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THE PROBLEM OF PHASIFICATION OF THE PARAMETERS OF THE STORAGE PROCESS OF A SPORTSHEAD OIL RAW MATERIAL WHEN BUILDING A FUZZY REGULATOR

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Abstract: *the article proposes an automated intelligent process control system for the storage of perishable oilseed raw materials based on phase-control. To solve the problem of phasing the process parameters, the modified Saaty method is used. In order to optimize the description, the obtained membership functions were approximated in the Maple symbolic mathematics package.*

Keywords: *phase-control, pacification, linguistic variables, membership function, rule base, Saaty method, fuzzy sets, oilseeds.*

When automating the management of processes, the storage of perishable oil-bearing raw materials is not enough to ensure the stabilization of technological regimes using PID-regulators. The quality and performance of such processes substantially depend on a combination of environmental parameters, which forces the process technician to constantly adjust the controller settings as the external conditions change, guided by his own professional experience. An automated intelligent control system that manages the processes of storing perishable oilseed raw materials using the practical experience and knowledge of the person (technologist) can be built using the principles of phase-control (fuzzy control) [1].

Consider the issue in relation to the process of storing perishable oilseeds in storage. Practical experience showed that the results of the technological process, first of all, depend on the temperature of the air in the storage, the moisture content of the raw materials and air, and the concentration of carbon dioxide [2]. The intensity of the storage process and the quality of the stored products essentially depend on the combination of the listed process parameters. However, the optimal combination of parameters, ensuring maximum performance and quality, and minimum process costs, do not remain constant and significantly depend on the process conditions: time of year, quality of technological materials, etc. For example, carbon dioxide content in the storage air is controlled by its ventilation. However, the efficiency of the ventilation process and the required energy consumption for air preparation are significantly different in the summer and winter periods.

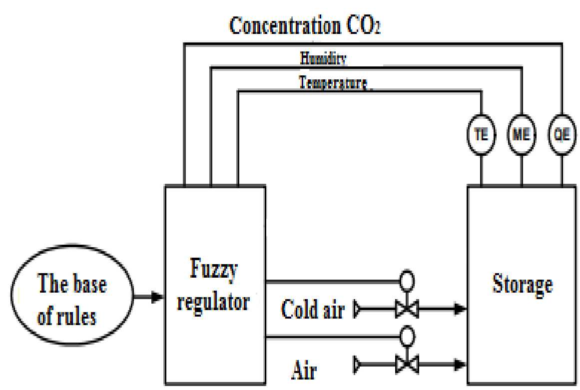

Fig. 1. ***Schematic diagram of the automation of the process control system of storage of perishable oilseeds.***

However, in the case of the microclimate parameters of the process of storing perishable oilseeds, it is necessary to take into account the property of adaptation of biological processes to small deviations of parameters and the simultaneous admissibility of significant deviations of parameters while maintaining the functionality of the process. The best option is to take into account when describing the membership functions of the knowledge of an expert technologist.

Under conditions of limited experimental data and the availability of an expert, the indirect modified Saaty method for constructing membership functions [7, 8] is effective. This method combines a fairly high degree of accuracy with ease of implementation. We apply this modified method to construct the membership functions in our case.

Table 1

Terms of linguistic variable "Temperature"

Range temperatures, °C	Term characteristic	Notation terma
< *Tmin*	Temperature is low	*n*
ΔT1	The temperature is slightly lowered.	*sn*
ΔT2	Optimal temperature	*z*
ΔT3	The temperature is slightly elevated.	*sp*
ΔT4	Temperature elevated	*p*
> *Tmax*	Temperature exceeded	*bp*

For the term "sn", we define the kernel of a fuzzy set, described by the membership function equal to T_{C1} °C (center of the temperature interval ΔT_1), and the boundaries of the fuzzy set are compatible with the kernels of fuzzy sets of neighboring terms. The function of belonging to the term "*sn*" will have a left shoulder and a right shoulder. Select 7 equidistant points (T_{l1}, T_{l2}, T_{l3}, T_{l4}, T_{l5}) on the left shoulder, including the core, and compare the value of the core (T_{C1} °C) with the selected points (except for the value of the core of the next term). When comparing, we use the rating scale [9,10]: 1 - there is no advantage; 3 - weak advantage; 5 - a significant advantage; 7 is a clear advantage; 9 is an absolute advantage; 2, 4, 6, 8 - intermediate estimates.

Taking into account the opinion of the expert, the following estimates were obtained:

The advantage of "T_{C1} °C" over "T_{l5} °C" is 9;
The advantage of "T_{C1} °C" over "T_{l4} °C" is 6;
The advantage of "T_{C1} °C" over "T_{l3} °C" is 3;
The advantage of "T_{C1} °C" over "T_{l2} °C" is 1;
The advantage of "T_{C1} °C" over "T_{l1} °C" is 1.

The results of the comparisons are presented in the form of a matrix (1), where aij is the level of the advantage of the element ui over uj ($i, j = 1, n$).

°C	T_{l5}	T_{l4}	T_{l3}	T_{l2}	T_{l1}	T_{C1}
T_{l5}	1					
T_{l4}		1				
T_{l3}			1			
T_{l2}				1		
T_{l1}					1	
T_{C1}	9	6	3	1	1	1

(1)

The matrix has the following properties: it is diagonal, it is inversely symmetric, it is transitive. These properties allow you to define all other elements of the comparison matrix using the formula (2):

$$a_{ij} = a_{kj} / a_{ki}, \text{ where } i, k, j = 1, \qquad (2)$$

°C	T_{l5}	T_{l4}	T_{l3}	T_{l2}	T_{l1}	T_{C1}
T_{l5}	1	6/9	3/9	1/9	1/9	1/9
T_{l4}	9/6	1	3/6	1/6	1/6	1/6
T_{l3}	9/3	6/3	1	1/3	1/3	1/3
T_{l2}	9/1	6/1	3/1	1	1/1	1/1
T_{l1}	9/1	6/1	3/1	1/1	1	1/1
T_{C1}	9	6	3	1	1	1

(3)

After calculating all the elements of the matrix of pairwise comparisons (3), we find the values of the membership function by the following formula (4):

$$\mu(u_i) = \frac{1}{a_{1i} + a_{2i} + \cdots + a_{ni}}, \qquad (4)$$

where $n = 6$; u_i - the *i*-th element of pairwise comparison (column); a_{1i} is the first value of the pairwise comparison of the *i*-th element; a_{ni} is the *n*-th value of the pairwise comparison of the *i*-th element. After rationing the calculated values by dividing them by the largest value, we obtain (Table 2).

Table 2

Values of the membership function for the left shoulder of the term "sn"

Temperature in storage, °C	T_{l5}	T_{l4}	T_{l3}	T_{l2}	T_{l1}	T_{C1}
The value	0,03	0,04	0,09	0,2	0,2	0,2

of MF for subnormal fuzzy set	0	6	2	7	7	7
MF value for normal fuzzy set	0,11	0,16	0,33	1	1	1

Using the piecewise linear approximation of the MF in the intervals between the calculated reference points, we obtain analytical expressions for the corresponding parts of the membership function for the left shoulder of the term "*sn*" (5):

$$\begin{cases} T \le Tmin;\ \mu_{sn}(T) = 0; \\ Tmin < T \le T_{l5};\ \mu_{sn}(T) = 0.687T - 8.25; \\ T_{l5} < T \le T_{l4};\ \mu_{sn}(T) = 0.294T - 3.466; \\ T_{l4} < T \le T_{l3};\ \mu_{sn}(T) = T - 12.17; \\ T_{l3} < T \le T_{l2};\ \mu_{sn}(T) = 4.187T - 52.013; \\ T_{l2} < T \le T_{l1};\ \mu_{sn}(T) = 1; \\ T_{l1} < T \le T_{C1};\ \mu_{sn}(T) = 1; \\ T > T_{C1};\ \mu_{sn}(T) = 0; \end{cases} \quad (5)$$

where T is the air temperature in the storage; msn (T) - membership function of the term "*sn*". To build the right shoulder use the same algorithm.

After combining the descriptions of the left and right shoulders of the MF, we obtain a complete description of the MF for the term "*sn*"

$$\begin{cases} T \le Tmin;\ \mu_{sn}(T) = 0; \\ Tmin < T \le T_{l5};\ \mu_{sn}(T) = 0.687T - 8.25; \\ T_{l5} < T \le T_{l4};\ \mu_{sn}(T) = 0.294T - 3.466; \\ T_{l4} < T \le T_{l3};\ \mu_{sn}(T) = T - 12.17; \\ T_{l3} < T \le T_{l2};\ \mu_{sn}(T) = 4.187T - 52.013; \\ T_{l2} < T \le T_{l1};\ \mu_{sn}(T) = 1; \\ T_{l1} < T \le T_{C1};\ \mu_{sn}(T) = 1; \\ T_{C1} < T \le T_{r1};\ \mu_{sn}(T) = 1; \\ T_{r1} < T \le T_{r2};\ \mu_{sn}(T) = 1; \\ T_{r2} < T \le T_{r3};\ \mu_{sn}(T) = -3.941T + 53.535; \\ T_{r3} < T \le T_{r4};\ \mu_{sn}(T) = -1.0625T + 14.673; \\ T_{r4} < T \le T_{r5};\ \mu_{sn}(T) = -0.294T + 4.177; \\ T_{r5} < T \le T_{C2};\ \mu_{sn}(T) = -0.647T + 9.058; \\ T > T_{C2};\ \mu_{sn}(T) = 0; \end{cases} \quad (6)$$

where T is the air temperature in the storage; msn (T) - membership function of the term "*sn*". To simplify the description of the MF, we perform an approximation to the piecewise linear characteristic by the Lagrange polynomial. The approximation used the Maple symbolic mathematics package, for which the following procedure is described:

```
lagr := proc (Data::(list(list)))
 local L, s, s1, Lg, x;
 L := 0;
for s1 in Data do
Lg := 1;
for s in Data do
if s1[1] <> s[1] then
Lg := Lg*(x-s[1])/(s1[1]-s[1]);
end if;
end do;
L := L+s1[2]*Lg;
end do;
L := collect(L, x);
unapply(L, x);
end proc:.
```

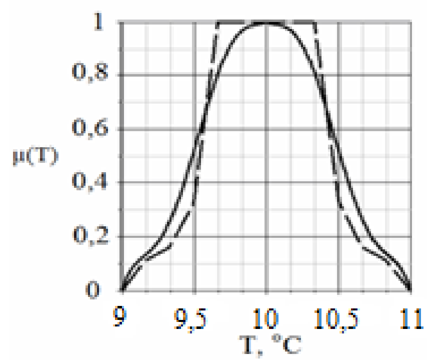

Fig. 2. ***The membership function for the term "sn": dotted line - piecewise linear characteristic; solid line - approximation by Lagrange polynomials.***

As a result of the approximation for the left shoulder of the MF, the description is obtained in the following form (7):

$$\begin{cases} T \le 9;\ \mu_{sn}(T) = 0; \\ 9 < T \le 11;\ \mu_{sn}(T) = a_{sn-1} + a^1{}_{sn-1}T + \\ + \sum_{n-2}^{5} a^n{}_{sn-1}\,(T - \Delta T_{sn})^n; \\ T > 13;\ \mu_{sn}(T) = 0; \end{cases} \quad (7)$$

where T is the air temperature in the storage; $\Delta Tsn = 11$; msn (T) - the membership function of the term "sn"; $a_{sn-l} = –2,52$; $a^1{}_{sn-l} = 0,27$; $a^2{}_{sn-l} = 3,177$; $a^3{}_{sn-l} = 20,833$; $a^4{}_{sn-l} = 29,947$; $a^5{}_{sn-l} = 13,02$;

Together with the right shoulder, the description of the MF *sn* will take the form (8):

$$\begin{cases} T \le 9;\ \mu_{sn}(T) = 0; \\ 9 \le T < 11;\ \mu_{sn}(T) = a_{sn-1} + a^1{}_{sn-1}T + \\ + \sum_{n-2}^{5} a^n{}_{sn-1}\,(T - \Delta T_{sn})^n; \\ 11 \le T \le 11;\ \mu_{sn}(T) = a_{sn-r} + a^1{}_{sn-r}T + \\ + \sum_{n-2}^{5} a^n{}_{sn-r}\,(T - \Delta T_{sn})^n; \\ T > 11;\ \mu_{sn}(T) = 0; \end{cases} \quad (8)$$

where T is the air temperature in the storage; $\Delta Tsn = 11$; $msn(T)$ - the membership function of the term "sn";
$a_{sn\text{-}l} = -2{,}52$; $a^1_{sn\text{-}l} = 0{,}27$; $a^2_{sn\text{-}l} = 3{,}177$;
$a^3_{sn\text{-}l} = 20{,}833$; $a^4_{sn\text{-}l} = 29{,}947$; $a^5_{sn\text{-}l} = 13{,}02$; $a_{sn\text{-}r} = 4{,}52$; $a^1_{sn\text{-}r} = 0{,}27$; $a^2_{sn\text{-}r} = 3{,}177$;
$a^3_{sn\text{-}r} = 20{,}833$; $a^4_{sn\text{-}r} = 29{,}947$; $a^5_{sn\text{-}r} = 13{,}02$;

The graphs for the initial version of the MF and the approximated dependence are presented in (Fig. 2). The approximate dependence is more consistent with the experience of the technologist, since it eliminates the horizontal part of the characteristic in the vicinity of the core.

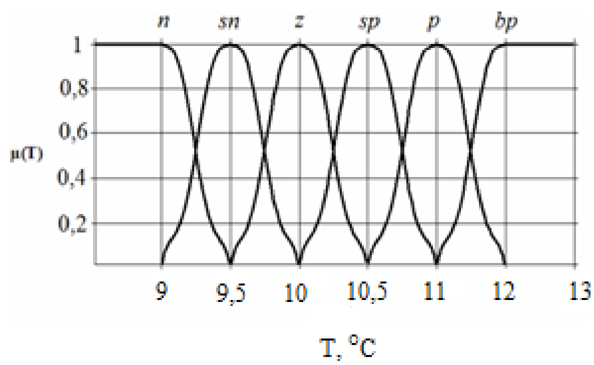

Fig. 3. ***The membership functions of the value "Temperature in the storage" to the terms of the linguistic variable "Temperature mode"***

At the same time, the nature of the change in the remaining intervals is preserved in accordance with the original schedule of the membership function. Using the described approach, the membership functions for the temperature in the storage are defined for all terms of the linguistic variable "Temperature mode", which allows phasing for this parameter of the storage process. Graphs of membership functions are shown in Fig. 3.

Thus, an intelligent process control system has been proposed for storing perishable oilseeds based on fuzzy logic, which allows you to use the accumulated experience of the plant technologist to optimize the operation of the complex in order to increase productivity, product quality and reduce costs. The question of the phasification of process parameters on the example of the parameter "temperature" using the modified Saaty method is considered. A new form of the membership function and its approximation is obtained.

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