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Energy Characteristics of Agricultural Processing Lines

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Abstract

Our research objective through the current paper was to develop a methodology for the study of energy-saving lines for processing agricultural products, to justify the parameters and energy-efficient modes of heat and cold supply equipment operation using natural cold, the energy characteristics of the freezing battery, and determine the range of variation of energy flows revenues and expenditures, receipt and processing of information for the development of cooling systems.

Keywords

Energy of Phase Transition Water-Ice, Heat Exchanger, Cold Accumulators, Controlled and Adjustable Processing Parameters, Energy, Material, Time and Operational Characteristics of the Lines, Temporary and Operational Characteristics of Lines, Automated Links, Storage Capacity.

Introduction

Due to the low technological level of most livestock farms and the lack of modern equipment, the quality of milk produced on farms is still unsatisfactory, and its processing is an energy-intensive and time-consuming process. In Russia as a whole, energy costs for processing 1 ton of milk average 33 kWh [1, 5-13].

The development and implementation of integrated energy-saving equipment and heat and cold supply units using natural cold, which reduce the energy intensity of the agricultural products processing.

Research Objective

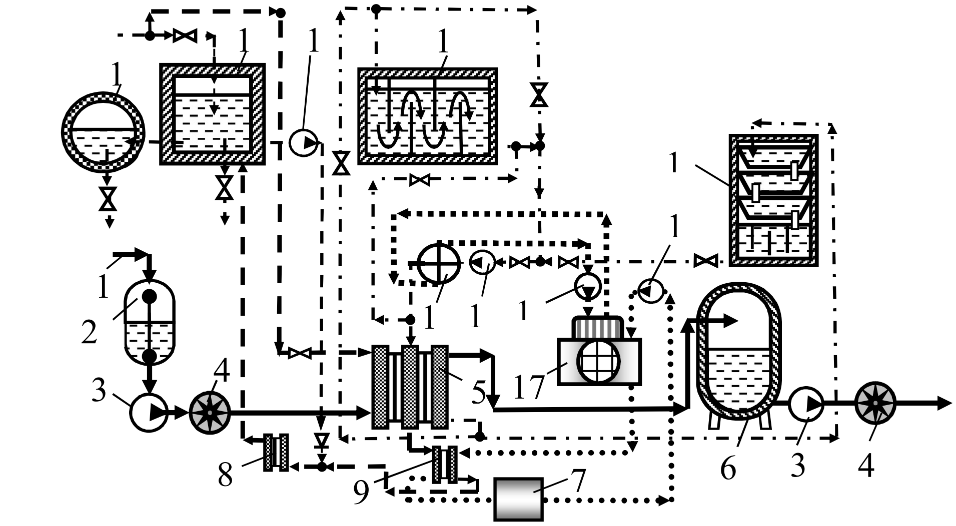
To develop a methodology for the study of energy-saving lines for processing agricultural products, to justify the parameters and energy-efficient modes of heat and cold supply equipment operation using natural cold in order to analyse the energy and material balance of the lines, the energy characteristics of the freezing battery, and determine the range of variation of energy flows revenues and expenditures, receipt and processing of information for the development of flexible cooling systems.

Results and Discussion

It has been established that the operating time of each link in the production line in the work cycle is a random variable distributed according to a law close to normal [6–13].

The energy flows and the energy balance of an agricultural processing line are analysed. Figure 1 shows the energy-saving process line for processing milk for farms using natural cold (Option of heat and cold supply equipment is applied).

Milk through the milk pipe 1 enters the air separator (releaser jar) 2, from where it is pumped through the milk pump 3 and the milk meter 4 to the current milk cooler 5, where it is cooled and enters thermos tanks 6, from where it is dispensed by the milk pump 3 through the milk counter 4 to the milk tank vehicle.



Milk; Coolant from NCSA; Coolant from the refrigeration unit and NACA; Circulating water for the condenser cooling system; Coolant

Fig. 1: Automated Energy-Saving Milk Processing Line Using Natural Cold

1 - Milk line; 2 - Milk collector-air separator (releaser jar); 3 - Milk pump; 4 - Milk counter; 5 - Current cooler; 6 - Reservoir-thermos; 7 - Capacity for cooling the condenser of the cooling unit; 8.9 - First and second stage heat exchangers; 10 - Warm water reservoir; 11 - Water heater; 12 - Water pump; 13 - Natural and artificial cold accumulator (NACA); 14 - Evaporator of the cooling unit; 15 - Coolant pump; 16 - Cooling unit compressor; 17 - Condenser of the cooling unit; 18 - Cooling system pump of the cooling unit condenser (cooling tower pump); 19 - Natural cold sectional accumulator (NCSA)

A quantitative assessment of the energy flows of the energy-saving process line considered as a single autonomous system was performed on the basis of the energy balance equation [5-7].

$$\sum_{j=}^{M}\sum_{m=1}^{K}\sum_{i=1}^{n}\left(W_1, W_2, \ldots W_l, \ldots, W_n\right) = \tag{1}$$

$$= \sum_{j=1}^{M}\sum_{m=1}^{K}\sum_{i=1}^{n}\left(W_1', W_2', \ldots, W_l', \ldots, W_n'\right) +$$

$$\sum_{j=1}^{M}\sum_{m=1}^{K}\sum_{i=1}^{n}\left(W_1'', W_2'', \ldots, W_l'', \ldots, W_n''\right)$$

Where W_l is the amount of energy supplied to the i-th device of the m-th machine of the j-th link; W_l' - the amount of energy spent by the i-th device of the m-th machine of the j-th link to perform useful work; W_l'' - the amount of energy lost by the i-th device of the m-th machine of the j-th link; M - the number of j-th links in the process line; K is the number of the m-th machines in the j-th link of the process line of the m-th machines in the j-th link of the process line; n is the number of devices consuming energy in the m-th machine.

Thus, the proposed system on farms with pre-cooling of milk from 35 ° C to 15 ° C will allow for the regeneration and use in the process of about 720 kWh electricity that can be used for technological needs [1, 5-13].

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Table 1: Characteristics and Operating Modes of the Links of Milk Processing Lines Connected to the Central Dairy Point

The name of the operating mechanisms of the process line links	Typical processing line			Process line with energy-saving technology					
	Number, pcs.	Nen, kW	Tav,man / day	Number, pcs.	Nen, kW	Tav, man / day	Number, pcs.	Nen, kW	Tav, man / day
Air separator pump	4	1,1	3,5	4	1,1	3,6	4	1,1	3,4
Milk pump	1	1,1	4,5	1	1,1	4,5	1	1,1	3,75
Refrigeration compressor	2	15	6,0	1	15,0	6,0	–	–	–
Coolant pump	2	1,5	6,0	1	1,5	6,0	1	1,5	6,0
Circulating water pump	2	4,0	6,0	–	–	–	–	–	–
Cooling tower fan	2	1,5	6,0	–	–	–	–	–	–
Thermos tank mixer	2	0,75	1,5	2	0,75	1,5	2	0,75	1,5
Milk delivery pump	1	0,75	1,5	1	1,1	1,4	1	1,1	0,65
Flushing pump	1	7,5	3,0	1	7,5	3,0	1	7,5	3,0

Table 2: Energy Flows of a Process Line with Energy-Saving Technology

Warm period				Cold period			
Energy input, kWh		Energy consumed, kWh		Energy input, kWh		Energy consumed, kWh	
Designation	Value	Designation	Value	Designation	Value	Designation	Value
ΣW_1	432,92	W''_{mv}	48,10	ΣW_1	204,65	W''_{mv}	22,74
W_v	20,4	W''_m	60,13	W_v	19,3	W''_m	45,48
W_c	7,0	W'_v	15,84	W_c	5,5	W'_v	15,0
W_k	101,7	W''_v	4,56	W_x	11,7	W''_v	4.3
W_o	28,0	W'_c	5,0	W_m	3,0	W'_c	4,13
W_x	11,1	W''_c	2,0	W_d	0,93	W''_c	1,37
W_m	3,0	$W'_к$	90,0	W_n	26,0	W'_x	9,0
W_d	2,0	$W''_к$	11,7	W_5	159,56	W''_x	2,1
W_n	26,0	W'_o	24,0	W_6	258,1	W'_m	2,3
W_5	301,22	W''_o	4,0	W_7	34,98	W''_m	0,7
W_6	253,72	W'_x	9,0			W'_d	0,72
W_7	39,36	W''_x	2,1			W''_d	0,21
		W'_m	2,3			W'_n	22,5
		W''_m	0,7			W''_n	3,5
		W'_d	1,54			W''_6	46,52
		W''_d	0,46			$W''_{6к}$	279,12
		W'_n	22,5			W''_{tn}	263,43
		W''_n	3,5				
		W''_6	46,52				
		$W''_{6к}$	279,12				
		W''_{tn}	593,34				

For convenience of analysis, the energy balance components (energy flows) are grouped by type of energy received from external sources and spent on technological operations (Fig. 2) [6-13].

The first group includes thermal energy contained in milk, which is supplied to the production line ΣW_1

$$\sum W_1 = \sum W_1'' + W_{AB}'' , \tag{2}$$

Where $\sum W_1''$ – energy losses during milk cooling in pipelines and when it is delivered to a milk tanker vehicle; $W_{ав}''$ - milk energy transferred by the coolant to atmospheric air.

The second group $\boldsymbol{\Sigma W_2}$ includes the energy flows of the process line links (air-separation pumps *Wv*, transporting *Wc, Wd* and mixing pumps *Wm*, coolant pumps *Wx* and washing systems *Wn*), the energy operating modes of which practically do not change for any types of lines throughout the year and do not affect the energy balance

$$\sum W_2 = \sum W_2' + \sum W_2'', \qquad (3)$$

where $\sum W_2'$ is the energy spent by the links on the technological process: removing milk from the vacuum line $W_в'$, moving milk through pipelines W_c', $W_д'$, stirring it in tanks during storage $W_м'$, moving coolant W_x', moving washing water and solutions through pipelines when washing technological equipment and the system as a whole W_n'; $\sum W_2'' = W_в'' + W_c'' + W_м'' + W_x''$; - energy loss in the process of energy converting from electrical to mechanical type.

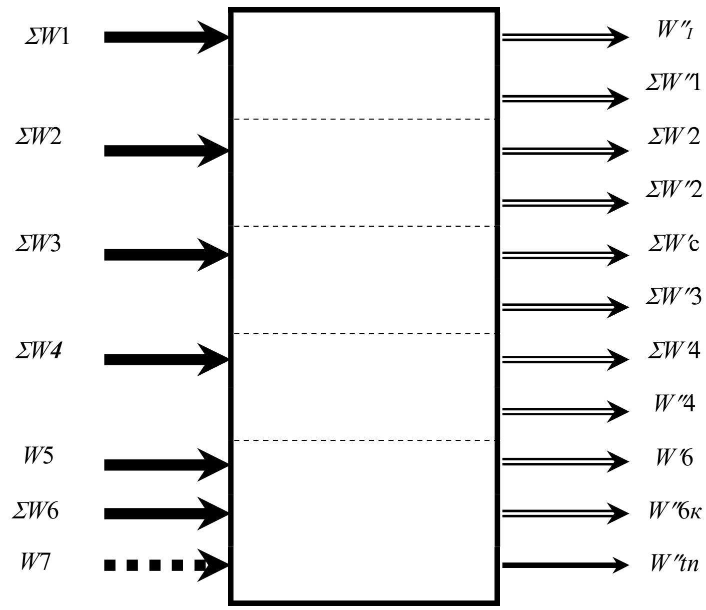


Fig. 2: The Energy Flow Scheme for the Farm Milk Processing Line with Energy-Saving Technology, taking into account the grouping of the Energy Balance Components

The energy flows of the compressor $W_к$ and the circulating water pump W_o are allocated into the third group ΣW_3, since their operating mode varies depending on the technology and type of the line during the year and affects the energy balance of the line

$$\Sigma W_3 = \Sigma W'_3 + \Sigma W''_3, \qquad (4)$$

where $W'3$ is the energy expended in compressing the coolant vapours $W'_к$ and moving the circulating water to cool the condenser of the cooling unit W'_o; $\Sigma W''_3 = W''_к + W''_o$ - energy losses in the process of converting energy from electrical to mechanical type.

The fourth group of energy consumers includes the energy flows ΣW_4 of the cooling tower fans, since a cooling tower is not needed in the production line with energy-saving technology

$$\Sigma W_4 = \Sigma W'_4 + \Sigma W''_4, \qquad (5)$$

Where $\Sigma W4$ 4 is the total energy spent on moving air to cool the water in the tower; $\Sigma W''4$ - energy losses in the process of converting energy from an electrical form to a mechanical one.

The fifth and sixth groups include the energy supplied to the line with water from the $W5$ farm's water supply sources and the energy spent on heating the water to flush the system ΣW_6

$$\Sigma W_6 = W''_6 + W''_{6к}, \qquad (6)$$

Where W''_6 – the energy lost when cooling water in pipelines during flushing; $W''_{6к}$ - energy lost during the discharge of waste water into the sewer.

For ease of presentation and further analysis of the energy balance equations for the process line, the individual loss components are grouped by type of energy: electrical and mechanical, lost in the electric motors of pumps and fans

$$\Sigma W''_{em1} = \Sigma W''_2 + \Sigma W''_4, \qquad (7)$$

Thermal energy lost with water and milk

$$\Sigma W''_{m1} = W''_{1} + \Sigma W''_{1} + W''_{6} + W''_{6к}. \quad (8)$$

As a result, the energy balance equation of a typical production line taking into account expressions (2) ... (8) will have the following form

$$\Sigma W_1 + \Sigma W_2 + \Sigma W_3 + \Sigma W_4 + W_5 + \Sigma W_6 =$$

$$\Sigma W'_2 + \Sigma W'_3 + \Sigma W''_3 + \Sigma W'_4 + \Sigma W''_{эm1} + \Sigma W''_{m1} \quad (9)$$

An analysis of the components of equation (9) shows that there are reserves for improving the energy characteristics of milk processing lines. These reserves include the use of thermal energy of milk supplied to the processing ΣW_1 (an average of 318 kWh per day). A great reserve is also the use of the natural air and water cold to cool milk. This operation consumes an average of 282 kWh per day, or $\Sigma W_3 + \Sigma W_4$, which is 24% of the total amount of energy consumed by the line for processing the daily milk yield.

In the cold season, the use of natural cold systems allows us to cool milk without the use of compressors *Wk*, circulating water pumps *Wo* and cooling tower fans *W4*. Therefore, the energy balance equations for the process line with energy-saving technology for the warm and cold seasons will differ significantly.

For the warm season

$$\Sigma W_1 + \Sigma W_2 + \Sigma W_3 + W_5 + \Sigma W_6 + W_7 =$$

$$= \sum W'_2 + \sum W'_3 + \sum W''_3 + \sum W''_{эм1} + \sum W_{m1} + \sum W''_{тн}, \quad (10)$$

For the cold season

$$\Sigma W_1 + \Sigma W_2 + W_5 + \Sigma W_6 + W_7 =$$

$$= \sum W'_2 + \sum W''_{эм1} + \sum W''_{m1} + \sum W''_{тн}, \quad (11)$$

Where W_7 is the regenerated energy for preheating the water used to flush process equipment and the system as a whole; $W''_{тн}$ - energy of the water used for the technological needs of the farm.

The regenerated heat energy ΣW_p which is used to heat water for the needs of the farm and flush the system, is determined from the expression

$$\Sigma W_p = W_7 + W''_{tn}, \quad (12)$$

Required cooling capacity of the cooling unit for production lines with artificial cold accumulators [6-13]

$$N_{ah} = T_f \cdot (N_{te} - Qn) / T_{ts}, \quad (13)$$

Where N_{te} is the required cooling capacity of the cooling unit in existing milk cooling systems, kW; *Qn* is the equivalent cooling capacity of the pre-cooling system, kW; T_f - the actual operating time of the cooling unit in existing (typical) cooling systems, h; T_{ts} - time between milking cycles, hours

A numerical analysis of the energy balance equations shows that due to the use of the milk thermal energy and the coolant condensation heat of the cooling unit, at least 456 kWh used for heating water can be regenerated per day

$$\sum W_p = W_7 + W''_{тн}. \quad (14)$$

In a cold season, the use of units that accumulate natural cold for cooling milk on farms located in the latitude of Moscow and to the north allows working without cooling units for 5 ... 6 months a year or more, while saving at least 282 kW h of electric energy per day

$$\Sigma W_{xv} = (\Sigma W_3 + \Sigma W_4). \quad (15)$$

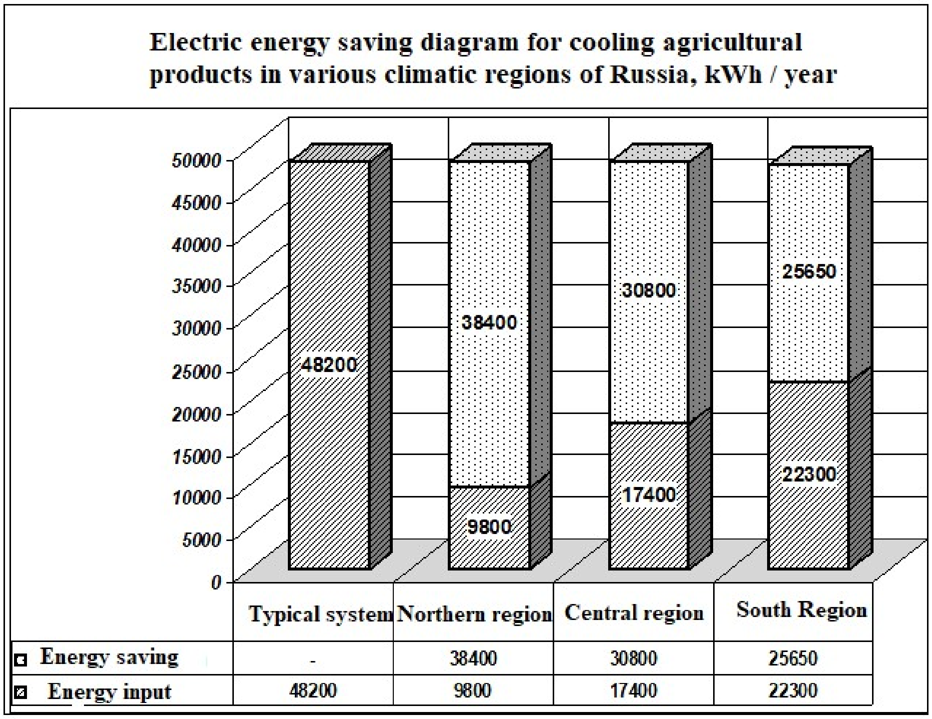
In a warm season, the energy consumption for milk cooling is reduced by 50 ... 65%, and the cooling capacity and installed capacity of cooling units are halved due to its pre-cooling. This saves at least 155 kWh of electricity per day.

$$\Sigma W_{mv} = \Sigma W_3 / 2 + \Sigma W_4. \quad (16)$$

The calculations of the energy balance equation components were carried out using materials from a statistical survey and characteristics of technological equipment for farms according to [5-13], table 1 and table 2. Comparative energy characteristics of the production line with energy-saving technology are presented in table 3.

Table 3: Energy Flows of an Agricultural Product Processing Line with Energy-saving Technology

Energy	Technology links	Designation of energy balance components	Average daily energy value, kWh, on the production line			
			Typical	Energy-saving		
			Per year	Per year	Warm period	Cold period
E N E R G Y I N P U T						
Thermal energy with milk		W_{1M}	318,78	**318,78**	432,92	204,65
Electric energy	Electric motors: milk, water, coolant pumps, compressors, fans, Electric heaters	W_{1E1}	79,7 259,4 23,4 293, 1	**67,67** **64,85** **–** **255,9**	69,5 129,7 – 253,7	65,83 – – 258,1
	Links of thermal action including seasonal	W_{1E2} W_{1E3}	32,6 293,08	**230,4** **255,91**	301,2 253,72	159,6 258,1
Thermal energy with water and air	Electric water heater, heat exchanger, cold accumulators.	W_{V1} W_{1vo3d}	32,56 –	**230,39** **37,17**	301,22 39,36	159,56 34,98
E N E R G Y C O N S U M P T I O N						
Mechanical energy **Thermal energy**	Milk, water, coolant pumps; compressors, reverse water pumps; cooling tower fans. Warm water reservoir	W_{2V} W_{2M} W_{2E1} W_{2E1}	64,3 228,0 18,0 -	**54,92** **57,0** **–** **428,39**	56,18 114,0 – 563,35	53,65 – – 263,43
E N E R G Y L O S S E S						
Thermal energy	Pipelines, reservoirs, milk tanker vehicles, etc.	W_{3T1} W_{3T2} W_{3T3}	664,42	**413,86**	433,87	393,86
Electro-mechanical energy	Electric motors: milk pumps, water pumps, compressors, etc.	W_{3E1} W_{3E2} W_{3E2}	20,8 31,4	**12,75** **7,85**	13,32 15,7	12,18 -



An analysis of energy flows shows that the largest amount of energy when cooling agricultural products using natural cold is saved in the northern region of the country, the minimum amount is in the southern region (see diagram).

Conclusions

It has been established that due to the cold accumulation and the use of milk thermal energy and the condensation heat of a cooling unit's coolant, a line with energy-saving technology regenerates 600 kWh of energy per day at an average in a warm period, and 290 kWh in a cold period that is used to heat the water that goes to the technological needs of the farm. In addition, in the cold season, the use of only seasonal type units that accumulate natural cold for cooling milk on farms located in the latitude of Moscow and to the north allows working without cooling units for 5 ... 6 months a year or more, which saves not less than 282 kWh of electricity per day. In the warm season, only due to pre-cooling of milk, the energy consumption for cooling is reduced by 50 ... 65%, and the cooling capacity and installed capacity of cooling units are 2 ... 2.5 times higher, which saves at least 155 kWh electricity per day. As a result, in the warm season, the energy consumption for cooling 1 ton of milk is 8 ... 13 kW • h and 1.8 ... 4 kW • h in the cold season.

References

1. Belov, A., A. (2018). Modeling the assessment of factors influencing the process of electro-hydraulic water treatment. VESTNIK NGIEI, 11, 103-112.
2. Sirovatka, V., I. 2014. Improvement of technological processes of manufacturing combic food in economy. Journal of VNIIMZH, 1, 4-11.
3. Vasiliev A.N., Budnikov D.A., Vasiliev A.A. Grain simulation process in the heating module universal electrical microwave field at various algorithms of electrical. In Journal of Agricultural Science Don. 2016. Vol. 1. No. 33. P. 12-17.
4. Dorohov, A., S., Kataev U., V., Ksacnashih, K., A., Skorohodov, D., M. 2018. Quality control of spare parts of agricultural machinery with automated measuring device. Nauka bez granic. Moscow: Avtograf, 2, 44-50.
5. Rodionova, A., V., Borovkov M., S., Ershov, M., A. 2012. Justification of the selected frequency of electromagnetic radiation in physical prophylaxis of harbols. NIVA POVOLZA, 1, 108-110.
6. Ershova, I.G., Belova, M.V., Poruchikov, D.V., Ershov, M.A. 2016. Heat treatment of fat-containing raw materials with energy of electromagnetic radiation. International research journal, № 09(51), 38-40.
7. Belova, M.V., Nonikova, G.V., Ershova, I.G., Ershov, M.A. Mikhailova, O.V. 2016. Innovations in technologies of agricultural raw materials processing. Journal of Engineering and Applied Sciences, Vol. 11, Issue 6, 1269-1277.

8. Ershova I.G. The economic efficiency of the use of microwave installations for heat treatment of offal / M.V. Belova, I.G. Ershova, N.T. Uyezd // International Scientific, Theoretical and Applied Journal "Bulletin of the Chuvash State Pedagogical University named after I. Y. Yakovlev." - Cheboksary: CSPU, 2013. - No. 4 (80). – P. 30–33.
9. Ershova I., Poruchikov D., Vasiliev A., Samarin G., Ruzhyev V., Zhukov A., Normov D. Technical and economic efficiency assessment of heat pump electric regulator application on agricultural object. International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies. – 2019. Vol. 10. No 6. – P. 877-885.
10. Ershova I.G., Uezdny N.T., Naumenko O.V., Novikova G.V. The economic efficiency of the use of microwave installations for baking bakery products // International Scientific, Theoretical and Applied Journal "Bulletin of the Chuvash State Pedagogical University named after I. Ya. Yakovlev." - Cheboksary: CSPU, 2013. - No. 2 (78). - P. 167–170.
11. Uchevatkin A.I. Bogoyavlenskii V.M., Lavrov V.A. Methods of research of technological systems for processing agricultural products as an object of management // FSEI HPE MGAU. M .: Agroengineering. 2007. N1 (21) .C. 48-49.
12. Uchevatkin A.I., Bogoyavlenskii V.M., Lavrov V.A. Control algorithms for discrete-controlled electric drives in the cooling system on technological lines of agricultural processing Products // Vestnik FSEI HPE MGAU. M .: Agroengineering. 2007. N 1 (21). 40-47.
13. Uchevatkin A.I., Bogoyavlenskii V.M., Lavrov V.A. Synthesis of a control system for discrete-controlled electric drives of a cooling system for technological processing lines of agricultural Products // Vestnik FSEI HPE MGAU. M .: Agroengineering, 2007. N 1 (21). 21-25.

