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Factors influencing the energy efficiency in dairy processing plants

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Summary. Panel heat exchangers (pasteurizers) are commonly used for the pasteurization of milk and dairy products. In the sterilization process sterilized tubes (sterilizers) are the most common solutions. Methods of increasing heat transfer efficiency were split into two groups. The first one includes methods used at the design stage (panels profiling, selection of the heat exchanger). The second group refers to methods that can be used during the use of heat exchangers (regulation of media flow intensity, control of the cleaning process frequency). The results of calculation of the impact of the deposits formation on the walls of the exchangers and the efficiency of energy conversion into the energy efficiency of four types of dairy plants were presented.

Key words: heat exchangers, dairy industry, energy efficiency, intensity of media flow, heat transfer coefficient, steam boilers.

SYMBOLS AND ABBREVIATIONS

A_C – 24 hour total thermal energy consumption in a dairy plant, [GJ/24h];
A_4 –24 hour thermal energy consumption necessary to obtain final products (energy used before the modernization), [GJ/24];
$A_{C41;}\,A_{C42}$ – 24 hour thermal energy consumption necessary to obtain final products (energy used after the modernization) (where η_{41} and η_{42}), [GJ];
d_1 – inner diameter of tubes, [m];
d_2 – outer diameter of tubes, [m]; Index *os* –deposit, *s* –wall of a tube;
EE_C – energy efficiency before the modernization ($EE_C = 1/\,W_C^{-1}$), [dm^3/GJ];
EE_{C41} ; EE_{C42} – energy efficiency after the modernization (where η_{41} and η_{42}), [dm^3/GJ];
$\%EE_{C41}$;$\%EE_{C42}$ – energy efficiency increase after the modernization (where η_{41} and η_{42}), [%];
F – heat transfer surface, [m^2];
k – heat transfer coefficient, [W/(m^2·K)];
L – tube length, [m];
$\dot{Q}$ – current thermal power, [W];
$\dot{Q}_{max}$ – maximum thermal power possible, [W];
W_C – unit thermal energy consumption [GJ/1000 l];
W_{C41}; W_{C42} – unit energy consumption indicators after the modernization where η_{41} and η_{42} , ($W_{C41} = A_{C41}/Z$; $W_{C42} = A_{C42}/Z$), [GJ/1000l];
Z – 24 hour production volume, [m^3/24h];
α_1 – heat transfer to the inner surface coefficient, [W/(m^2·K)];
α_2 – heat transfer to the outer surface coefficient, [W/(m^2·K)];
η – heat exchanger thermal efficiency;
η_1 – partial efficiency of transformation at stage 1;
η_2;η_{21} – partial efficiency of transformation at stage 2 before and after the modernization;
η_3;η_{31} – partial efficiency of transformation at stage 3 before and after the modernization;
η_4;η_{41};η_{42} – overall efficiency of transformation in production plants;
λ – thermal conductivity of the tubes material, [W/(m·K)];
ΔB_{U41};ΔB_{U42} – energy savings expressed by coal equivalent where η_{41} and η_{42}($\Delta B_{U41} = \frac{300\Delta_{41}}{29,3076}$;$\Delta B_{U42} = \frac{300\Delta_{42}}{29,3076}$), [Mg/year];
Δt_m – average logarithmic temperature difference, [K] or [^{o}C];
$\Delta_{41\,;}\,\Delta_{42}$ – decrease of thermal energy consumption where η_{41} ($\Delta_{41} = A_C - A_{C41}$) and where η_{42} ($\Delta_{42} = A_C - A_{C42}$), [GJ/24h];
SE_{41};SE_{42} – decrease of energy consumption during a year period $300\Delta_{41}$ and $300\Delta_{42}$ (where η_{41} and η_{42}), [GJ/year];

INTRODUCTION

Thermal processing of food is done to reduce the concentration of harmful substances such as bacteria or their spores. The product quality is affected by heat processes and sediments accumulated on the walls of the exchangers, formed by the reaction of milk components to the temperature. In dairy industry plate and pipe heat exchangers are commonly used. Efficiency is a concept with no clear empirical content. It may be regarded as a feature of efforts to achieve a positive outcome. Specific energy consumption (SEC-Specific Energy Consumption) varies depending on the type of dairy plant as well as on the efficiency of the thermal treatment of raw material. The possibilities of saving energy were presented by [5]. In the cited works a complete answer to the question what is the correlation between the state of surface contamination of heat exchangers and the conversion of energy efficiency and demand for energy carriers by the processing plant, was not found. Patterson (1996) made various attempts to organize concepts in this area. The aim of this study is to analyze the possibility of increasing the heat transfer efficiency especially in the heat exchangers and to analyze the efficiency of energy conversion and its impact on energy consumption of dairy plant. The scope of work includes discussion of the example of two types of heat exchangers (plate and pipe) and on two levels (methods used by heat exchangers users and methods used by the designers of these devices). The calculations take into account the thermal efficiency of steam boilers in four types of dairy plants.

PURPOSE AND METHODS

DEFINITION OF EFFICIENCY

Efficiency is commonly regarded as the result of economic activity, being this an indicator of the result obtained to the input made. Efficiency means positive outcome, effectiveness, process efficiency. The efficiency assessment is often associated with the relationship between the amount of manufactured products or outcomes (effects, results), and the quantity of factors used in the production process, i.e. inputs. Energy efficiency can also be defined as a reduction of energy consumption that occurs during processing, transmission, distribution or final use affecting the changes in technology, providing the same or higher level of production [22, 16]. Definition of energy consumption indicators (kWh/1000 liters of milk) and fuel consumption (GJ/1000 liters of milk), etc., allows for the control the energy efficiency of the plant. Nowadays the efficiency concept is often combined with eco-efficiency, aiming to achieve high environmental standards, and these translate into reduction of processing plant negative impacts on the environment.

According to Kostowski [10] thermal efficiency η of the exchanger is expressed as a relationship of two thermal powers:

$$\eta = \frac{\dot{Q}}{\dot{Q}_{\max}}, \tag{1}$$

where: the maximum possible value $\dot{Q}_{max}$ is limited in the heat exchanger by the factors temperature difference on their entrance to the exchanger. In the further analysis efficiency η will be regarded as efficiency defined by heat stream $\dot{Q}$ obtained from the equation:

$$\dot{Q} = kF\Delta t_m. \tag{2}$$

From an industrial point of view (i.e. the final product) in order to increase the efficiency of heat transfer in various heat exchangers, we should seek to maximize the value of $\dot{Q}$. In the present model $\dot{Q}_{max}$ assumes a constant value, so that the growth achieved in the heat flux will increase the overall efficiency η.

At the same time the production process requires $\dot{Q}$ value to be constant and it is regarded as the energy input. Under these conditions $\dot{Q}_{max}$ should be as large as possible, to achieve the greatest value of the thermal efficiency coefficient η. The energy efficiency of the processing plant is expressed as EE indicators, being these the inversion of specific energy consumption.

INCREASING THE EFFICIENCY OF HEAT TRANSFER IN HEAT EXCHANGERS

Methods for improving the efficiency of heat exchange are: choosing the right plate profile and the corresponding profile of the heat exchanger, appropriate control of flow rate and the proper cleaning of the heat exchanger.

Plate profile. Each plate consists of three basic elements A, B & C (Figure 1).

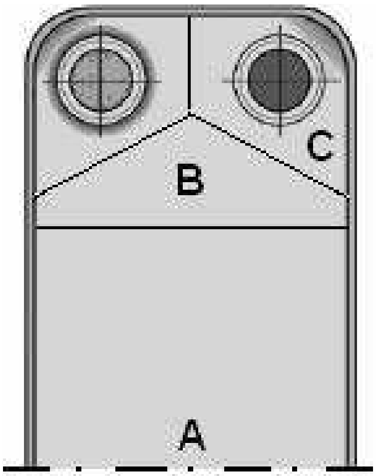

Fig. 1. Main parts of the plate in the heat exchanger: A - the main heat exchange zone at mid-plate, which is a critical area to produce a flow of high turbulence, according to the required pressure drop, B - the area of distribution at the top and bottom plates, corresponding to a uniform media distribution across the width of the plate and eliminating “dead “spaces, C - the main element of the corner of the plate - for a low inlet pressure and lower flow speed (connectors allow factors supplying / discharging to / from the heat exchanger).

The process of flow (exchange) begins where the holes are located (Figure 1-C). Plates with blind holes make it possible to change the direction of factor flow, thus creating a multi-circulation system (serial, parallel or mixed). Then the fluid flows through the area B to produce heat transfer in the center of the plate.

The size of the panel surface results in its shape, which is the way its profile is carved. The panel is strongly "wrinkled", which increases its surface area and provides greater stiffness [11]. Bansal et al. [1] have demonstrated a correlation between the shape of the panel and the tendency to the formation of sludge. It was found that the material of which the heat exchanger surface is made has an influence on the formation of impurities during the thermal processes to which the milk is subjected during its processing [18, 23].

Selection of heat exchanger. The selection of heat exchanger is supported by computer programs, prepared by the manufacturers. The parameters to be taken into consideration when choosing a heat exchanger are: the initial (input) and final (output) temperatures of factors between which the exchange of heat takes place, the flow rate of these factors, the heat transfer coefficient, the flow of heat exchanged and the heat transfer surface. When selecting the heat exchanger surface supply should be considered. The study Zander & Zander [26] describes the course of design processes when composing connection configuration in a panel heat exchanger. In the study [20] a mathematical model was formulated to predict accumulation of milk sediment (stone) in the heat exchanger as a function of time and place. [13, 14] developed a model that allows control of temperature and vapor pressure.

Liquids flow intensity. To obtain the objective intensity of the heat flow, it is necessary to ensure adequate temperature difference. In industrial practice, temperature process of milk heat processing is archived for a period of two years. [6] developed the concept of automatic process control system of milk pasteurization and visualization of this process enabling the control of the process. Reducing the milk flow intensity will increase the duration of heat exchange. In this case, the heat exchanger efficiency expressed in l / h is reduced, so that less quantity of product will be processed. It means that the heat exchanger lost its efficiency. It was found that there is a correlation between the rate of contamination accumulation and the Reynolds number. There is also a correlation between the air content in milk and air pollution. If the air content in milk is less, less sediment is produced [3, 9].

The washing process. The presence of contaminants is a transition state, as they are removed during the washing process. The cleanliness of machinery and equipment incorporated in the production line is of great importance in maintaining hygienic conditions during milk processing. So far a complete mechanism of milk stone formation in heat exchangers has not been presented. There are two types of milk sediments. The first is the relatively soft sediment, formed at 75-115°C temperature. Due to its high protein content (50-70% mass), this type of stone is called protein stone. The second type of sediment is formed at higher temperatures, above 110°C. It is hard, it has a granular structure with a high mineral content (up to 80% mas.) and therefore it is called mineral sediment. Studies have shown that β-lactoglobulin plays a major role in the sedimentation process. The amount of sediment increases with time, i.e. with prolongation of heat exchanger work and depends on the heat exchanger section (regenerative, heating) [23]. The most common solution is the CIP cleaning method (cleaning in place). In the industry two types of CIP cleaning can be used: 1 – two-phase cleaning using alkali (usually sodium hydroxide) and then using acids (nitric or phosphoric acid), 2 – one phase cleaning using detergents containing wetting agents, surface agents or chelated compounds.

There are three solutions to minimize or reduce the formation of pollutants: 1 - modify the heat treatment process, to which a liquid is subjected, through changes in the temperature profile;

2 - modification in the design of the heat exchanger by changes in configuration or in the final surface of the heat exchanger;

3 - modifying the milk liquid processed, for example, by adding oxidizing agents to prevent the particles merging.

EFFECT OF SEDIMENT LAYERS ON HEAT TRANSFER DETERIORATION

This aspect will be shown using the example of milk cooling after pasteurization process. The calculations assumed that this process takes place in seven pipe heat exchanger. Temperature range of factors is respectively: for milk 75-30°C, for water 5-30°C, which means that the milk is cooled to a temperature of 30°C. Heat transfer coefficient k_1 for pipe compartments is determined by the formula (3):

$$\frac{1}{k_1} = \frac{1}{\alpha_1 d_1} + \frac{\ln \frac{d_2}{d_1}}{2\lambda_s} + \frac{\ln \frac{d_{2os}}{d_{1os}}}{2\lambda_{os}} + \frac{1}{\alpha_2 d_2} \tag{3}$$

The heat flow, including different sediment thicknesses is determined by the formula (4):

$$\dot{Q} = k_1 \pi L \Delta t_m \tag{4}$$

PLANTS CHARACTERISTICS, USE OF STEAM BOILERS AND ENERGY EFFICIENCY OF PRODUCTION PROCESS

There was used a methodology contained in the work of Wojdalski & Kaleta [7], in which three stages of energy efficiency partial conversion η_1, η_2 and η_3 were adopted. The study takes into account the working conditions of steam boilers and relationships mentioned in the work of Szargut & Ziębik [2, 21], [8]. Next, the energy efficiency of four types of dairy plants (Table 1) were analysed, with different values of transformation efficiency at stages 2 and 3. Table 2 contains figures derived from the four types of individual dairy plants [7]. Partial conversion of energy efficiency η_1, η_2, η_3 and η_4 was presented.

Table 1. Types of analysed dairy plants

Types of plants	Processing characteristics
T1	Drinking milk, milk beverages, cream, curds, cheese, butter, casein, milk powder
T2	Processing structure similar to type T1 plants, but without milk powder production
T3	Processing structure similar to type T1 plants but without drinking milk, milk beverages, cream and curds production
T4	Exclusive production of drinking milk, milk beverages, cream and curds

Table 2. Input data for calculations, before the introduction of improvements

Item	Analysed plant			
	I (T1)	II(T2)	III(T3)	IV(T4)
A_C [GJ/24h]	432.60	119.00	148.10	59.30
W_C [GJ/m^3]	2.3207	1.3607	1.5542	1.0882
EE_C [dm^3/GJ]	430.9	734.9	643.4	918.9
Z [m^3/24h] (scope)	185 (180-188)	89 (84-91)	95 (90-116)	54 (50-62)
η_1	0.993	0.992	0.989	0.996
η_2	0.661	0.682	0.710	0.697
η_3	0.708	0.742	0.713	0.720
η_4	0.465	0.502	0.501	0.500
A_{41} [GJ/24h]	201.16	59.74	74.15	29.65

24 hour consumption of thermal energy (A_C), specific consumption of thermal energy (W_C), production energy efficiency (EE_C), the average production value (Z) and the ranges of its variation were taken into account. It was found that before modernization the partial performance changes for individual plants were: η_1 η_2 and η_3.

The overall record of changes for individual plants is described by formulas (5) and (6):

$$\eta_1 \cdot \eta_2 \cdot \eta_3 = \eta_4 \quad \text{whereas} \quad \eta_4 = \frac{A_4}{A_C}. \qquad (5),(6)$$

Thus:

$$A_4 = \eta_4 \cdot A_C$$

As a result of changes which improve heat transfer and increase thermal efficiency of a steam boiler two options were considered to increase energy efficiency of dairy plants.

Option I

The increased efficiency of transformation only at the stage 3 (devices for milk heat treatment) was considered, and the ratio η_3 increased to η_{31}. These coefficients took the intermediate values between the conditions of heat exchange for panels without sediment and the layers of milk and boilers sediment.

Thus, the overall record of change is expressed in the following form (formula 7):

$$\eta_{41} = \eta_1 \cdot \eta_2 \cdot \eta_{31}. \qquad (7)$$

It was assumed that input energy level A_{41} did not change (A_4=A_{41}). Thus:

$$\eta_{41} = \frac{A_{41}}{A_{C41}} \quad \text{and} \quad A_{C41=} A_{41}/\eta_{41}. \qquad (8)$$

24 hour reduction of energy consumption for individual plants is:

$$\Delta_{41} = A_C - A_{C41}. \qquad (9)$$

Thus year reduction of thermal energy consumption (300 24 hour periods/year) SE is:

$$SE_{41} = 300 \cdot \Delta_{41}. \qquad (10)$$

Option II

It was assumed that increased performance took place also at the stage 2, and that stem boiler thermal efficiency coefficient η_2 increased to η_{21}. Input energy volume A_{41}=A_{42}. The overall record of changes is expressed:

$$\eta_{42} = \eta_1 \cdot \eta_{21} \cdot \eta_{31}, \qquad (11)$$

$$\eta_{42} = \frac{A_{42}}{A_{C42}} \quad \text{and} \quad A_{C42=} A_{41}/\eta_{42}. \qquad (12)$$

24 hour and year reduction of energy consumption SE for individual plants is respectively:

$$\Delta_{42} = A_C - A_{C42} \quad \text{and} \quad SE_{42} = 300 \cdot \Delta_{42}. \qquad (13),(14)$$

Specific thermal energy consumption indicators W_{C41} and W_{C42} were calculated. Energy efficiency for individual plants is expressed:

$$EE_{41} = \frac{1}{W_{C41}} \quad \text{and} \quad EE_{42} = \frac{1}{W_{C42}}. \qquad (15),(16)$$

Energy efficiency increase for individual plants was expressed by means of indicators $\%EE_{41}$ and $\%EE_{42}$. Year savings of coal equivalent (ΔB) obtained as a result of increased transformation performance for every option (with η_{41} and η_{42}) were expressed as ΔB_{U41} and ΔB_{U42}.

RESULTS AND DISCUSSION

Figure 2 shows the changes in heat stream $\dot{Q}_{os}$ caused by the formation of sediment in relation to the heat stream in the heat exchanger without sediment $\dot{Q}$ of milk and/or boiler stone of different thicknesses. In the case 5, 6 and 7 the situation of stone rising from the outer side of the tubes was shown. Heat exchangers are washed regularly from the side of food product flow. But there is also stone formation from the water side, especially if it is hot water. Dairy plants use treated water, which contributes to the slower formation of stone. So in the case of pasteurization both milk stone (the common one) and boiler stone (much less often) may appear. Case 8 describes the critical situation in which the sediment is formed on both sides of the tubes.

Fig. 2. Changes of heat stream $\dot{Q}_{os}$ caused by sediment formation in relation to heat stream in a heat exchanger with no sediment $\dot{Q}$: 1-no sediment; 2-milk stone of 0.12 mm thick;3-milk stone of 0.28 mm thick; 4-milk stone of 0.55 mm thick; 5- boiler stone of 0.14 mm thick; 6-boiler stone of 0.3 mm thick; 7-boiler stone of 0.6 mm thick; 8-milk stone of 0.55 mm thick inside the tube and boiler stone of 0.6 mm outside the tube.

Figure 2 shows that the sediment significantly reduces the value of heat stream exchanged. This stream decreases when increasing the sediment thickness, thus the milk stone affects more the heat transfer than boiler stone. Milk sediment of 0.12 mm thick (case 2) makes that heat stream is 0.67 of exchanged heat stream in the heat exchanger without sediment; the sediment of 0.28 mm thick (case 3), this value is 0.46 and for sediment of 0.55 mm thick (case 4) is only 0.30. In case of boiler stone the relationship of heat stream exchanged in an exchanger without sediment is respectively: for sediment of 0.14 mm thick (case 5) 0.70, for sediment of 0.30 mm thick (case 6) 0.53 and for sediment of 0.6 mm thick (case 7) 0.36. More adverse effect of milk stone on heat exchange is caused by lower value of its thermal conductivity coefficient compared to the same coefficient for boiler stone.

If both types of sediment occur simultaneously (case 8) this parameter is 0.19. It should be noted that the analyzed cases 5, 6 and 7 may also partially cover the inner surfaces of the steam boiler especially in the case of using water, which was not fully treated or residual deposits [12]. The calculation of the energy efficiency of the plant in the option I in accordance with the adopted methodology takes into account the partial efficiency indicators increasing from η_3 to η_{31}, that in cases 1-2 and 1-5 are respectively, above 0.67 and 0.70 (Figure 2). Option II also included increasing the thermal efficiency of steam boilers, which was affected by a number of additional factors cited in the work of [24]. The greatest savings were obtained for plants equipped with powdered milk processors. Using only option I led to annual savings of 3528 GJ and using it together with option II enabled to reduce energy demand by 7122 GJ (Table 3). Plants of this type are also the bigger energy consumers most energy intensive of the four types mentioned [4].

Prior to the introduction of improvements to process 1000 liters of milk 2.3207 GJ was consumed in the plant, it means more than double in the plant type IV (T4). At the same time energy efficiency of the plant type IV (T4) was highest among those listed in Table 4.

This was associated with the smallest range of thermal treatment and the least number of manufactured products (Table 1). Due to the smallest size of the daily processing Z, annual savings amounted to only 1317 GJ (Table 3). This represented about 5.4 times less in comparison with the biggest plant of type I (T1) equipped with powdered milk processor. The largest overall increase in energy efficiency occurred in plants of type II (T2) and III (T3), of respectively 13.1% and 12.9%. This increase resulted from the biggest improvement of transformation efficiency expressed as η_{21} and η_{31}. Increase of heat exchange efficiency in each plant (at stage 3) affected the energy efficiency improvement of entire plants from 2.01% in the plant type I (T1) to 7.72% in the plant type III (T3). At the same time, Table 4 shows that increasing the transformation efficiency at stage 2 led to increase of entire plants energy efficiency from 5.01% in the plant type I (T1) to 13.10% in the plant type II (T2). It should be highlighted that understanding the mechanism of thermal insulation failures and their elimination could also improve the energy efficiency of dairy plants (Perz 2009). To identify service failures of insulation systems thermography can be used [15, 17]. In studies on heat transfer the work of Kaljuzhnyj et al. (2010) can be useful.

Table 3. Plants characteristics after improvements

Item	Analysed plant			
	I(T1)	II(T2)	III(T3)	IV(T4)
η_1	0.993	0.992	0.989	0.996
η_{21}	0.681	0.721	0.744	0.708
η_{31}	0.728	0.781	0.770	0.766
$\eta_{41}=\eta_1\cdot\eta_2\cdot\eta_{31}$	0.478	0.528	0.541	0.532
$\eta_{42}=\eta_1\cdot\eta_{21}\cdot\eta_{31}$	0.492	0.558	0.567	0.540
A_{C41} [GJ/24h]	420.84	113.14	137.06	55.73
A_{C42} [GJ/24h]	408.86	107.06	130.78	54.91
$\Delta_{41} = A_C - A_{C41}$ [GJ/24h]	11.76	5.86	11.04	3.57
$\Delta_{42} = A_C - A_{C42}$ [GJ/24h]	23.74	11.94	17.32	4.39
$300\cdot\Delta_{41}$ [GJ/year]	3528	1758	3312	1071
$300\cdot\Delta_{42}$ [GJ/year]	7122	3582	5196	1317

Table 4. Increase of plants energy efficiency after improvements

Item	Analysed plant			
	I(T1)	II(T2)	III(T3)	IV(T4)
$W_{C41} = \frac{A_{C41}}{Z}$ [GJ/1000 l]	2.2748	1.2712	1.4427	1.0320
$W_{C42} = \frac{A_{C42}}{Z}$ [GJ/1000 l]	2.2100	1.2029	1.3766	1.0168
EE_{41} [dm^3/GJ]	439.3	786.9	693.1	969.0
$\%EE_{41} = \frac{EE_{41}}{EE_C}$ [%]	2.01	7.03	7.72	5.45
EE_{42} [dm^3/GJ]	452.5	831.3	726.4	983.5
$\%EE_{42} = \frac{EE_{42}}{EE_C}$ [%]	5.01	13.10	12.90	7.03
$\Delta B_{U41} = \frac{300\Delta_{41}}{29,3076}$ [Mg/year]	120.38	59.98	113.01	36.54
$\Delta B_{U42} = \frac{300\Delta_{42}}{29,3076}$ [Mg/year]	243.01	122.22	177.29	44.94

The results obtained refer to the study of Xu & Flapper (2011) relevant to energetic aspects of milk processing and the environmental impact of dairy production.

CONCLUSIONS

Based on the referred literature and own calculations we can say that heat transfer efficiency and energy efficiency of dairy plants may be affected by the following factors:

- Panel´s profile. More sculpted panels provide bigger heat exchange surface. There is a relationship between the plate pattern and a tendency to the sediment formation. Causing high turbulence profiles limit the accumulation of sediment which favors large values of the heat transfer coefficient.
- Selection of heat exchanger. Selection of heat exchanger is nowadays supported very often by computer programmes. Some of them take into account the formation of milk sediment.
- Flow intensity. Reducing milk flow intensity will increase the duration of heat exchange time and reduce the heat exchanger efficiency (l/ h). There is a relationship between the Reynolds number and the sediment accumulation speed.
- Washing process. If the heat exchange conditions are disturbed and the product leaving the heat exchanger does not reach the temperature required by the process technology, the installed devices should undergo a washing process in order to improve the working conditions of the pasteurizer / sterilizer.
- Washing removes the sediment of milk and boiler stone causing the decrease of heat transfer coefficient and therefore helps to increase heat exchange efficiency. Washing is a short-term process, but the effect persists over the entire cycle.
- For the adopted factors it was determined that the greatest amount of energy savings occur in plants with the highest daily milk processing and processing profile consisting of the largest number of manufactured products. The largest increase in energy efficiency was achieved in these types of plants in which the biggest improvement in total energy consumption of both individual changes of heat exchangers and steam boiler was reached.

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CZYNNIKI WPŁYWAJĄCE NA ZWIĘKSZENIE EFEKTYWNOŚCI ENERGETYCZNEJ ZAKŁADÓW MLECZARSKICH

Streszczenie. Przedstawiono wpływ czynników technologicznych i technicznych na efektywność wymiany ciepła i efektywność energetyczną zakładów mleczarskich. Wyniki obliczeń uwzględniają wpływ profilu płyty, doboru wymienników ciepła, natężenia przepływu cieczy, procesu mycia i sprawności cieplnej kotłów parowych. Dla przyjętych czynników określono efektywność energetyczną czterech typów zakładów mleczarskich. Największe możliwości zaoszczędzenia energii występują w zakładach o największym dobowym przerobie mleka i profilu przerobu składającego się z największej liczby gotowych wyrobów. Największy wzrost efektywności energetycznej uzyskano w tych typach zakładów, w których łącznie wystąpiła największa poprawa efektywności energetycznej poszczególnych przemian energii zarówno wymienników ciepła jak i kotła parowego. Wykazano, że zwiększenie sprawności przemian energii wpłynęło na wzrost efektywności energetycznej badanych zakładów od 5,01 do 13,10%.

Słowa kluczowe: wymienniki ciepła, przemysł mleczarski, efektywność energetyczna, natężenie przepływu, współczynnik przenikania ciepła, kotły parowe.