OPTIMIZATION OF THE HEAT PIPES HEAT AND MASS RECOVERER

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Abstract

In the report, the problems of optimization of systems of a complex recovery of heat and dust from drying equipment vapor-dust-gas exhausts are considered. Key elements of such heatmassrecoverers (HMR) are the heat pipes (HP). In the HMR, the specificity of dryers aerosol exhausts is used. However, the designing and optimization of such devices exploitation conditions requires the new approaches at the calculation of the combined processes of aerodynamics and heatmasstransfer. The experimental simulation of the intensity of a masstransfer of a dust from a stream onto the HP surface is conducted. The asymptotic model of the dust layer forming based on the masstransfer limiting equilibrium hypothesis is proposed. The kinetics of interaction the dust layer and condensate is investigated. Based on computer experiment the optimization of a heatmassrecoverer with HP is conducted. The influence of HP length, sizes of HP evaporators and condensers, arrangement parameters on the technical and economic performances of the system is determined. The economical parameters of system are accepted as an objective function. The optimization is conducted for sugar and food concentrates productions. The results of calculations are compared to the industrial trials data.

KEYWORDS.

Heat pipes, heatmassrecovery, heatmasstransfer, drying equipment, thermalphysic model

INTRODUCTION.

Food technologies in Ukraine are characterized by significant expenses of energy and expenses of raw material and a ready product. Specific expenses of energy in agrarian and industrial complex in two…8 times exceed a level of the advanced firms of the advanced countries.

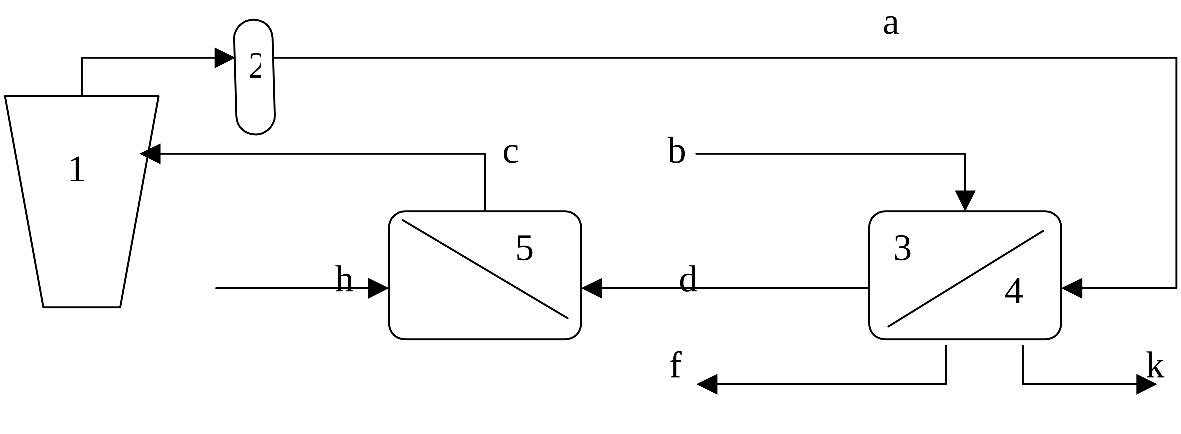

Fig. 1. The scheme of a complex recovery of heat and duct exhausting from a dryer.
1-a dryer, 2 - a cyclone, 3-HMR cooling section, 4-HMR heating section, 5 - air heater, a- exhausting heat-carrier, b - cool air, c - hot heat-carrier, d - hot air, f - product solution, h - energy-carrier, k - emission.

Expenses of raw material and a ready product except for economic have serious ecological consequences also [1]. To the greatest degree, it concerns furnaces and dryers of food manufactures. Therefore, with aerosol emissions of a dryer for a year it is lost from 6 up to 24 GJ of heat, from 4,5 up to 125 tons of a ready product (coffee, dry milk, sugar, etc.) [2]. This dust of a product does not allow using the traditional heat recovering devices with the advanced heat transfer surface. In OSAFT the system of complex recycling of heat and a foodstuff dust [2] is patented, which technical idea consists in the fulfilled drying agent specificity (water solubility of a dust and presence of vapor in a the heat-carrier stream) and unique features of modern modules for the organization of a heat transfer – heat pipes (HP) is used. It is offered to direct the aerosol vapor gas dust stream after dryers (fig. 1) in the heat pipes heatmassrecoverer (HPHMR).

The scheme (fig. 1) in a complex solves the problems of energy savings (recycling of heat of the fulfilled heat-carrier), resources savings (valuable foodstuff dust removals from an aerosol stream), ecological safety maintenance (dehydration, dust-removal and decrease of emissions temperature). However, designing and optimization of such devices operation modes demands new approaches to calculation of combined processes of aerodynamics and heat-mass transfer. In the OSAFT, the processes some its results make scientific bases of designing HMR [3-6] were consistently studied.

THE MODELLING OF COMBINED PROCESSES IN HMR.

The thermalphysic model.

The thermosiphon HMR acts as a filter, a wet scrubber, and a heat recoverer. The complex of the combined processes in HMR is explained by the scheme (fig. 2).

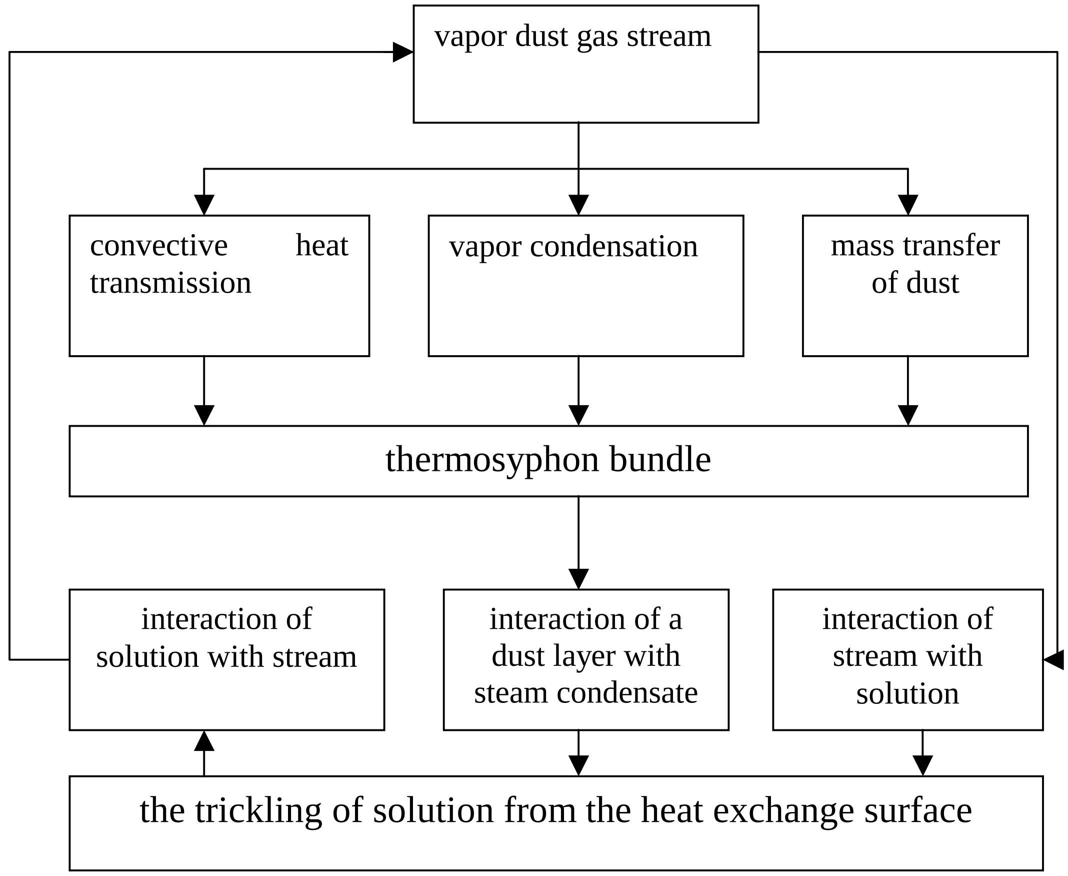

Fig.2. The combined processes in HMR

Let's consider how to model these processes in conditions of their combined passing.

Modeling of heat mass transfer processes on the HP surface.

The vapor dust gas stream ***a*** (fig. 1) when it flows finned surfaces of the HP evaporators which are located in HMR cooling section, initiates three processes. In the first, it is the convective heat transfer from the hot heat-carrier to the HP. In the second, it is the partial condensation of vapor from a stream on the HP surface if there are corresponding conditions. In the third, this is the sedimentation of the solid phase of fine-dyspersated product particles in the HP intercostal space. A level of these processes understanding is different.

It is possible to consider that the heat emission process the heat-carrier cross-flow a bunch of finned pipes are investigated enough. Therefore, according to the A. A. Zhukauskas's recommendations for staggered pipes with individual spiral rolling fins the criterion equation for calculation of the Nusselt number at a turbulent flow mode looks like:

$$\mathrm{Nu} = 0{,}0081(s_1/s_2)^{0,2}(s/d)^{0,18}(h/d)^{-0,14}\,\mathrm{Re}^{0,8}\,\mathrm{Pr}^{0,4} \qquad (1)$$

where: S_1 and S_2 pitch between HP rows, accordingly cross and long pitch, s and h- accordingly, a pitch between fins and their height, d - the HP diameter.

When the conditions for partial condensation of vapor from a heat carrier are made on the HP surface, the additional heat transfer due to the phase transformation is evaluated by the effective heat-transfer coefficient [7]:

$$\frac{\alpha.\textit{эф}}{\alpha} = 1 + \frac{1{,}11 r\varepsilon\left[\varphi.P_S(t_\Gamma) - P_S(t_P)\right] + \left[P_S(t_\Gamma) - P_S(t_0)\right]}{R_0 T_{\Gamma.}\rho._\Gamma Cp_\Gamma\left[1 + E(\varepsilon. - 1)\right](t_\Gamma - t_0)} \qquad (2)$$

The second item in the equation (2) is the correction for humid heat exchange and it shows the increase of $\alpha_{E\Phi}$ relative to the "dry" convective heat exchange. That is why this correction numerator involves the quantities characterizing heat exchange at the partial condensation of vapor (latent heat ***r*** and difference of the partial pressure of vapor, according to temperatures of stream t_Γ, of fins t_P and of the HP base t_0.). The correction denominator involves air enthalpy difference that characterizes the "dry" heat exchange. The correction dimensionless is got by dividing on R_0, T_Γ, ρ_Γ. In the ideal gas approximation, this quotient represents the air pressure at tube space.

Challenge is definition of mass transfer intensity from an aerosol stream on a surface of the HP. The model of a hard deposits layer formation was based on a hypothesis of final balance of the mass transfer ***m***, in other words of the ***m*** proportionality to the process speed factor ***k***, to the product particles concentration in a stream ***c***, to the accumulating stream speed ***w***, to the reserve of weight of subsidence on surface Δm and to the operation term τ. And, Δm that is defined as a difference of final weight of subsidence m_∞ and weights of a subsidence drank ***m*** during moment τ/5/:

$$dm = k\,c\,w\,(m_\infty - m)\,d\tau$$

For conditions of a soluble coffee production technique the law of growth of an average thickness of a pollution layer is received:

$$\delta = 0{,}63\times10^{-2}\,[1 - \exp(-75\times10^{-4}\,\tau)] \qquad (3)$$

Three-zoned model of interaction of a dust layer with a condensate.

The dust of sugar, coffee, dry milk, etc. is well dissolved by water, therefore, in conditions of the partial condensation the saturation of a pollution layer by a condensate will pass. The model of such process is provided as three-zoned [5,7]. In the first zone (consolidation), there is an expansion of the area of spots of contact “a material - a HP surface”, an increase of the adhesive - cohesive forces. On border of the first and second zones the maximal adhesive forces value is reached. The second zone (relaxations) passes in third one (fluidity). The model is confirmed experimentally, the adhesive forces quantitative dependences of the dust moisture content are received [7]. Thickness of a film on a surface in the third zone is defined by action of combined forces of stream inertia, adhesion ***(Pa)*** and a superficial tension **(σ)**.

Processing of experimental data is executed as the criterial equations

$$\Omega = A\,(We)^{n}\,(P)^{m} \tag{5}$$

From $\Omega = \rho gRn/\sigma$ the thickness of a film is calculated as a difference of radiuses of a film ***(Rn)*** and the HP ***(Rm)*** depending on the Weber number ***(We)*** and dimensionless complex $P=PaRm/\sigma$, which shows a ratio of adhesion forces and superficial tension forces.

For different kinds of products, constants of the equation (5) are resulted in the table 1 [7].

Table 1

Constants of the equation (5)

Product	A	n	m
Starch	4×10^{-4}	–0,06	2,89
Sugar	32×10^{-3}	–0,11	0,87
Coffee	31×10^{-4}	–0,15	1,16

Intercomponental mass exchange in the HMR inter-row space.

The interaction of a condensate flowing down from the HP with an aerosol stream is a difficult problem for modeling /6,8/. Actually, it is necessary to define the result of heat mass exchange processes between a vapor dust gas stream and the solution drops reacting with water-soluble particles of a product dust. The mass exchange intensity is characterized by set of 11 parameters. There are stream parameters: speed w, viscosity μ, density ρ, diameter of particles d_T and concentration C_T and condensate drops parameters: their diameter d_K, density ρ_K and concentration C_K in tube space volume. Besides mass exchanged factors: mass output β both diffusions D and a gravitational constant g are taken into account among them. It is possible using the theory of similarity (the π - theorem, a method of the analysis of dimensions) and some simplifications to receive the criterial equation connecting characteristic parameters:

$$\mathbf{St = 3{,}16{*}10^{-16}\,(Pe_{Д})^{3{,}32}\,(C)^{2{,}5}\,(B)^{1{,}2}} \tag{6}$$

Diffusion Pecle number ($Pe_Д = vd_T/D$) is responsible for the diffusive boundary layer formation, and Reynolds number (Re) characterizes a hydrodynamical situation in HMR. The parametrical complex (C) shows a degree of a dust content of a stream, and (B) - a degree of irrigation.

Optimization of the heat mass recoverer in sugar manufacture.

The optimization calculations purpose is to define a thermosiphon heat mass recoverer layout that would provide the greatest profit (П), i.e. the maximal value of the functional (Ф) in a size of changing of regime parameters. In problems of optimization the following parameters are accepted as varied ones:

- the regime parameters of streams (charges, temperatures in hot heat-carrier and air inputs, moisture content and a dust content of the hot heat-carrier);
- the device configuration (thermosyphon number, number of rows, longitudinal and cross-section steps between the HP);
- the economic parameters (the price of the HP, the electric power, fuel, a product).

The conclusions about expediency of an analyzed variant of the heat mass recoverer layout are done based on its economic characteristics. Depending on cost of fuel, the electric power and a product, the rational combination of design data can vary.

The ratio for the analysis of heat mass recoverer systems efficiency can be presented as:

$$\mathbf{П = (И_1 - И_2) + 0{,}15\,(К_1 - К_2) = \Delta И - 0{,}15\,\Delta К} \tag{7}$$

Thus, ΔИ is a reduction (change) of costs, and ΔК - cost of HP, airways, a device case ($К_к$) and system assembling.

Reduction of costs due to economy of the energy carrier is defined depending on its kind.

The initial data of heat-transmitting modules (thermosyphons) remained identical in all variants of calculations and were in accord with parameters of tab. 2.

Table 2

Constructive and regime characteristics of the heat mass recoverer in a PSA line.

№	Parameter	Dimension	Designation	Value	
				min	max
1	Thermosyphon height	m	H	2	6
4	Number of thermosyphons	piece	N	100	12000
5	Number of thermosyphons rows	piece	n	6	25
11	Heat carrier rate	m^3/s	$V_Г$	9,3	9,2
12	Entrance temperature	^0C	$t_г'$	70	70
13	Concentration of a dust	kg/kg	$C_г$	276×10^{-6}	276×10^{-6}
14	Moisture content	kg/kg	$x_г$	0,0115	0,0115
15	Air consumption	m^3/s	V_X	9,2	9,2
16	Air temperature	^0C	$t_в'$	0	30

Cost of natural gas in calculations was 0.074 $/kg, the electric power – 0.034 $/kWh, a product – 0.34 $/kg, steam – 2.51 $/GJ, thermosyphon - 20 $/piece.

The computer experiment was carried out with the purpose of the analysis of influence of the basic device design data: thermosiphon lengths, sizes of longitudinal and cross-section steps, lengths of evaporation and condensation sites (i.e. a partition arrangement in the device) on functional value.

Variational optimization is carried out for the two meters long HP with equal values of evaporation and condensation sites, at $s_1 = s_2 = s_0$. Results of calculations are resulted on fig. 3,4.

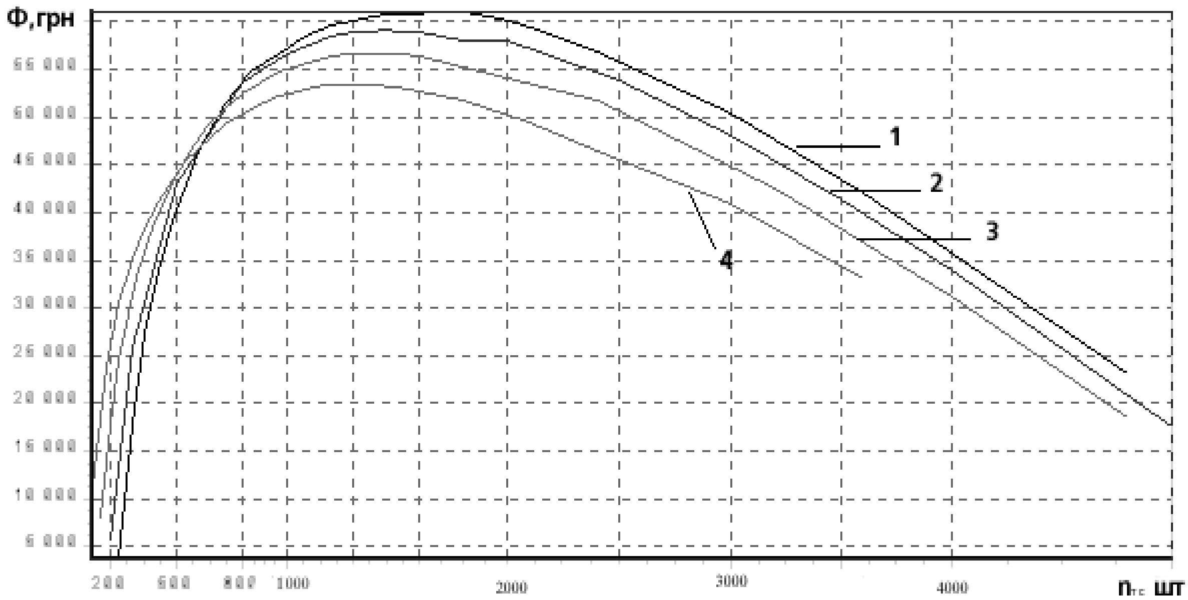

Fig. 3. The dependence of the functional from the number of pipes number of rows 1-12, 2-10, 3-8, 4-6.

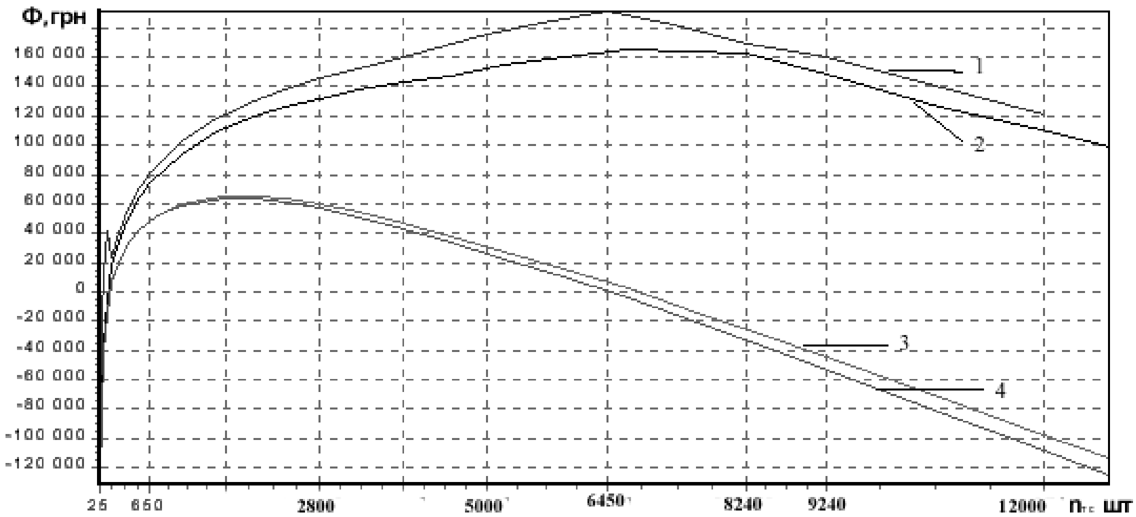

Fig. 4. The Dependence of the functional from the number of pipes
The period of cleaning: 1 - 5, 2 - 48 hours, 3 - 150, 4 - 300 days.

The analysis of the received results shows, that in the heat recovering system of press drying devices the greatest effect is reached in HMR, consisting of 1600 thermosyphons. Thus, the maximal effect (12 thousand USD.) corresponds to the configuration from 12 rows with 120 … 130 thermosyphons in a row. It is interesting, that with reduction of number of rows from 12 down to 6 the functional value is reduced on 10 %, and the number of HP providing a maximum functional has much greater range: 200 … 300 piece. However, limiting values of the functional (12.3 thousand USD.) it is possible to reach at 20 rows configuration with 80 HP per row.

The key parameters forming a functional size are the collected product dust and the utilized heat. The more number of HP the more product dust is taken from a stream. Under condition of the every shift device cleaning the linearity of dependence is kept up to value 6450 HP. The ceiling price of utilized during the year sugar makes 45.3 thousand USD. The price of utilized during the year heat grows, practically, linearly up to number of HP=1500 (functional reaches 18.9 … 20.8 thousand USD depending on a cleaning mode), and the further growth of number of HP up to 12000 piece, i.e. almost on the order, raises the functional up to 27.4 thousand USD (fig. 4). Hence, the heat recovery power efficiency is sharply reduced at number of HP is greater then 1500 piece.

Total action of the heat and dust recycling forms the functional size. The maximal functional value (35.8 thousand USD) is reached at the number of HP = 6450 and every shift cleaning, at the HP = 7000 the ***Ф*** = 30.6 thousand USD (every 48 hours cleaning).

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