BIOPRODUCTS DRYING OPTIMAL CONTROL IN OSCILLATING REGIMES

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Abstract: On the basis of the developed approaches and mathematical model (MM) of the bioactive products drying block is carried out the optimization problem of the equipment choice and its operation modes in view of deleted binary mixture an ethanol - water composition changes. The analysis of the problem with engaging of the Pontryagin's maximum principle has revealed optimal control structure. There is developed the automated control system of drying installation with firmware, based on modern microprocessor technique. The guidelines on an drying processes intensification, worked out on the basis of the internal and external interconnected heatmasstransfer research, and the process optimal control considerably raise productivity of drying aggregates, reduce fuel and power expenditures.

1 INTRODUCTION

Biotechnology is an effective production method of bioactive products. Drying as a final stage of the technological process plays an important role in the production, since the thermal and mechanical effects in the drying process affect the quality of the products.

Let's consider the drying process of irreplaceable aminoacids (α –forms) originated in the microbiology synthesis.

The experiments in (Yenikeev E.S., Ivanova E.N.) have discovered that vacuum-conductive and pseudo-liquefied drying methods don't enable in all cases to obtain the products of high quality as α-aminoacids (especially treonin) have high inclination to an agglomeration. There is the following explanation of the agglomeration of particles in the drying process. Binary liquid (ethanol-water 50 vol. %) is moving out of the material being dried. Ethanol as being more volatile component is moving out more quickly and, therefore, an abundance of water in the material is growing up.

As it is known from the technology of aminoacids (Gracheva I.M., 1980) they are crystallized in ethanol-water blend and are well dissolved in water. Therefore crystal's partial dilution and their adhesion take place in the drying process.

It has been shown in (Sadykov R.A., 1988) that the production problem of homogeneous dispersible or powdery product might be solved by vacuum-oscillating drying mode (Sadykov R.A., 1986, Sadykov R.A., 1988). This process is frequentative alternation of heating of the material in pseudo-liquefied layer, pressure impulse drop with subsequent vacuumization (material cooling by pressure dumping in drying chamber) and layer impulse jog by air supply. Material layer at jogging strikes on special destroying elements is divided finely and mixed up. Typical curves of the kinetic and the termogram of the drying process based on combined pressure drop and vacuum (CPDV) are shown in fig.1. (U - liquid specific mole contention).

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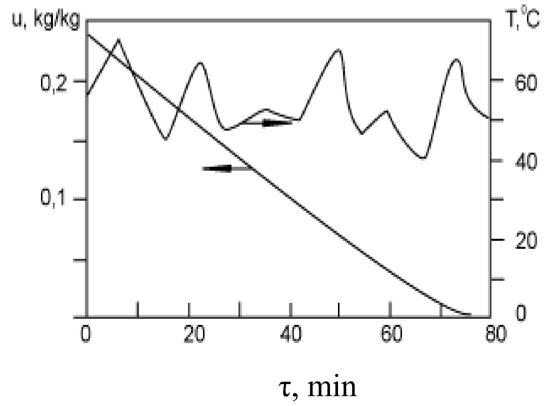

Figure 1: Kinetic 1 and termogram 2 of L-treonin (G=0,007 m3/s, T_h =86ºC, h=0,07 m, τ_h =8 min, τ_v =5 min)

To find out the dependence of τ_k - CPDV drying time aminoacids on some regime parameters it has been carried out the complete four-factor experiment (Ivanova E.N.). The following regressive formula has been derived:

τ_k= - 2007 + 8,616τ_h + 4,5τ_v + 88056G + 174,6h + 33,28τ_hh – 0,0075$\tau_h\tau_v$ – 782,76τ_hG,

where τ_k - kinetic time, s; τ_v - vacuumization time, s; G – heat carrier volume flow m^3/s ; h – layer thick, m; τ_h - heating time, s. It is worth to note that this formulation is reliable for some given regimes of the process only. It can not be used for formalization of the drying process in general and for its optimization.

The full theory of the drying process for moving off multicomponent (intersoluble partlysoluble and interinsoluble) liquid systems (Sadykov R.A., 1989, Sadykov R.A., 2004) is absent now and the development of adequate mathematical models (MM) of the process is quite actual. MM describes moving kinetic of every component in binary liquid blend (Sadykov R.A., 1985). The report is devoted to an optimization of such MM.

2 DRYING PROCESS OPTIMIZATION OF IRREPLACEABLE AMINOACIDS

During optimization of production process variants of technical performance are compared among themselves by reduced costs after CPDV optimization regime in every variant (Golubev L.G., 1978). The comparison was performed by criterion minimization of the drying stage contribution to cost price of product unit. It means profits maximization in view of fixed productivity.

The problem of optimization CPDV regime is to select M value and G(τ), T_{hc} (τ), z(τ) functions when $\tau \in [0, \tau_k]$ and z=0 in vacuumization stage, z=1 in heating.

$$I(\tau_k) = \frac{1}{M}\int_0^{\tau_k}\{z[\beta_0 + G\beta_a + G(T_{hc} - T_{at})\beta_T] + (1-z)(\beta_0+\beta_V)\}d\tau, \quad (1)$$

M – dry aminoacid mole number; T_{hc} – heat carrier temperature at a layer input; T_{at} – ambient air temperature; β_0 - characterizes expenses independent on regime; β_a - sterile air 1 m^3 cost β_T - cost of heating 1 m^3 air up to 1 K; β_V - cost of vacuumization pump work in unit time. It is necessary to keep conditions which ensure product none overheating, sufficiently low finite humidity, pseudoliquified regime in heating and none asportation aminoacids with heat carrier.

$$T_{at} \le T_h \le T_{h\,max},\ T \le T_{max},\ U(\tau_k) \le U_k,$$

$$M_{min} \le M \le M_{max},\ G \le G_{max}$$

The detailed consideration (1) with taking into account equations system of CPDV drying MM (Sadykov et al., 1985) clarifies that $M=M_{max}$, $G=G_{max}$ in optimal regime; to select $T_{rp}(\tau)$ and z(τ) Pontryagin's maximum principle is used (Pontryagin et al., 1983).

The are set: state variables vector $\bar{\chi} = (\chi_0, \chi_1, \chi_2, \chi_3, \chi_4)$=(I(τ), U(τ), T(τ), x(τ), p_c(τ)), dual variables vector $\bar{\xi} = (\xi_0, \xi_1, \xi_2, \xi_3, \xi_4)$,Pontryagin's function

$$H = \sum_{i=0}^{4} \dot{\xi}_i \dot{\chi}_i$$

and problem's Hamiltonian

$$\eta(\tau) = \max_{z=0;1}\{H(\tau)\},$$

$$T_h \in [T_{at}, T_m],$$

$$T_m = \begin{cases} T_{h\,max}, & T<T_{max} \\ T_{h\,max} + \dfrac{T - T_{max}}{2K}\left(T_{max} - \dfrac{rM \cdot \dot{U}_h}{G\rho_{hc} c_p} - T_{h\,max}\right), & T \geq T_{max} \end{cases}$$

where T_m - heat carrier maximum temperature providing accomplishment of condition : $T<T_{max} + 2K$ (index h – means heating , v - vacuumization)
c_p – specific mass heat of a heat carrier at a constant pressure
ρ_{hc} – heat carrier density at a heater input
State and dual variables must satisfy the equations:

$$\dot{\chi} = z\dot{\chi}_h + (1-z)\dot{\chi}_v, \quad \dot{\xi}_i = -\sum_{i=0}^{4} \frac{\partial \dot{\chi}_i}{\partial \chi_i}\xi_i,$$

$$i = \overline{0,4} \quad (2)$$

and edge conditions:

τ=0: χ_0=0, χ_1= U(0), χ_2= T(0), χ_3= x(0), χ_4= p_{at};
$\tau = \tau_к$: $\chi_1 = U_к$, $|\xi_0| + |\xi_1| = 1$, $\xi_2 = \xi_3 = \xi_4 = \eta = 0$.

(3)

State variable p_c is inserted with a view of obvious separation of heat carrier's pump-down stages and vapour's pump-down stage: during the first stage $\dot{U} = \dot{T} = \dot{x} = 0$ and during the second stage are correct of MM equations (Sadykov et al., 1985):

$$U\dot{x} = (y_y - x)\dot{U},$$

where y_y – ethanol mole fraction in eliminated vapour phase, x – alcohol mole fraction
Dots mean time differentiation.

$$\dot{U} = -\frac{c\rho Q[p(x,T)]}{V(\alpha c - \beta r) + c\mu M}, \quad \dot{T} = \frac{r}{c}\dot{U};$$

where,

$$\alpha = \frac{y-x}{RTU}[\gamma_1\mu_1 p_1(T) - \gamma_2\mu_2 p_2(T)][1 - 4{,}74x(1-x)^2],$$

$$\beta = \frac{p(x,T)}{RT}[y\mu_1\frac{d\ln p_1(T)}{dT} + (1-y)\mu_2\frac{d\ln p_2(T)}{dT}] - \frac{\rho}{T},$$

$$\rho = \frac{\mu p(x,T)}{RT}.$$

Q(p) – effective eviction speed
r – specific molar evaporation heat of a thin mixture
c – specific mole heat of a humid material at account on a mole number of a dry material
μ_1 – alcohol molecular weight
μ_2 – aqua molecular weight

Then $p_c(\tau)$ must satisfy equations:
γ_1 – activity ratio of an alcohol fumes
γ_2 – activity ratio of an aqua fumes
$P_1(\tau)$ – alcohol fumes saturation pressure
$P_2(\tau)$ – aqua fumes saturation pressure
p_c - pressure in the drying chamber

$$\dot{p}_{cv} = \begin{cases} -\dfrac{x}{V} p_c Q(p_c), & p_c > p(x,T) \\ [1-4{,}74x(1-x)^2](\gamma_1 p_1 - \gamma_2 p_2)\dot{x} + \left[x\gamma_1 \dfrac{dp_1}{dT} + (1-x)\gamma_2 \dfrac{dp_2}{dT} \right]\dot{T}, \\ p_c \le p(x,T) \end{cases} \tag{4}$$

$$\dot{p}_{ch} = p_{at} - p_c \tag{5}$$

Formulation (4) is relevant to the physics of process and is derived from its MM.

Formulation (5) is supplied for substitution of an intermittent growth (of the p_c, to the value of p_{at}) for uninterrupted process while there is a material jogging. The above make it possible to use the theorem of Pontryagin with limits on the differential features of $\dot{\overline{\chi}}$.

The substitution is relevant because the value of p_c has no influence on a heating stage (it assumes that p_c is equal to an atmospheric pressure). Fast approaching of the p_c to the p_{at} before vacuumization is necessary.

Meanwhile due to (5) the p_c differs from the p_{at} in a value less then 0,03% in 8 sec from the beginning of the process. In (2) the $\dot{\overline{\chi}}$ is continuous by control (T_h,z) and is continuously differential by $\overline{\chi}$ all over the entity of real physical limits of alternation of $\overline{\chi}$ except of hyper surface:

$$p_c - p(x, T)=0, \tag{6}$$

where $\dot{\overline{\chi}}$ has ordinary discontinuity (Korn et al., 1978). Though the left part of (6) is continuously differential by $\overline{\chi}$ and this enables the continuity of $\overline{\xi}$ and H by τ (Korn et al., 1978) on the segment [0, $\tau_к$]. From the maximum's principle it is following that ξ_0=const≤0. Thus $\partial\dot{\chi}_i / \partial\chi_4 = 0$ $i = \overline{0,3}$ and

$$\dot{\xi}_4 = -\frac{\partial \dot{p}_c}{\partial p_c}\xi_4,$$

On account of the limitedness $\partial\dot{p}_c / \partial p_c$ and the stipulation $\xi_4(\tau_к)=0$ enables $\xi_4(\tau)$=const=0. Invariability of ξ_0 and ξ4 simplifies the problem.

While solving the boundary problem (2)-(3) with every fixed τ the control is selected which enables maximum *H* from the following : a) z=0; b) z=1 и $T_h=T_{at}$ and c) z=1 и $T_h=T_m$.

Such simplicity of the control choice law is a result of affine dependence H from T_h and from discontinuity of z value area.

The method of resolving the boundary problem – is a reduction to the series of Cauchy problems (Krylov V.I., 1977). Cauchy problems integration is complicated by discontinuity in right-hand members (2). The solution has extreme points therefore special numerical method has been designed.

Its difference from prevalent methods consists in the combination of different step of integration choice laws - Rhunge law (problems (Krylov V.I., 1977) for "flat" sectors and immediate estimation in extreme points.

The prime cost of product unit minimums discovered in such a way (for *i* variant of the equipment) have been used for the comparison of reduced costs for each variant.

$$R_i = P_i + E\ C_i \quad (7)$$

R - reduced costs

P – prime cost

E - normative factor recoupment of capital investments

C – capital costs

To design industrial crystal aminoacid drying block the best variant has been selected.

Thus the method of the CPDV drying optimal regimes has been proposed. It is based on the MM of the process and takes into account componentwise contents of ethyl alcohol and aqua in aminoacids. It can be used in design and valuation of oscillating drying apparatus and their automated control systems. The results of this work can be generalized in the case of removal of an endless amount of thin mixture components from drying products. It is necessary to note that there are probable situations in such distention when it fails to set optimal G in advance. So $G(\tau)$ function must be searched as $T_d(\tau)$ $z(\tau)$, by solving the problem of Pontryagin's maximum principle.

3 AUTOMATION DRYING PROCESS

The algorithm of automatic optimum control mode is based on optimization model which, in turn, is formulated on the basis of MM of drying process in view of the technology requirements raised to an end-product.

The automated control system model of drying workshop is designed to allow familiarizing with the processes proceeding in drying installation at absence of technological object.

The laboratory-scale plant consisting of several oscillating drying installations includes the following technological control objects: dryer; charging device; unloading mechanism; receiver; condenser; hotwell.

The system emulator implements the following functions of the automatic control and supervision:

1 Automatic control: dryer top pressure; dryer lower part temperature; air temperature to a dryer; air temperature from a dryer; pressure before a receiver.

2 Remote supervision: dryer top pressure; product temperature on an entry; product temperature on an exit; dryer lower part temperature; air temperature to a dryer; air consumption in a dryer; pressures before a receiver.

The automated control system model includes the following levels (**fig. 2**): a level of sensing transducers and actuating mechanisms; a level of control unit (PLC); a level of the operators interface (HMI).

In the laboratory-scale plant of the drying plant control system the role of sensing transducers is played by PC with program emulation of drying installation work. The program simulates work of field sensing transducers, emulating their current output signals. Current signals are transferred to the next level - on an input of the control unit.

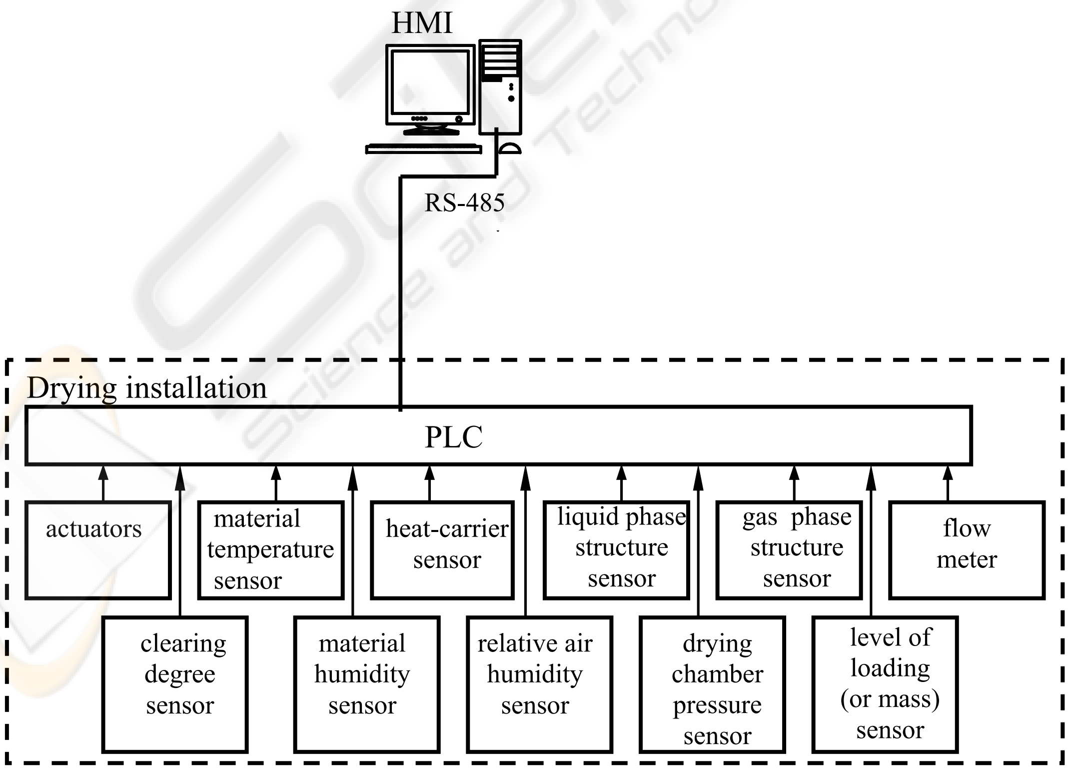

Figure 2: Model of control system of the drying plant.

At this level the control logic of technological installation is implemented. According to which incoming data from sensing transducers and actuators is being processed and analyzed. Generation of control actions on the specified algorithm takes place.

The control level of the drying plant automation system is implemented on modern microprocessor devices. One controller with necessary input-output modules is used for each drying plant.

There are following modules included:

The programmed control unit with a support of InterBus network. Implements drying installation control algorithms.

The analog input module. Signals from pressure and consumption sensors.

The module of signals from temperature transmitters.

The module of discrete output signals. It is used for management of quick-acting valves, the ventilating fan and the vacuum pump.

One control unit with modules of input-output provide implementation of the following functions:

- Data acquisition from sensing transducers;
- Preprocessing and normalizations of analogue and discrete signals;
- Output of control actions on actuators;
- Management of technological installation: data from sensing transducers level is being processed and analyzed. Control actions on the specified algorithms of regulating are being generated.

The level of operator interface supplies the operator with on-line information of a process passing. Ensure reception of managing instructions from the operator and transfer instructions to the control unit. At this level functions of accumulation and representation of the archival historical information are implemented by SCADA-system.

In the capacity of workstations of operators are used PC with the network InterBus interface. An operating system established at operators stations - Microsoft Windows. OPC Server provides data exchange between the managing controllers and the operators interface.

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