Organisation of the Influence Factors System for Foodstuffs Lyophilization

Gabriela-Victoria ANGHEL (✉)
Dumitru MNERIE
Dumitru TUCU
Titus SLAVICI
Alin Vasile MNERIE

Summary

Optimization of the utilization of the system of foodstuffs lyophilization (freeze drying) presupposes a total analysis of the influence factors systemic model. All the factors that have some direct influence on the lyophilization process and the factors that have indirect influence and are in relation with the optimization criteria were considered. Using the competent opinions of nine experts and after the identification of all the influence factors and their restrictions a method through which an organized system was formed was applied. Finally, the values of entropy system and of the organization level of the factors system were determined.

Key words

foodstuff, lyophilization, organization, factors

Mechanical Engineering Faculty, Politehnica University of Timisoara,
Mihai Viteazul 1, 300222 Timisoara, Romania
✉ e-mail: cepus03@yahoo.com

Received: November 23, 2006 | Accepted: March 22, 2007

Introduction

Lyophilization is a process recommended for drying of heat-sensitive products which can suffer physical and structural damage during the drying, such as: fruit, vegetables, chicken meat, shrimp meat, pharmaceuticals, etc. (Teleki et al., 2002). Among the available drying techniques, the freeze-drying provides the highest quality product (Jennings, 1999). The goal of this paper was to present the freeze-drying (lyophilization) process as method of food preservation.

For an approach to the optimization of the system of foodstuffs lyophilization, it is necessary to establish the generalized functions and the accompanying restrictions, taking into account the performance indicators of the lyophilization technique system.

Optimization of the systems of foodstuffs lyophilization presupposes the application of an combination of actions meant to determine the optimal conditions for lyophilization installation used to meet in the best way the requirement imposed, considering, concurrently, the activities relating to inputs, outputs and internal links, in the generalized system of the operation of the lyophilization system, as an active part, in continual interaction. In its turn, the latter is conceived as a succession of operating elements, having well-individualized characteristics, correlated and determined in interdependence with the construction of new variants of the lyophilizers.

Material and methods

The method applied has some specific steps. First, nine experts in lyophilization,were selected and then it was necessary to establish the generalized optimization functions and the accompanying restrictions. All the considerations presented, for a generalized system of operation with the lyophilization process and proper installation, were based on inputs and outputs.

In order to facilitate the sustainable operation using the variables in the system, each was denoted by a capital latter, related to their names, having an index of the group of variables to which it belongs. The variables were grouped as follows:

A. *Input variables*, considered as hypothetically controllable and established beforehand were classified into three groups as follows.

a. The group of variables related to the *lyophilization technique system*, which include the characteristics considered to be most important in defining their qualities (Bacauanu, 2005):

- duration of lyophilization by unit of product – D_1
- the exposed surface of thermal exchange – S_1
- cooling velocity – V_1
- the quality factor of the thermal transfer – Q_1
- the corrosion resistance of the material messed up in contact with foodstuff – R_1
- the condition of the metal surfaces in contact with the product – M_1
- the vacuum capacity of the lyophilization space – C_1

b. The group of variables related to *other components* of the laboratory lyophilization installation used, which include the following characteristics:

- the metallic structure of the material in contact with the foodstuff – A_2
- lightness of the enclosure on sublimation – E_2
- thermal conductivity of the thermal transfer materials – T_2
- the heat loss factors – F_2
- the condition of the electrical cables for connection of the thermocouples –C_2

c. The group of variables relative to the *de-pressure system* in sublimation process and automation system:

- output de-pressure – P_3
- the humidity level of evacuated vapors – U_3
- the minimum frequency of temperature and pressure readings – F_3
- the degree of accuracy of measurements – I_3
- the sensitivity threshold of automated commands – S_3

B. *Adjustments variables*, (Bruttini et al., 1999), such as:

- freezing velocity – M_4
- the thermal transfer surface of the food (Carapelle et al., 2001) – D_4
- compensation for the breakage mechanical effects of the structural elements – B_4
- compensation for the heat losses of the environment – T_4
- setting the food in the lyophilization system – P_4
- the sensitivity threshold of the lyophilization system – S_4

The state variables can be considered, also, technically, checked and controlled by an aggregate of connection variables, which offer the possibility of adjustments also called:

C. *Output variables* that characterize the functioning of the laboratory lyophilization installation, with relation to the *results obtained*, are function of the changes of the input variables. These variables are also called state variables and can be placed into two groups:

a. State variables related to the *operation parameters* of the laboratory lyophilization installation, which include:

- the final quantity of lyophilization product – F_5
- the final humidity of the product – H_5
- the temperature of the dry product – U_5
- the size – G_5

b. State variables related to the *quality* of the laboratory *process*:
- deep freezing velocity – Z_6
- reconstitution capacity (Sagara, 2001) – A_6
- hygroscopic stability – O_6
- final lyophilization temperature – T_6

c. Variables related to the *technical – economic* performance of the operation of the laboratory lyophilization installation:
- the direct cost of lyophilization – C_7
- the indirect cost of lyophilization – I_7
- the reliability of the installation – F_7
- the functioning safety – S_7

The variables presented above act as independent magnitudes, but, for practical considerations, some inter-determination relations can however be acknowledged.

For a complex analysis of the lyophilization system, it has to be included in a system of classification. According to the variant classification that was applied, systems were divided:
- according to the degree of inter-determination:
- determinist systems;
- probabilistic systems;
- according to the degree of complexity:
- simple systems;
- complex systems;
- extremely complex systems.

The system under analysis belongs to the category of probabilistic systems, following some simplifications, made for the purpose of facilitating the analysis, modeling, and subsequently, optimization (Anghel et al., 2004). The system can be brought to the condition of a determinist system; according to its degree of complexity, it falls into the groups of complex systems characterized by great dimensions, large number of functions, complex behaviors, with various direct and inverse connections. These last acting, positively or negatively diminishing amplifying the disparity, respectively.

Results and discussion

The aim of this study was to make a total analysis of the systemic model.

The connection and the determination of relations between the variables of the system were determined. Through the given system the following variables were proposed:

- N_i - input variables, where: $N_i = 7 + 5 + 5 = 17$
- N_e – output variables, where: $N_e = 4 + 4 + 4 = 12$
- N_r – adjustment variables, where: $N_r = 6$

Thus, the total number of variables proposed by the system is:

$$N_t = N_i + N_e + N_r = 17 + 12 + 6 = 35 \quad (1)$$

The vectorial or tensional nature of variables, in most of the cases with several dimensions, was allowed. The connections between the variables can be direct, with or without the influence of the lyophilization system, some of them holding, nevertheless, even an intermediary position between the two extremes. Actually, the number of connections was established cumulative.

Theoretically, connections are possible between all variables. Results of analysis of some functional hypotheses, for study, modeling and optimization, i.e. the situation of the connections between variables, are presented in Table 1.

Table 1. The situation of the connections between input variables and output variables.

Input (V_e) variables (V_i)	Output variables												$\Sigma (V_e \rightarrow V_i)$
	F_5	H_5	U_5	G_5	Z_6	A_6	O_6	T_6	C_7	I_7	F_7	S_7	
D_1	1	1	1	1	1	1	1	1	1	0	1	0	10
S_1	1	1	1	1	0	0	1	0	1	0	1	1	8
V_1	1	1	1	1	1	1	1	1	1	0	1	1	10
Q_1	1	1	1	0	1	1	1	1	1	0	1	1	10
R_1	1	0	1	1	0	0	1	1	1	1	1	1	9
M_1	1	1	1	0	1	1	0	1	1	0	1	1	9
C_1	1	1	1	1	1	1	1	1	1	1	1	1	12
A_2	1	0	1	1	1	1	0	0	1	0	1	0	7
E_2	1	0	1	1	1	1	0	1	0	0	1	1	8
T_2	1	1	0	1	1	1	0	0	1	1	1	0	8
F_2	1	1	0	0	1	1	0	1	0	0	1	1	7
C_2	0	1	0	1	1	1	0	1	0	1	1	1	8
P_3	1	1	0	0	0	1	0	1	0	1	0	1	6
U_3	0	1	0	0	1	0	0	0	1	1	0	1	5
F_3	1	1	0	0	0	0	0	0	1	0	1	1	5
I_3	0	0	0	0	1	1	1	1	1	1	0	1	7
S_3	0	1	0	0	1	1	0	0	1	1	0	0	5
$\Sigma (V_i \rightarrow V_e)$	13	13	9	9	13	13	7	10	13	8	13	13	134

Table 2. The situation of the connection between the adjustment variables and input variables.

Adjustment variables (V_r)	Input variables (V_i)																	$\Sigma (V_i \to V_r)$
	D_1	S_1	V_1	Q_1	R_1	M_1	C_1	A_2	E_2	T_2	F_2	C_2	P_3	U_3	F_3	I_3	S_3	
M_4	1	1	1	1	1	0	0	0	1	0	1	0	1	1	1	1	1	12
D_4	1	1	1	1	0	0	1	0	0	0	1	0	0	0	0	1	1	8
B_4	1	1	1	1	1	1	1	0	0	0	1	0	0	0	0	1	1	10
T_4	1	1	1	1	0	1	0	1	0	0	1	0	0	0	0	1	1	9
P_4	1	1	1	1	0	0	0	1	1	1	1	1	1	0	1	1	1	13
S_4	0	0	0	1	0	0	0	1	0	1	1	1	0	1	0	1	1	8
$\Sigma (V_r \to V_i)$	5	5	5	6	2	2	2	3	2	2	6	2	2	2	2	6	6	60

Table 3. The situation of the connection of the adjustment variables and output variables.

Adjustment variables (V_r)	Output variables (V_e)												$\Sigma (V_e \to V_r)$
	F_5	H_5	U_5	G_5	Z_6	A_6	O_6	T_6	C_7	I_7	F_7	S_7	
M_4	1	1	1	0	1	1	0	0	1	0	1	1	8
D_4	1	1	1	0	1	0	0	0	0	0	1	1	6
B_4	0	1	1	0	0	1	0	1	1	0	1	1	7
T_4	1	1	0	1	1	1	1	1	1	1	1	1	11
P_4	1	1	1	0	0	0	0	1	1	0	1	1	7
S_4	1	1	0	0	1	1	0	0	0	1	0	1	6
$\Sigma (V_r \to V_e)$	5	6	4	1	4	4	1	3	4	2	5	6	45

The existence of the relation between two variables was denoted as "1" while the absence of connection between two variables was denoted as "0".

The share of the connections existing between variables was calculated by the relation:

$$P_{ie} = \frac{N_{ie}}{N_i \times N_e} \times 100 = \frac{134}{17 \times 12} \times 100 = 65.69\ \%. \quad (2)$$

where N_{ie} represents the total number of relations between variables i and $(N_i x N_e)$ and represents the total number of relations that can be considered:

$$N_{ie} = (V_i \leftrightarrow V_e) = \Sigma (V_i \to V_e) = \\ = \Sigma (V_e \to V_i) = 134 \quad (3)$$

Considering also the $\{N_r = 6\}$ – adjustment variables, the situation of their connection with the input variables and the output variables, respectively, is presented in Tables 2 and 3.

The share of the connections between the adjustment variables and the input variables was calculated by the relation:

$$P_{ri} = \frac{N_{ri}}{N_r \times N_i} \times 100 = \frac{60}{6 \times 17} \times 100 = \\ = 58.82\ \% \quad (4)$$

where N_{ri} represents the total number of connections between variables; and $(N_r x N_i)$ represents the total number of connections that can be considered:

$$N_{ri} = \Sigma (V_r \leftrightarrow V_i) = \Sigma (V_r \to V_i) = \\ = \Sigma (V_i \to V_r) = 56 \quad (5)$$

The share of the connections existing between the output variables and the adjustment variables are calculated by relation:

$$P_{re} = \frac{N_{re}}{N_r \times N_e} \times 100 = \frac{45}{6 \times 12} \times 100 = 62{,}50\ \% \quad (6)$$

where N_{re} represents the total number of connections between variables:

$$N_{re} = \Sigma (V_r \leftrightarrow V_e) = \Sigma (V_r \to V_e) = \\ = \Sigma (V_e \to V_r) = 45 \quad (7)$$

and $(N_r x N_e)$ represents the total number of the connections that can be considered.

Relating this to the overall system the above results the following conclusions were made:

The highest share is held by the connections achieved between *the input and the output* variables *(66.69 %)* through the medium of the process itself, not yet sufficiently known;

The chosen *adjustment variables* of the lyophilization system are more closely linked to this *output variables (62.50 %)*, than to the *input* ones *(58.82 %)*, but the shares are close enough, proving the representative and balanced choice of variables;

For establishing priorities and for achieving the total optimization of the systemic model proposed, the data included in Tables 1, 2 and 3, represents genuine starting points for necessary subsequent by importance order establishment of those variables/factors;

In order to achieve total characterization of the system, the *global share* of the existing connections was determined using the relation:

$$P_{gs} = \frac{N_{ie}+N_{ri}+N_{re}}{N_i \times N_e + N_r \times N_i + N_r \times N_e} \cdot 100 =$$

$$= \frac{134+60+45}{17 \times 12 + 6 \times 17 + 6 \times 12} \cdot 100 = 63.22\ \%,$$

$$= 63.22\ \%, \tag{8}$$

also, the value of the *entropy* of the system, as a magnitude that characterizes the intermediary of the system was calculated by the relation:

$$H_S = \sum_{i=1}^{l} p(S_i) \cdot \log_2 p(S_i), \tag{9}$$

where l is the total number of connections in the system and $p(S_1) \div p(S_l)$ represent the estimative probabilities of occurrence of the structural state S of the system.

In the considered system, considering all equi-probable states the maximum entropy of the system was calculated by the relation:

$$H_{S_{min}} = -\frac{239}{239} \cdot \log_2 \left(\frac{1}{239} \right) = 7.90087 \tag{10}$$

If all possible equi-probable connections are considered, the minimum entropy of the system was calculated as follows:

$$H_{S_{max}} = -\frac{378}{378} \cdot \log_2 \left(\frac{1}{378} \right) = 8.56224 \tag{11}$$

The absolute organization of the system was determined by:

$$I = H_{S_{max}} - H_{S_{min}} = 8.56224 - 7.90087 = 0.66137 \tag{12}$$

That value can be regarded as good for the factors system considered, with the note of subjectivism of the experts. It could be better with the replay of method, with same experts or after a new selection.

Conclusions

The analysis of influence factors system is an important step in optimization of the lyophilization process and afferent installation. For a better onset it is necessary to make an order of importance of the factors considered. This consideration forms an operator for an integrated methodology. That can be used periodically, with to operation of the necessary corrections. Another conclusion is regarding the level of knowledge in the complex lyophilization field. Each expert knows just the aspects from his point of view. For the optimization of the entire lyophilization system, especially for the foodstuff, it is necessary to lead the study group with a unit vision, unbiassedly according to all the influence factors.

References

Anghel, G.V., Mnerie. D., Ţucu, D., Oprea, M. (2004). The lyophilization using in the studies of cereals, 1st International and 18th Croatian congress of technologists for Post-Harvest technology „ZRNKO '04", November 17-18, 2004, Stubicke Toplice, Croatia, 12, 52.

Bacauanu, A. (2005). Freeze-drying (lyophilization) – method of food preservation. I. Freeze drying process, Proc. The 4th International Conference SIPA'05, Timisoara, Romania, Ed. Orizonturi Universitare,13-16

Bruttini, R. Freeze Drying, Pharmaceuticals Encyclopaedia of Bioprocess Technology Fermentation, Biocatalysis and Bioseparation, Ed. John Wiley and Sons Inc., New York, 1999, 1276 – 1289

Carapelle, A., Henrist, M., Rabecki, F. Drying Technology, 19 (2001), 1113-1124

Jennings, T. A. (1999). Lyophilization - Introduction and Basic Principles, Interpharm Press, Buffalo Grove, IL

Sagara, Y. Food Sci. Technol. Res., 7 (2001), 183-190

Teleki L., Mnerie D. (2002). Integrated engineering elements applied for obtaining foods preserved by drying. In Proc C21 International Conference on Integrated Engineering, Timişoara, Ed. Politehnica, Timişoara, 163-164

acs72_59