

ХОЛОДИЛЬНА ТЕХНІКА

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POWER EFFICIENCY OPPORTUNITIES FOR INDUSTRIAL REFRIGERATION SYSTEM OF FOOD PROCESSING ENTERPRISE

Rising prices on power supply are forcing business owners to search the ways of operating costs reducing. Refrigeration system in the food industry is a major source of power consumption. The utilization of cold accumulation systems allows reducing of refrigeration unit power consumption. In this paper the refrigeration system with a system of cold accumulation and dry cooling tower is considered. The possibility of power consumption reducing due to the organization of the enterprise refrigeration system operation process in the night period according to electricity multiple tariffs has been analyzed.

Key words: Refrigeration system, Three band tariff; Cold accumulation system, Energy efficiency, Dairy plant.

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ШЛЯХИ ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ ХОЛОДИЛЬНОЇ УСТАНОВКИ ПІДПРИЄМСТВА ХАРЧОВОЇ ПРОМИСЛОВОСТІ

Зростаючі ціни на енергоносії змушують власників підприємств шукати шляхи зниження експлуатаційних витрат. Холодильна установка на підприємствах харчової промисловості є одним з основних джерел енергоспоживання. Використання систем акумуляції холоду дозволяє зменшити споживання електроенергії холодильною установкою. В даній роботі розглянуто холодильну установку з системою акумуляції холоду та сухою градирнею. Проаналізовано можливість зниження витрат електроенергії за рахунок організації роботи холодильної системи підприємства в нічний період по тризонному тарифу на електроенергію.

Ключові слова: Холодильна установка; Тризонний тариф; Система акумуляції холоду; Енергоефективність; Молокозавод.



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I. INTRODUCTION

Nowadays, most of the Ukrainian industry is working very energy consuming. According to the Law of Ukraine «On Energy Saving» No. 783-XIV of the 1994 energy saving potential in industry in Ukraine is estimated at least as 25% of annual energy consumption. Given that energy costs are constantly rising, the task of implementing energy-saving technology is very relevant especially for the food industry, where there is a constant need for cooling.

The main motive of introduction of energy saving technologies in the enterprise is certainly lower operating costs. Another incentive – limits on energy consumption (eg, gas) for enterprises.

Energy conservation is often seen as something quite simple, such as the replacement of conventional incandescent light bulbs with LED or additional insulation of equipment and pipelines.

However, energy conservation requires a systematic approach and should include organizational and technical measures for the entire chain of receipt, transformation, transmission and consumption of the corresponding type of energy. Effectively solve the problem of energy conservation can only be comprehensive and best of all – at the stage of design work. In this paper energy consumption of dairy plant refrigeration unit was considered.

Milk is one of the most important products for human organism. The most effective and efficient way to maintain milk's quality and freshness is cooling. The demand on milk producers is to produce milk with a composition that meets the needs of consumers. The chemical processes depend on temperature control. At lower temperatures, chemical processes are slowed and spoilage of the product is delayed. Milk contains various nutrients that are essential for the life of all living beings. It is also the perfect growing medium for micro-organisms, although at 4 °C micro-organisms cannot duplicate and the microbiological spoilage of milk is avoided. After having

followed the right milking and hygienic procedures, quickly cooling milk to 4 – 3°C is the best way to avoid microbiological growth and chemical changes.

II. MILK COOLING SYSTEM REQUIREMENTS

Milk quality is assessed according to the European standard EN 13732-2013 “Food processing machinery. Bulk milk coolers on farms. Requirements for construction, safety and hygiene” This standard applies to refrigerated bulk milk tanks with air cooled condensing units

Table 1 – Classification by the cooling time of milk

Class	Installed cooling time for all milkings at a temperature between +35°C and +4°C, h
0	2
I	2,5
II	3
III	3,5

When using direct cooling mixer and install a condenser must work are interrelated, if the system is controlled by a thermostat.

When using the cooling system with an intermediate coolant stirrer and cooling medium circuit should work interconnected if they are controlled by a thermostat.

If the tank for two milkings is empty or contains 50% of its nominal volume at a temperature of +4°C and it is added at one time 50% of the nominal volume at a temperature of +35°C, the entire amount of milk to be cooled to a temperature of +4°C for a predetermined cooling time. If the tank for four milkings is empty or contains 25%, 50% or 75% of its nominal volume at a temperature of +4°C and it is added at one time 25% of the nominal volume at a temperature of +35°C, the entire amount of milk should be cooled to a temperature of +4°C during a predetermined cooling time.

The above requirements are applicable at ambient temperature between +5°C and temperature control.

In normal operation, supported by the milk temperature between cooling periods should not exceed +4°C. This requirement applies at an ambient temperature between +5°C and temperature control.

III. REFRIGERATION SYSTEM FOR DAIRY PLANT

Two types of milk cooling systems are used on dairy farms: direct expansion and with intermediate coolant. The system where the evaporator plates are incorporated in the lower portion of the storage tank in direct contact with the milk is called direct expansion system. Milk cooling takes place within the tank. One or more agitators move the milk over the evaporator plates for cooling. There is a limit to the size of refrigerated milk cooling and storage tanks due to structural issues. There is also a limit to the refrigerated surface area. The ability to remove heat from the milk fast enough to meet cooling requirements with high milk loading rates is not possible without reducing evaporator surface temperature to the point where freezing of milk may occur. This is particu-

larly challenging when milk temperatures approach 3°C. It is important to know that agitating milk for long periods of time can also be harmful to milk quality.

and automatic control intended for installation on farms or at milk collecting points.

Safety and environmental requirements for refrigeration systems are declared in standard EN 378:2000 “Refrigerating systems and heat pumps”. Equipment for regulating the temperature of the milk must be operated at any amount between 40% and 100% of the milking of the tank and the volume of milk at a temperature from 0°C to +35°C, and at ambient temperature from +5°C to an acceptable operating temperature (Table 1).

Generally, this milk cooling system cannot cool the milk as fast as the milk enters the tank. There must be time between milkings such that the cooling system can catch-up and cool the milk to 7°C. An intermediate cooling fluid, such as chilled water from an ice accumulator or a glycol-water mixture from a chiller is used to cool milk rapidly in a heat exchanger rather than direct expansion. Theoretically there is no limit to the surface area in a heat exchanger, only economical and practical limits.

The trend towards larger milking herds, greater milk production per cow and larger more efficient milking parlors [cows per hours] has increased milk flow rate [l/hr], with large volumes of milk to be cooled within a 24 hour period.

A mechanical refrigeration cycle is nearly always used to either cool the milk directly or indirectly via an intermediate cooling fluid. The system consists of a motor driven compressor that compresses the cold refrigerant gas returning from the evaporator so that the refrigerant can be condensed at high temperature. The high pressure - high temperature gas from the compressor flows to the condenser where the refrigerant is de-superheated and condensed by transferring heat to a cooling medium, usually air and/or water. The high- pressure liquid from the condenser will be a few degrees warmer than the cooling medium. This liquid is then metered thru a thermostatic expansion valve into the low- pressure evaporator that is in contact with milk (direct expansion), water (ice accumulator) or glycol-water solution in a chiller. Here the liquid refrigerant boils at low pressure and temperature absorbing heat from the milk, water or glycol-water. The low-pressure vapor is removed from the evaporator by the compressor where the vapor is again compressed and the cycle is completed.

Variety of energy conserving measures exists to improve the overall efficiency of milk cooling systems. This system cools the milk directly in the milk storage tank. The lower section of the tank is the evaporator. There is a

chance that the milk can be frozen at the evaporator if the evaporator temperature is too low and there is insufficient mixing of the milk that allows the milk to remain in contact with the evaporator too long.

Here an intermediary fluid, such as water or a water-glycol solution, is employed to transport heat from the milk to the evaporator. The chiller generally works in conjunction with a dual stage plate cooler. The chiller provides $-2-1^{\circ}\text{C}$ water – propylene glycol solution to the second stage of the plate cooler. When milk enters the second stage of the plate cooler, chilled solution from the chiller “instantly” cools the milk to 4°C . The milk enters the bulk tank or silo completely cooled.

Generally, instant chilled water/glycol cooling systems are slightly less efficient than direct expansion sys-

tems. The reason for the lower efficiency is the lower suction pressure to achieve lower evaporator temperatures inherent to instant cooling systems and the pumping energy required to move the water/glycol thru the heat exchanger. The lower temperatures and short heat transfer period along with pumping energy cause the instant cooling system to use more energy per hundredweight than a direct expansion system.

Having a single circulation pump requires careful sizing of the evaporator chiller and milk plate heat exchanger because each will have the same flow rate [lpm]. The two heat exchangers [evaporator and milk cooler] are coupled. Manufacturers of plate heat exchangers usually recommend that the coolant flow rate be 2 to 3 times the flow rate of product being cooled.

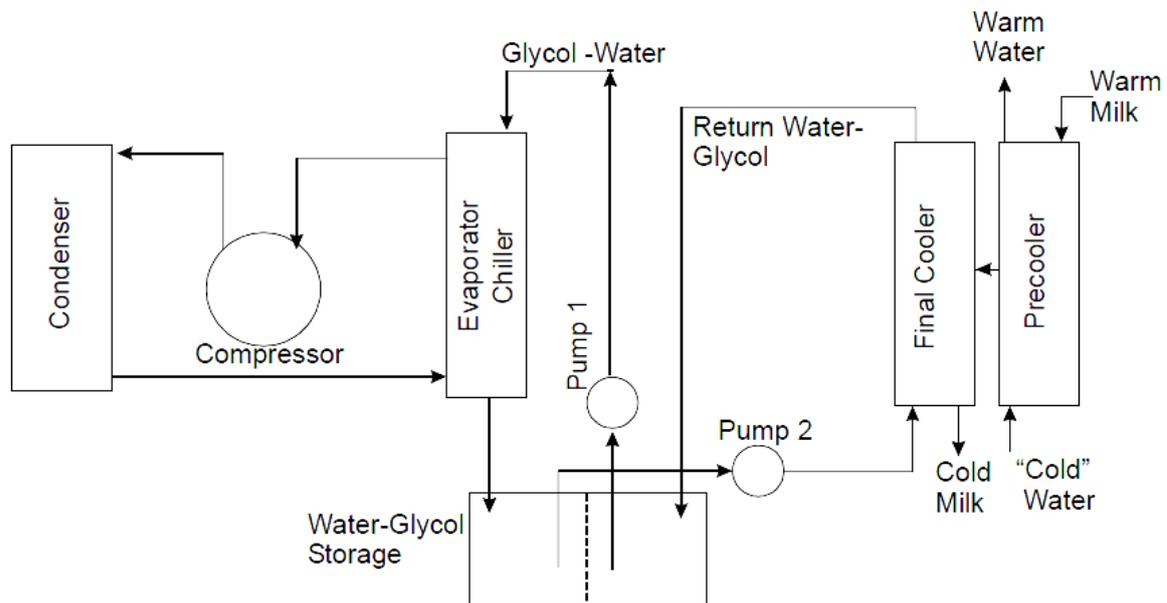


Figure 1 – Instant milk cooling system with decoupled, two pump, system

A better practice may be a decoupled system where two pumps are used, one for the evaporator and a second for the plate heat exchanger. Such a system is shown in Figure 1. Here the two pumps can be sized individually to optimize the performance of the evaporator/chiller section and the final plate heat exchanger. With this system there is also an opportunity to have two feedback control loops; one to maintain the correct temperature of the water-glycol storage and second to achieve proper temperature of the cooled milk.

The advantages of dual-circuit:

- The accuracy of maintaining the temperature of ice-water mixture at the outlet of the installation;
- The possibility of transporting refrigerant over a long distance;
- Tightness of the hydraulic circuits;
- A smaller amount of refrigerant than the ice accumulator;
- Compactness in comparison with ice accumulator.

– Disadvantages of dual-circuit:

- Because of the double dT (evaporator, refrigerant and cooling at an intermediate heat exchanger, cooling water) system works at a low boiling point of refrigerant, compared with film evaporators to $5..7\text{ K}$
- By 25 ... 30% more powerful compressors;
- Correspondingly higher energy demand by 10 ... 15%;
- Accordingly the need for a more condenser's area by 10 ... 15%;
- There is no way to compensate for peak loads due to energy storage.

Benefits of ice accumulation systems:

- The ability to compensate for peak loads by energy storage;
- The ability to use night tariff with energy accumulation.

Ice accumulation system disadvantages:

- Dimensions;
- A low boiling point refrigerant;
- Additional heat loss;

–High energy consumption and high cost of electricity costs in case of cancellation of the night tariff (as was the case in Western Europe in recent years).

IV. EFFICIENCY EVALUATION

Refrigeration plant for dairy must meet the following requirements:

1. Maximum ambient temperature (summer): 42°C.
2. Minimum ambient temperature (winter): -25°C.
3. The water temperature 0.5 - 1°C.
4. Maintain the temperature of milk to 4°C.
5. Number of independent refrigeration systems: min 2 pcs.
6. The system shall conform to the requirements of modern Ukrainian industrial refrigeration.

For the intermediate refrigerant (ice water) on the dairy plant cooling an HFC refrigeration system with screw compressors and air-cooled condenser is used. Water inlet temperature is 6°C, 1°C at the outlet, the cooling capacity is 300 kW, the mass flow rate is 14 kg/s, power consumption: 102 kW. Power consumption of 2 water pumps is 15 kW.

Energy consumption for every hour of refrigeration unit operation can be determined as follows:

$$N = Q \frac{N_r}{Q_r}, \tag{1}$$

where N_r – energy consumption of refrigeration unit, kW, Q_r – cooling capacity of refrigeration unit, kW.

Taking into account the necessary cooling energy consumption per hour of operation of the unit shown in Fig. 3.

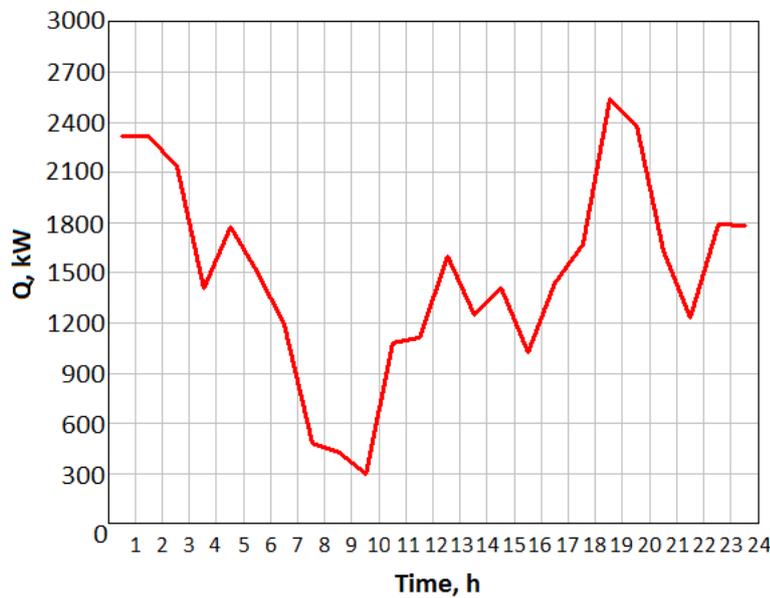


Figure 2 – Heat demand by hour.

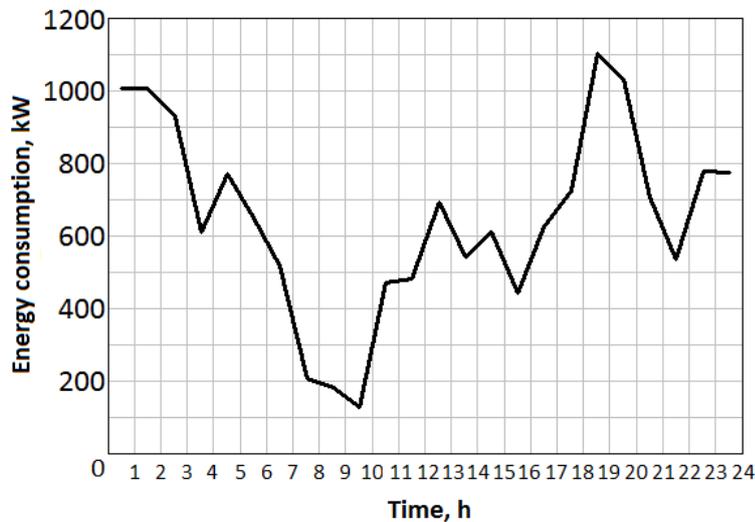


Figure 3 – Energy consumption diagram

The diagram indicates energy consumption by hour for refrigeration unit. The highest demand in cooling is between 18:00 and 5:00.

From the Resolution No. 309 of NERC "On tariffs for electricity supplied to the population and human settlements", dated 10 March 1999. with changes and additions: there are different tariffs for population and com-

mercial organizations and plants. An organization as well as every interested person can arrange a 2-zoned or 3-zoned tariff for electricity. According to this tariffication system prices for electricity are significantly lower during nighttime which makes it really attractive for business owners.

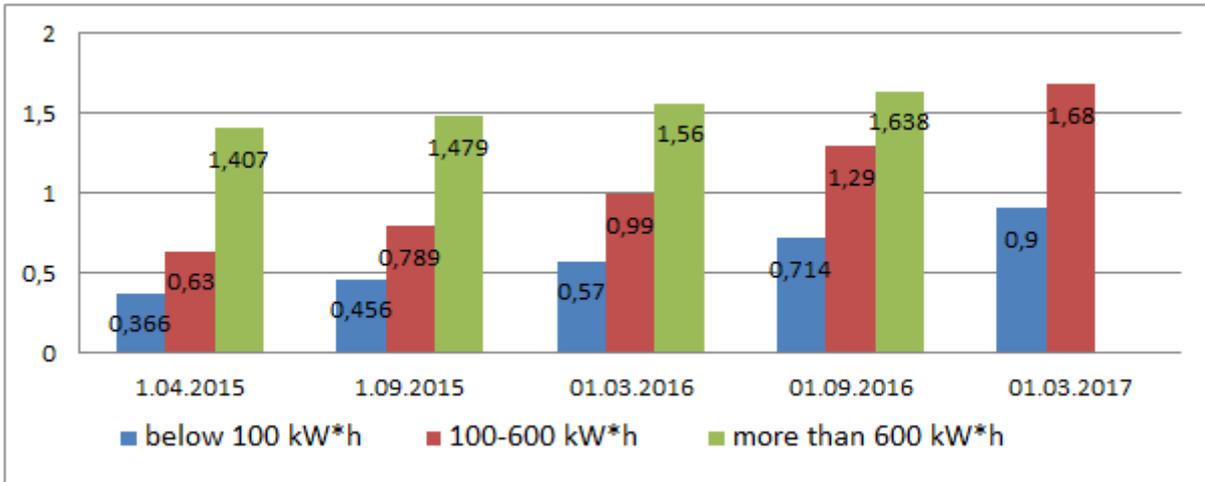


Figure 4 – Tariff rates for the calculation of the cost of electricity on the day zones

According to the Resolution of the National Electricity Regulatory Commission of Ukraine (NERC) of 20.12.2001 №1241 payments to consumers for electricity tariffs, differentiated by time periods, established in 2005 by agreement with NERC limits following tariff zones.

- For of industrial enterprises (from January 1, 2005.).
- "Peak zone" – Factor for tariff 1.8
- "Halfpeak zone" – Factor for rate 1.02
- "Night zone" – Factor for rate of 0.3 (0.25 from 1 August 2005) (75% less electricity costs).

Amount of accumulated refrigerated water can be

calculated as follows:

$$Q_{o_a} = Q_r \cdot n \cdot 7 \cdot 3600 - \left[Q_o^{23} \cdot 1 \cdot 3600 + \sum_{i=0}^5 (Q_{o_i} \cdot 1 \cdot 3600) \right] \quad (2)$$

where Q_{o_a} – accumulated water amount kJ, n – number of simultaneously operating units, Q_o^{23} – cooling capacity at 23:00 hour.

Thus, we can estimate the energy consumption according to 3 zoned tariff.

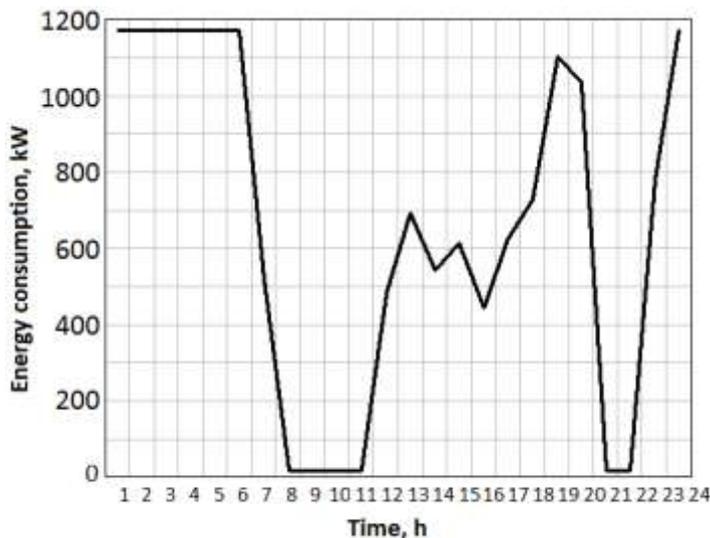


Figure 5 – Energy consumption diagram for refrigeration system with accumulation

According to Ukrainian electricity tariffication system we can organize refrigeration unit operating hours in such way that during “Peak” operating hours our energy consumption will be minimal. In the three-band tariff minimum electricity costs are in the period from 23:00 to 6:00, so during this time, all settings will be operating at full capacity, pools overlook the necessary refrigeration requirement and, at the same time, accumulating a stock of ice water in the first tank. We accept that both pumps will also operate continuously. According to the graph in Figure 6, we can save energy due to the reorganization of

production processes at the plant, while the power consumption is minimized during peak hours and a maximum at night when the tariff rate is minimal (0.25).

Since some of the cooling process of the product come with high initial temperature, energy is completely wasted all the produce cooling using ice water. If set to dry cooling tower, the product may be initially cooled to 41°C temperature and then cooling with ice water. To do this, to analyze production processes with the aim of hourly load calculation, which can be removed using a dry cooling towers.

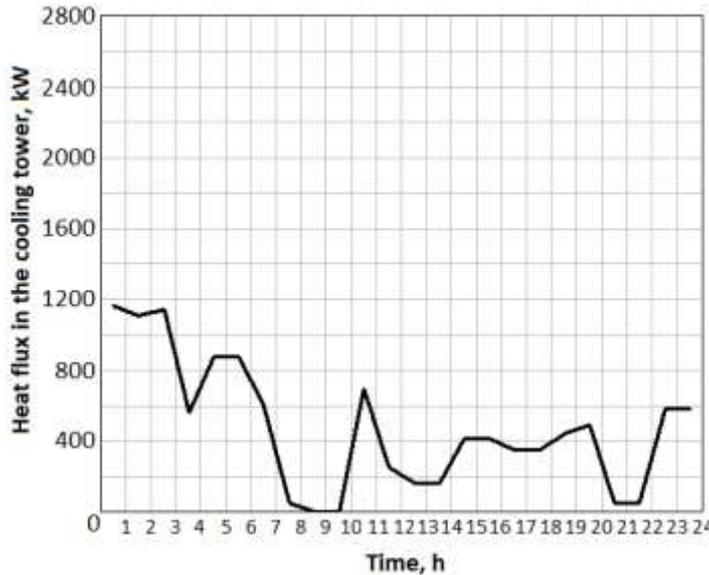


Figure 6 – Amount of heat that could be withdrawn with cooling tower

For specific product we take from the tables of its enthalpy at the final (dry coolers) temperature of 41°C, and then, according to the mass of the product M [kg], the difference of the initial I_r [kJ/kg] and end I_k [kJ/kg] enthalpy and time process t [s], we determine the thermal

$$\text{load} - Q_0 = M * (H - I_k) / t, \text{ kWh.}$$

The remaining cooling load is can be determined as the difference between full heat load and heat flux in cooling tower.

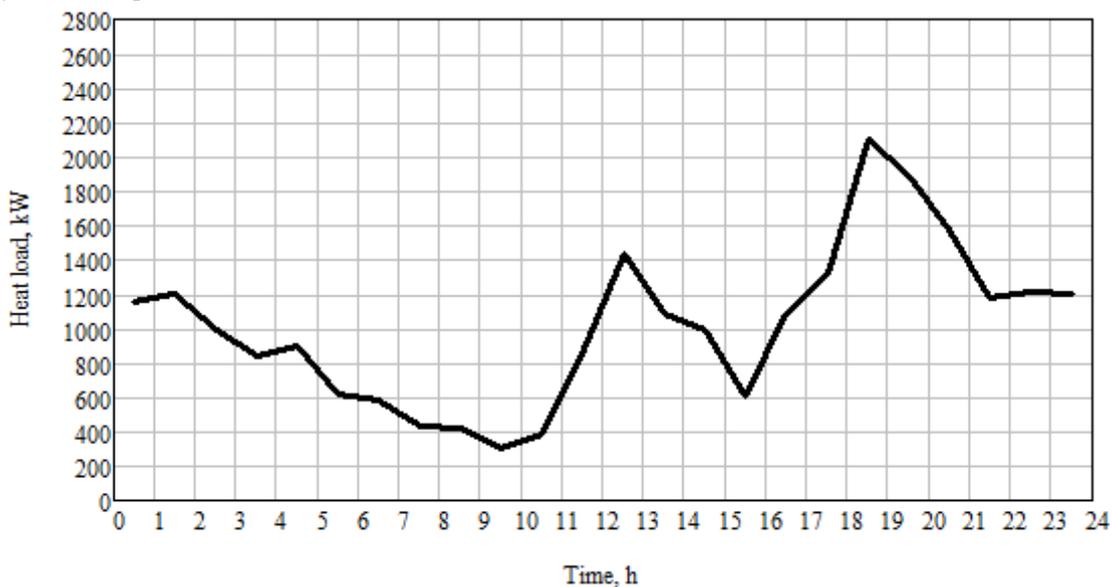


Figure 7 – Total heat load on the refrigeration system with cooling towers

V. CONCLUSIONS

There are different options for refrigeration system organization at dairy plant. All of them have their benefits and disadvantages. An analysis of the refrigeration system for dairy plant shows that the energy consumption as well as energy costs can be greatly reduced by using combined refrigeration unit with ice water accumulation. By organizing operation mode of the refrigeration system in such way that maximum cooling load appears during night hours when electricity tariff is 25% from nominal. Addition of the dry cooler to the refrigeration system allows to precool milk and thus lower energy consumption by 10-15%.

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ПУТИ ПОВЫШЕНИЯ ЭНЕРГОЭФФЕКТИВНОСТИ ХОЛОДИЛЬНОЙ УСТАНОВКИ ПРЕДПРИЯТИЯ ПИЩЕВОЙ ПРОМЫШЛЕННОСТИ

Растущие цены на энергоносители заставляют владельцев предприятий искать пути снижения эксплуатационных расходов. Холодильная установка на предприятиях пищевой промышленности является одним из основных источников энергопотребления. Использование систем аккумуляции холода позволяет уменьшить потребление электроэнергии холодильной установкой. В данной работе рассмотрена холодильная установка с системой аккумуляции холода и сухой градирней. Проанализирована возможность снижения расходов электроэнергии за счет организации работы холодильной системы предприятия в ночное время по трехзонному тарифу на электроэнергию.

Ключевые слова: Холодильная установка; Трехзонный тариф; Система аккумуляции холода; Энергоэффективность; Молокозавод.

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