads to increasing of a band of stratum perturbation, i.e. to extra gyration, weevil migration. Such stream turbulization together with lowering of time of weevil contact with a pipe surface intensifies the heat emission. The influence of a pipe diameter is specific. At first, the increasing D is attended by increasing α. It is explained by decreasing of an angle of a flow separation band (fig. 2), i.e. the major pipe surface «works». However, having reached some maximum, α begins to be reduced. With increasing V, the values α_{max} are displaced in the side of major D. All this is bound to forming of hold-up spot in the frontal part of the pipe. With velocity increasing, the greater diameter for confinement of hold-up spot of a grain stratum is required. The value of a critical diameter appropriate to a point of inflection is obtained at generalization of experimental data: $D_{kp} = 1{,}21 - V^{0{,}05}$

At (D/d)<8, i.e. at a flow along the small diameter pipes, the lower half of the pipe surface practically does not adjoin to a grain stream. It was remarked on the patterns of a flow by a grain along the pipes by a diameter 10…16мм. The contribution of the lower half of cylinder to common heat exchange makes only 25 … 30 %. With increasing of a pipe diameter, the band of continuos flow grows, but the time of contact of particles with a surface grows also, the degree of a stratum turbulization is reduced. The degree of intensification of heat emission is defined by these (positive and negative) factors relation. The generalization of experimental data is conducted in the shape:

$$D < D_{kp} \quad Nu = 1{,}3\, Pe^{0{,}11} \left(D/d_3\right)^{0{,}93} \left(S_1 S_2 / D^2\right)^{-0{,}18}; \tag{5}$$

$$D \geq D_{kp} \quad Nu = 1{,}59\, Pe^{0{,}11} \left(D/d_3\right)^{0{,}6} \left(S_1 S_2 / D^2\right)^{-0{,}18}. \tag{6}$$

PRACTICAL RESULTS

Air-preheater

Air-preheater was tested in a condition of heat utilizer and as heater. In a condition of utilizer, the hot stream chamber was joined by flue to the upper windows of settling vessels of grain drying installation DSP-32-OT. Air from environment transited through the cold stream chamber was heated by means of heat pipes and arrived in heat aggregate. In a condition of heater the heat pipes were oriented vertically, the hot gas from heat aggregate washed evaporative sections of heat pipes, and in the cold stream chamber air was heated. By results of trials it is visible, that at flow of the heat carrier (6,4... 6,9) x 103 $м^3$/h, the aerodynamic drag of a recuperator makes 74... 85 Pa. By results of experiences, both the gas (V_g) and air (V_a) flow rates and air enthalpy on inlet and outlet of heater was determined. It allowed calculating a thermal loading of devices, which varied from 40 up to 510 kW. The heat transfer coefficient (K), treated to a smooth surface of heat pipes, made (40... 157) W/m^2K. In all ranges of temperature and heat demands, air-heater differed by high intensity of a heat transfer.

Block grain dryer with a layer recuperator on HP

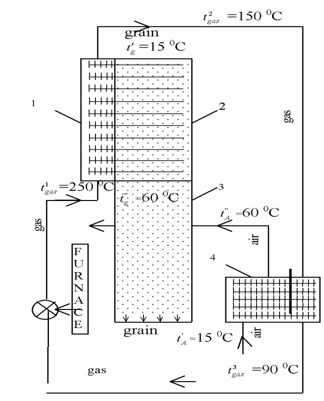

Fig. 4. The block grain dryer.

To eliminate direct contact of furnace gases to a grain and to create effective drying installation – is a problem, which should be solved for a heightening of grain quality. The grain dryer constructions with heat transfer from gases to a grain by means of HP deserve attentions in this connection. Such grain dryer scheme is submitted in a fig.4. The block grain dryer calculation was conducted under the standard program on computer. The estimation of intensity of heat emission of a bundle of HP to a grain stratum was conducted on the criteria equations, reduced above. The lowering of expenditure of fuel is reached by a deep recirculation of the heat carrier. The inappreciable amount of gas equal to air consumption, necessary for combustion will be rejected. I.e. the mass transformation ratio comes nearer to 1, therefore heightening of levels of transformation of an energy has not reduced in the overexpenditure of fuel. Thus, block grain dryer with a HP preheater of a grain ensures ecologically safe drying at simultaneous lowering of fuel expenditure on 20 %.

CONCLUSION

The realization of complex theoretical and experimental researches, computer simulation has allowed to develop scientific and technical fundamentals of a heightening of effectiveness of heat technologies of bread baking and grain drying. Use of system approach principles, modern tools of heat transfer architecture has enabled to find and to justify paths of modernizing operating and making the in essence new schemes of transformation and transmission of a thermal energy. It is shown that two-phase heat transfer system can decide the enumeration problems. The scientific-methodological, analytical, experimental outcomes are obtained which can be used at the further development of the energy-saving theory.

Nomenclature

$(\psi_m;\psi_i)$- transformation ratios of heat carrier consumption and heat content; ε-common energy effectiveness; E_T-fuel energy; Q-heat loses ratio, heat flow; q-returned heat loses; J-power inputs level; τ-time; R-economy reserve; P-unused energy potential; t_2, $t_и$-temperatures of grain and HP evaporator;λ-heat conductivity ratio; $\Re$-heat resistance; y_o, h-pitch, and height of the HP; N-number of HP; δ-stratum width; G_3-grain mass flow rate; c_{p3}-grain specific heat content; t_3, $t_в$-temperatures of grain and air; $F_я$, $V_я$- with Vя and cross-section area and volume of the representative mesh; F_K-area of condenser; α_3 α_K -heat transfer coefficients from grain and condenser; D, d_3-diameters of HP and weevil; D_{kp}-HP critical diameter; V-grain flow velocity; S_1,S_2-longitudial and transversal step of HP; Nu- Nusselt number; Pe- Pecle number.

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