Energy Characteristics of Agricultural Processing Lines

1Ershova Irina, 2Vasilyev Alexey, 3Samarin Gennady, 4Tikhomirov Dmitry, 5Kudryavtsev Alexander, 6Poruchikov Dmitrii, 7Ukhanova Viktoria

1, 2, 3, 4, 6, 7 Federal Scientific Agroengineering Center VIM, Russian Federation, Moscow, 1-y Institutsky proezd, 5
5Scientific and Production Association. S.A. Lavochkin: Khimki 2, Leningradskaya Street
Email: eig85@yandex.ru, vasilev-viesh@inbox.ru, samaringn@yandex.ru, tihda@mail.ru, kudralex94@yandex.ru, dv.poruchikov@yandex.ru, v.ukhanova@owen.ru

Received: 20th April 2020, Accepted: 05th May 2020, Published: 30th June 2020

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.
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].

\[
\sum_{j=1}^{M} \sum_{m=1}^{K} \sum_{i=1}^{n} (W_{1}, W_{2}, \ldots, W_{j}, \ldots, W_{n}) = \\
= \sum_{j=1}^{M} \sum_{m=1}^{K} \sum_{i=1}^{n} (W_{1}', W_{2}', \ldots, W_{j}', \ldots, W_{n}') + \\
\sum_{j=1}^{M} \sum_{m=1}^{K} \sum_{i=1}^{n} (W_{1}'', W_{2}'', \ldots, W_{j}'', \ldots, W_{n}'')
\]

Where \(W_{i}\) is the amount of energy supplied to the i-th device of the m-th machine of the j-th link; \(W_{i}'\) - the amount of energy spent by the i-th device of the m-th machine of the j-th link to perform useful work; \(W_{i}''\) - 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].
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 |
|-------------------------------------------------------------|-------------------------|-------------------------------------------|
| Air separator pump                                          | 1.1, 4.5, 3.5           | 4, 1.1, 3.6, 4                           |
| Milk pump                                                   | 1, 1.1, 4.5             | 1, 1.1, 4.5, 1                           |
| Refrigeration compressor                                    | 2, 15, 6.0              | –, –, –, –                              |
| Coolant pump                                                | 2, 1.5, 6.0             | 1, 1.5, 6.0, 1                          |
| 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                          |
| Milk delivery pump                                         | 1, 0.75, 1.5            | 1, 1.1, 1.4, 1                          |
| Flashing pump                                               | 1, 7.5, 3.0             | 1, 7.5, 3.0, 1                          |

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

| Energy input, kWh | Energy consumed, kWh | Designation | Value | Designation | Value |
|-------------------|----------------------|-------------|-------|-------------|-------|
| $\Sigma W_1$      | $W_{mv}$            | 432.92      | 48.10 | $\Sigma W_1$ | 204.65 |
| $W_v$             | $W_{mv}$            | 20.4        | 15.84 | $W_v$       | 19.3  |
| $W_c$             | $W_{mv}$            | 7.0         | 4.56  | $W_c$       | 5.5   |
| $W_k$             | $W_{mv}$            | 101.7       | 50.0  | $W_k$       | 24.0  |
| $W_o$             | $W_{mv}$            | 28.0        | 24.0  | $W_o$       | 9.0   |
| $W_x$             | $W_{mv}$            | 11.1        | 11.7  | $W_x$       | 11.7  |
| $W_m$             | $W_{mv}$            | 3.0         | 2.3   | $W_m$       | 2.3   |
| $W_d$             | $W_{mv}$            | 26.0        | 1.54  | $W_d$       | 1.54  |
| $W_6$             | $W_{mv}$            | 260,16      | 0.46  | $W_6$       | 0.46  |
| $W_7$             | $W_{mv}$            | 34.98       | 22.5  | $W_7$       | 22.5  |
| $W_8$             | $W_{mv}$            | 34.98       | 3.5   | $W_8$       | 3.5   |

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 $\Sigma W_1$.

$$\Sigma W_1 = \Sigma W_{AB} + W_{AB}.$$

Where $\Sigma W_{AB}$ – energy losses during milk cooling in pipelines and when it is delivered to a milk tanker vehicle;

$W_{AB}$ – milk energy transferred by the coolant to atmospheric air.

The second group $\Sigma W_2$ includes the energy flows of the process line links (air-separation pumps $W_v$, transporting $W_c$, $W_d$ and mixing pumps $W_m$, coolant pumps $W_x$ and washing systems $W_n$), 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.
\[ \sum W_2 = \sum W'_2 + \sum W''_2 , \]  

where \( \sum W'_2 \) is the energy spent by the links on the technological process: removing milk from the vacuum line \( W'_6 \), moving milk through pipelines \( W'_c, W'_o \), stirring it in tanks during storage \( W'_M \), moving coolant \( W'_4 \), moving washing water and solutions through pipelines when washing technological equipment and the system as a whole \( W'_H \); \( \sum W''_2 = W''_6 + W''_c + W''_M + W''_X \); - energy loss in the process of energy converting from electrical to mechanical type.

\[ \sum W_3 = \sum W'_3 + \sum W''_3 , \]  

where \( W'_3 \) is the energy expended in compressing the coolant vapours \( W'_K \) and moving the circulating water to cool the condenser of the cooling unit \( W'_C \); \( \sum W''_3 = W''_K + W''_C \) - energy losses in the process of converting energy from electrical to mechanical type.

The fourth group of energy consumers includes the energy flows \( \sum W_4 \) of the cooling tower fans, since a cooling tower is not needed in the production line with energy-saving technology

\[ \sum W_4 = \sum W'_4 + \sum W''_4 \]  

where \( \sum W'_4 \) is the total energy spent on moving air to cool the water in the tower; \( \sum W''_4 \) - 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 \( W_5 \) farm's water supply sources and the energy spent on heating the water to flush the system \( \sum W_6 \)

\[ \sum W_6 = W'_6 + W''_6 \]  

where \( W'_6 \) - the energy lost when cooling water in pipelines during flushing; \( W''_6 \) - 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

\[ \sum W'_{em} = \sum W'_{2} + \sum W'_{4} \]  

Thermal energy lost with water and milk.
\[ \sum W_1 = W_1 + \sum W_2 + W_3 + W_4 \] 
\[ \sum W_5 = \sum W_6 + W_7 \]

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

\[ \sum W_1 + \sum W_2 + \sum W_3 + \sum W_4 + \sum W_5 + \sum W_6 = \sum W_1 + \sum W_2 + \sum W_3 + \sum W_4 + \sum W_5 + \sum W_6 \]

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 \( W_1 \) (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 \( \sum W_3 + \sum W_4 \), 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 \( W_k \), circulating water pumps \( W_o \), and cooling tower fans \( W_4 \). 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

\[ \sum W_1 + \sum W_2 + \sum W_3 + \sum W_4 + W_5 + \sum W_6 + W_7 = \sum W_1 + \sum W_2 + \sum W_3 + \sum W_4 + W_5 + \sum W_6 + \sum W_7 \]

For the cold season

\[ \sum W_1 + \sum W_2 + \sum W_3 + \sum W_4 + W_5 + \sum W_6 + W_7 = \sum W_1 + \sum W_2 + \sum W_3 + \sum W_4 + W_5 + \sum W_6 + \sum W_7 \]

Where \( W_7 \) is the regenerated energy for preheating the water used to flush process equipment and the system as a whole; \( W_{\text{mn}} \) - energy of the water used for the technological needs of the farm.

The regenerated heat energy \( \sum W_7 \) which is used to heat water for the needs of the farm and flush the system, is determined from the expression

\[ \sum W_7 = W_7 + W_{\text{mn}} \]

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

\[ N_{ah} = T_f \left( N_{te} - Q_n \right) / T_{ts} \]

Where \( N_{ah} \) is the required cooling capacity of the cooling unit in existing milk cooling systems, kW; \( Q_n \) 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.

\[ \sum W_p = W_7 + W_{\text{mn}} \]

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.

\[ \sum W_{xy} = \left( \sum W_3 + \sum W_4 \right) \]

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.

\[ \sum W_{xy} = \sum W_3 / 2 + \sum W_4 \]

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.
| 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 |
| **ENERGY INPUT**        |                                                       |                                         |         |               |             |             |
| Thermal energy with milk| Electric motors: milk, water, coolant pumps, compressors, fans, Electric heaters | W1M  | 318,78 | 318,78        | 432,92      | 204,65      |
|                         |                                                       | W1E1 | 318,78 | 67,67         | 69,5        | 65,83       |
|                         |                                                       |     | 79,7   | 259,4         | 129,7       |             |
|                         |                                                       |     | 23,4   | 253,1         | 253,7       | 258,1       |
|                         | Links of thermal action including seasonal            | W1E2, W1E3 | 32,6   | 230,4         | 301,2       | 159,6       |
|                         |                                                       |                                         | 293,08  | 255,91        | 253,72      | 258,1       |
| Thermal energy with water and air | Electric water heater, heat exchanger, cold accumulators. | W1V1, W1vозд | 32,56 | 230,39 | 301,22 | 159,56 |
|                         |                                                       |                                         | –       | 37,17         | 39,36       | 34,98       |
| **ENERGY CONSUMPTION** |                                                       |                                         |         |               |             |             |
| Mechanical energy       | Milk, water, coolant pumps; compressors, reverse water pumps; cooling tower fans. Warm water reservoir | W2V   | 64,3   | 54,92         | 56,18       | 53,65       |
| Thermal energy          |                                                       | W2M  | 54,92  | 57,0          | 114,0       | –           |
|                         |                                                       | W2E1, W2E1 | 228,0  | –             | –           | –           |
|                         |                                                       |     | 18,0   | –             | –           | –           |
|                         |                                                       |     | –      | 428,39        | 563,35      | 263,43      |
| **ENERGY LOSSES**      |                                                       |                                         |         |               |             |             |
| Thermal energy          | Pipelines, reservoirs, milk tanker vehicles, etc.     | W3T1, W3T2 | 664,42 | 413,86 | 433,87 | 393,86 |
| Electro-mechanical energy| Electric motors: milk pumps, water pumps, compressors, etc. | W3T3, W3E1, W3E2 | 20,8  | 12,75 | 13,32 | 12,18 |
|                         |                                                       | W3T3 | 413,86 | 12,75         | 13,32       | 12,18       |
|                         |                                                       | W3E1 | 433,87 | 7,85          | 15,7        | –           |
|                         |                                                       | W3E2 | 393,86 | –             | –           | –           |
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.