Opportunities for Improving Energy Efficiency in the Refrigeration Sector of a Milk Processing Factory

K. Kostov, I. Ivanov, I. Denev and D. Dinkov

***Abstract* - Energy efficiency for industrial facilities can be achieved by ensuring optimal flow of the production and technological process with the required quality at minimal energy consumption. Managing energy costs in a manufacturing enterprise is a key activity in the implementation of comprehensive energy management. It is known that in dairy processing plants the refrigeration sector occupies a significant share in their energy balance. From this point of view, any organizational or technical measure leading to a reduction in energy consumption can be considered an economical and energy-efficient solution. The article discusses and analyses the factors related to the possibility of reducing energy consumption in the refrigeration sector of a milk processing plant with a capacity of 4000 l / day of milk. It examines the implementation of energy-efficient equipment in the industrial facility under consideration and analyses the environmental benefits and the reduction of CO2 emissions. The scientific novelty is demonstrated by assessing the technical feasibility and economic feasibility of integrating new energy-saving technological units, as well as by proposing new ways of organizing the work of the refrigeration sector of the milk processing plant.**

***Keywords* – Energy efficiency, dairy plant, refrigeration sector, energy consumption.**

I. INTRODUCTION

With the recent changes in European [1] and Bulgarian legislation [2], the efficient conversion and use of energy is now considered a fundamental prerequisite for sustainable economic growth. The additional criteria introduced require a stronger promotion of cost-effective energy efficiency measures in all areas of the energy system and in all relevant sectors where activities affect energy demand, such as transport, the food industry and, last but not least, agriculture [3], [4], [5]. The legal frameworks introduced aim to accelerate the development and dissemination of innovative technological solutions, with the aim of improving the competitiveness of industry in the European Union and protecting the environment. Due to the presence of multiple interconnected technological units and facing increasingly intense market competition, for the sustainable development of dairy enterprises, it is necessary to save energy as much as possible.

Refrigeration systems, as part of the production chain of dairy enterprises, consume significant amounts of energy and therefore generate a large part of the operating costs. The refrigeration sector plays a critical role in maintaining milk processing operations, where temperature control is of utmost importance. The energy consumption and management of refrigeration installations in milk processing is significantly different. These systems consume large amounts of energy therefore, it is necessary to pay attention to their energy and cost efficiency.

The objective of this publication is, based on an energy efficiency audit, by applying a systematic approach that includes methods to identify, evaluate and analyse energy flows and costs, to identify possible ways to improve, increase the energy efficiency and economic profitability of the refrigeration system of the considered dairy plant.

II. SUBSTANTIVE PART

The structure of dairy plants is determined by the region and the market demand for various dairy products, [6], [7], [8].

The object under consideration is a dairy plant with a capacity of up to 4000 litters of processed milk per day. The dairy processes cow's milk all year round and sheep's milk seasonally. Sheep's milk is processed from April to July. The amount of milk of a given type accepted for processing does not exceed 2000 litters per day. White brine cheese and yogurt are produced from the processed milk. The whey that is left over during the production of white brine cheese is used for animal feed.

The technological process for the production of white brine cheese is divided into two stages. In the first stage, the milk cooled to the curdling temperature (35°C ÷ 36°C) is fed into the vats, in which the following processes are carried out: curdling of the milk, cutting of the curd, turning, draining of the whey, self-pressing, pressing, cutting of the cheese block and water salting. The separated whey is taken out of the production room via the whey system. The second stage involves closing the cheese in boxes, which are placed in a refrigerated ripening room with a temperature of 10 ÷ 12˚C, where the ripening is no less than 45 days. This stage is defined as the stage of true ripening of the cheese and its titratable acidity rises to 240 ÷ 250˚T. This is achieved after the fermentation of lactose to lactic acid during the first 10 ÷ 15 days.

Once the cheese has reached full ripening, one part of the boxes is opened and drained, and the drained cheese is cut into pieces weighing approximately 400 ÷ 500 g. These pieces are packed in hermetic vacuum packs using a vacuum packaging machine.

In the production of yogurt, the heat-treated yogurt is cooled to a temperature of 45 ℃ and fermented, the amount of starter required is determined by the volume of the milk prepared for fermentation and in accordance with various technological considerations, but is usually within 0.5 to 1.5%. Fermentation is carried out by feeding the production starter with a pump to the fermentation vessels sequentially and periodically.

After fermentation and packaging, the yogurt coagulates in a thermostatic chamber, where the temperature must be maintained within 42 to 45 ºC. This process continues until the acidity of the milk reaches 75 ÷ 80 °T or pH = 4.6 ÷ 4.7.

Intermediate cooling takes place in a refrigeration chamber for about half an hour until the milk temperature reaches about 25 ºC.

Then the milk must be further cooled to a temperature of 10 ºC, and moved to another refrigeration chamber. This transfer must be done very carefully due to the risk of breaking the not yet well-strengthened collagen.

At the end of cooling, the milk must have a titratable acidity of 115 ÷ 120 °T. The final cooling to a temperature of 2 ÷ 4 ºC takes place in a refrigerated storage chamber.

Figure 1 presents the technological scheme with the energy source. It clearly shows the great influence that the refrigeration sector has on energy consumption in the considered facility.

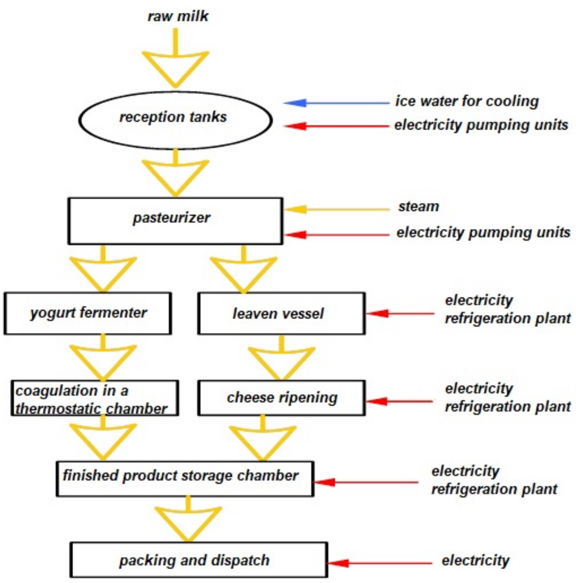

Fig. 1. The technological scheme of the dairy plant.

According to the technology, the refrigeration sector operates in an autonomous mode, with its automation ensuring normal operation of the individual components of the refrigeration plant. It consists of a chamber for intermediate cooling of yogurt, a chamber for pre-maturation, a chamber for maturing white brine cheese and a chamber for storing finished products.

From the analysis of the data, when compiling the balance of electrical energy, it is striking the high share (89%) of the electricity consumed by the production system for production needs. To ensure the necessary temperature for the technological processes of fermentation, maturation, storage of finished products, the refrigeration installation has the highest share.

When conducting an energy audit of a dairy plant, it is necessary to fully understand the energy consumption in order to identify opportunities for improvement without negatively impacting the production processes.

Since the publication deals with the refrigeration sector in particular, it is necessary to analyse the potential for temporary free cooling, to determine whether the capacity of the installation is suitable for the current load and whether the refrigeration equipment is not operating at partial load for extended periods.

The analysis was carried out by examining the current energy consumption in a 55m^2 cold storage chamber for the storage of finished products with a room temperature of 2°C.

The refrigeration capacity data of the cold room are presented in Table 1.

TABLE I
BASE CAMERA - CURRENT STATUS

№ and purpose of the cold chamber	room temperature	Q1	Q2	Q3	Qo
	ºC	W	W	W	W
Cold room No. 4 for storage	2	1650	4120	4845	10615

where:
Q_1 - heat flow through cooling surfaces;
Q_2 - heat flow for cooling;
Q_3 - operational heat flows.

The analysis of the calculations made for the consumption of cold shows that only the load through the enclosing elements and from opening the doors is variable during the year, while the remaining loads can be assumed to be constant.

If we assume that the cold load will be greatest at an outdoor air temperature of $t_{calc.}$ = +28ºC, then at t_{out} = -10ºC the load through the enclosing structures will be zero and the constant cold loads will remain.

Introducing the concept of power factor:

$$a = \frac{(t_{cam.} - t_{out.})}{(t_{cam.} - t_{calc.})} \quad (1)$$

then the product of this factor and the maximum cooling capacity calculated at $t_{calc.}$ = +28ºC, will give the consumed cooling capacity at any outdoor temperature different from $t_{calc.}$

By introducing this coefficient, the owner of the dairy company will be able to easily calculate his operating costs depending on the season, which in turn would allow him to forecast his costs. This, in turn, would allow the release of funds for the development of new activities, the reduction of the specific cost of the livestock production and the development of human resources in the company.

By analysing and processing the data, the obtained baseline energy results are presented in Table 2.

TABLE II
BASELINE - DAIRY PROCESSING SECTOR

№	Name	dimension	value	source
1	Annual production - Nin	t/y	1440	by reporting data

2	Annual cold losses of the refrigerator in existing conditions	kWh/y	39247	Calculated
3	Electricity consumed when operating compressors	kWh/y	14536	COP 2,7
4	Annual energy consumption before implementation of energy saving measures - Ein	MWh/y	14,536	C/1000

After compiling the baseline balance, it is necessary to proceed to determining the parameters according to the forecast line. Data on the refrigeration capacities of the chambers are shown in Table 3.

TABLE III
COOLING POWER OF THE CHAMBERS

№ of the refrigerated chamber	room temperature	Q_1	Q_2	Q_3	Q_o
	°C	W	W	W	W
refrigerated chamber 1	2	569	0	1312	1881
refrigerated chamber 2	2	491	841	1189	2521
refrigerated chamber 3	2	172	1280	1302	2754
refrigerated chamber 4	2	172	1280	948	2400
Total		**1404**	**3401**	**4751**	**9556**

The energy results by forecast line are presented in Table 4.

TABLE IV
FORECAST LINE - REFRIGERATION SECTOR FOR MILK PROCESSING

№	Name	dimension	value	source
1	Annual production - **Nexp**	t/y	1440	by reporting data
2	Annual cold losses from the refrigerator by design	kWh/y	37996	Calculated
3	Electricity consumed when operating compressors	kWh/y	12665	COP 3
4	Annual energy consumption after implementing energy saving measures - **Eexp**	MWh/y	**12,665**	G/1000

III. RESULTS

The energy savings factor (ESR) is calculated in relation to the energy consumption of systems and production processes within the scope of the measurement impact using the formula:

$$ESR = \left[\frac{\sum_{i=1}^{n} \left(\frac{E_{in}}{N_{in}} . N_{\exp} - E_{\exp} \right)}{\sum_{i=1}^{n} \left(\frac{E_{in}}{N_{in}} . N_{\exp} \right)} \right] .100 \quad (2)$$

where:

Ein – Energy consumption before the introduction of the measure;

Eexp – Energy consumption after the introduction of the measure;

Nin – Output produced before the introduction of the measure;

Nexp – Output produced after the introduction of the measure;

Ein/Nin – Specific consumption before the introduction of the measure;

Eexp/Nexp - Specific consumption after the introduction of the measure.

The calculated GHG emission reduction results are presented below in tabular form (Table 5).

TABLE V
CO_2 EMISSIONS - BASELINE

№	Name	**MWh**	emission factor gCO_2 / kWh	t/CO_2
1	Baseline energy consumption	14,54	**0,486**	7,07

CO_2 EMISSIONS - FORECAST LINE

№	Name	**MWh**	emission factor gCO_2 / kWh	t/CO_2
1	Energy consumption forecast line	12,67	**0,486**	6,16

Saved emissions t/CO_2	**0,91**	**t/CO_2**
Percentage of emissions saved %	**6,26%**	

The obtained values for the energy savings factor (ESR) from the energy audit of the refrigeration sector of the dairy processing plant provide the company operator with a clear picture of the energy consumption of the refrigeration installations and identify opportunities for improvement.

The energy audit performed proves that while maintaining the milk processing capacity, the installation is suitable, at constant load. Analysing the environmental effect of carbon emissions, the annual reduction is 0,91 t/CO_2.

The problem under consideration is not one-sided and depends on many factors, the main one for each investor being the economic effect of the introduced measures and how profitable the implementation of such a replacement of the refrigeration equipment is.

IV. CONCLUSION

The proposed energy saving solutions depend on the operation of the refrigeration plant and their application is linked to the correct selection and mode of operation of the equipment. This applies above all to the type of compressors, the refrigeration capacity factor, the choice of condensers and evaporators. As an expected result of this energy audit, positive changes are expected in the company's production process, products and marketing, by reducing energy costs and reducing the amount of harmful emissions released into the environment.

The resulting energy savings ratio (ESR) for the proposed energy saving measures is 12,87 % in terms of energy consumption. The energy savings resulting from the implementation of the measures amount to 1,871 MWh/year.

REFERENCES

[1] Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955

[2] Energy efficiency law, in force from 14.11.2008

[3] S. Snow, C. Clerc, N. Horrocks, Energy audits and eco-feedback: Exploring the barriers and facilitators of agricultural energy efficiency improvements on Australian farms, Energy Research & Social Science, Volume 80, 2021, 102225, ISSN 2214-6296, https://doi.org/10.1016/j.erss.2021.102225.

[4] C. Rodríguez, C. Rodas, J. Muñoz, Ap. Casas, A multi-criteria approach for comparison of environmental assessment methods in the analysis of the energy efficiency in agricultural production systems, Journal of Cleaner Production, Volume 228, 2019, Pages 1464-1471, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2019.04.388.

[5] V. Martinho, Energy consumption across European Union farms: Efficiency in terms of farming output and utilized agricultural area, Energy, Volume 103, 2016, Pages 543-556, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2016.03.017.

[6] A. Feil, C. Amaral, D. Schreiber, Al. Maehler, Sustainability performance of small and medium dairy enterprises in Brazil, Sustainable Production and Consumption, Volume 39, 2023, Pages 301-310, ISSN 2352-5509, https://doi.org/10.1016/j.spc.2023.05.024.

[7] G. Aikenhead, K. Farahbakhsh, J. Halbe, J. Adamowski, Application of process mapping and causal loop diagramming to enhance engagement in pollution prevention in small to medium size enterprises: case study of a dairy processing facility, Journal of Cleaner Production, Volume 102, 2015, Pages 275-284, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2015.04.069.

[8] J. Vayssières, F. Guerrin, J. Paillat, P. Lecomte, GAMEDE: A global activity model for evaluating the sustainability of dairy enterprises Part I – Whole-farm dynamic model, Agricultural Systems, Volume 101, Issue 3, 2009, Pages 128-138, ISSN 0308-521X, https://doi.org/10.1016/j.agsy.2009.05.001.