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Antonina Kalinichenko [1,2], Olha Kalinichenko [3]

[1] Opole University,
pl. Kopernika 11a, 45-040 Opole, Poland
e-mail: akalinichenko@uni.opole.pl
Dr., Professor of Department of Engineering Processes
[2] Poltava State Agrarian Academy,
1/3 Skovorody str., 36003 Poltava, Ukraine
e-mail: kalinichenko_a@ukr.net
Dr., Prof., Department of Economic Cybernetics and Information Technologies

[3] Jagiellonian University,
24 Gołębia str., 31-007 Kraków, Poland
e-mail: ola.kalinichenko@gmail.com
student

THE USE OF HEAT PUMPS IN AGRARIAN PRODUCTION

Abstract. *Reuse of excess thermal energy of technological processes in agrarian production gives possibility not only to save energy sources of enterprise due to reuse, but also to limit emissions of heat in the atmosphere. The article compares traditional technologies of cooling of milk and heating of technological water and shows efficiency of technology of the combined production of heat and cold on the basis of heat pump use. The technical and economic calculations of efficiency of heat pump use is presented. Through the use of heat pump of "liquid - liquid" type system allows to maintain high precision temperature control of technological processes, thereby improving the quality of dairy products and reduce production costs.*
Keywords: *heat pumps, renewable sources of energy, dairy production.*

Антоніна Калініченко [1,2], Ольга Калініченко [3]

[1] Опольський університет,
пл. Коперніка, 11а, 45-040 м. Ополє, Польща
e-mail: kalinichenko_a@ukr.net
д.с.-г.н., проф., кафедра технологічних процесів
[2] Полтавська державна аграрна академія,
вул. Сковороди, 1/3, 36003 м. Полтава, Україна
e-mail: kalinichenko_a@ukr.net
д.с.-г.н., проф., професор кафедри економічної кібернетики та інформаційних технологій

[3] Ягеллонський університет,
вул. Голембя 24, 31-007 м. Краків, Польща
e-mail: ola.kalinichenko@gmail.com
студент

ВИКОРИСТАННЯ ТЕПЛОВИХ НАСОСІВ В АГРАРНОМУ ВИРОБНИЦТВІ

Анотація. *Повторне використання надлишкової теплової енергії технологічних процесів у аграрному виробництві дозволяє не тільки заощадити енергоресурси підприємства за рахунок їх повторного використання, а й обмежити викиди тепла в атмосферу. У статті співставлено традиційні технології охолодження молока й підігріву технологічної води та продемонстровано ефективність технології комбінованого виробництва тепла й холоду на основі використання теплових насосів. Представлено технічні та економічні розрахунки ефективності використання теплового насосу. За рахунок використання теплових насосів типу «рідина – рідина», система дозволяє з високою точністю підтримувати температурні режими технологічних процесів, що дозволяє покращити якість молочної продукції та зменшити собівартість продукції.*
Ключові слова: *теплові насоси, відновлювальні джерела енергії, молочна продукція*

Антонина Калиниченко,
Ольга Калиниченко

ИСПОЛЬЗОВАНИЕ ТЕПЛОВЫХ НАСОСОВ В АГРАРНОМ ПРОИЗВОДСТВЕ

Аннотация. *Повторное использование избыточной тепловой энергии технологических процессов в аграрном производстве позволяет не только сэкономить энергоресурсы предприятия за счет их повторного использования, но и ограничить выбросы тепла в атмосферу. В статье сопоставлены традиционные технологии охлаждения молока и подогрева технологической воды и продемонстрирована эффективность технологии комбинированного производства тепла и холода на основе использования теплонасосов. Представлены технические и экономические расчеты эффективности использования теплового насоса. За счет использования теплонасосов типа «жидкость - жидкость», система позволяет с высокой точностью поддерживать температурные режимы технологических процессов, позволяет улучшить качество молочной продукции и уменьшить себестоимость продукции.*
Ключевые слова: *тепловые насосы, возобновляемые источники энергии, молочная продукция.*

Introduction. The basis of dairy products quality is laid mainly in the process of receiving and primary processing on the farm. Strict adherence of milk cooling and sanitation measures is provided by appropriate technological equipment.

Significant impact on the cost of production has technology of milk cooling and water heating on a dairy farm, which depends on the cost of energy incurred in the production process.

Fresh milk initial temperature is about 32 ºC. Prior to transportation it is cooled to 4 ºC and stored on the farm in special tanks and baths up to 36-48 hours. Refrigeration equipment dissipate thermal energy using cooling radiators in condenser circuit. In this case the thermal energy of milk scatters in premises with refrigeration equipment, thus significantly increasing its temperature. In addition this process consumes a large amount of electric energy. Water required for cleaning of milking equipment is typically heated by electric heaters.

So, today up to 65% of electricity on dairy farms is consumed for two main processes: cooling of milk and heating of technological water for cleaning of milking equipment. Moreover, these processes are performed completely independently from each other. A more rational approach would be to redistribute and reuse thermal energy already existing in the technological process. Reducing energy costs will allow to reduce the cost of the final product.

The world experience shows that one of the most effective and economical types of equipment to obtain heat is the heat pump. This is ecological, low-temperature heating device, which in contrast to traditional technology of heating and cooling uses the internal energy of production processes [4-6].

Heat pumps allow to receive heat from low potential sources and at the same time use it in both the cooling and heating processes in different circuits. The principle of operation is based on the Carnot cycle, that describes converting a given amount of thermal energy through transfer of fluid from one aggregate state to another.

The tasks of work was to compare traditional technologies of cooling of milk and heating of technological water; to present the energy saving methods of their improvement; to show efficiency of technology of the combined production of heat and cold on the basis of heat pump use; to prove the economic efficiency of the offered technology and feasibility of its implementation.

Results of the experiment. Reuse of excess thermal energy of technological processes in agrarian production gives possibility not only to save energy sources of enterprise due to reuse, but also to limit emissions of heat in the atmosphere. The combined production of heat and cold currently is one of the most economic-effective systems with the use of heat pumps [1-3, 16, 17].

The research work was on the basis of dairy farm Ltd "Bilahro" in Velikobagachansky region (Ukraine). Investigated farm has 1,000 cows, including 650 milch. On average, for one milking get almost 3.5 thousand liters, or 7 thousand liters per day. To receive the required quality of milk, manufacturing process needs to cool product from 32 to 4 ^oC. Twice a day after each milking it needs hot water for washing technological equipment. It takes 350 liters, part of which – 100 liters, used at the start of washing (it should have 85 ^oC). To complete the washing and rinsing equipment it is used 250 liters of water, which is enough to heat only to the temperature of 55 ^oC.

We calculated the heat balance of agritechnological processes [7, 9, 11, 14-17].

Milk cooling. The amount of energy that can be obtained from the milk during its cooling:

$$Q_{milk} = m_{milk} \cdot c_{milk} \cdot (T_2 - T_1)\ kW = 3506{,}1 \cdot 0{,}00105 \cdot (32\text{-}4) = 103{,}1\ kWh, \quad (1)$$

where m_{milk} – mass of milk per milking, kg;

c_{milk} – heat capacity of milk, kWh/(kg · ^oC);

T_1 – temperature of milk after cooling, ^oC;

T_2 - initial temperature of milk, ^oC.

So, during the initial cooling of milk on a farm 0.2 MW of the collected heat is daily scattered in premises ("released into air").

Water heating. The amount of energy required for the first phase – heating of 350 liters of water from 12 º C to 55 º C.

$$Q_w^I = m_w \cdot c_w \cdot (T_4 - T_3) = 350 \cdot 0.0011 \cdot (55 - 12) = 16.56\ kWh, \quad (2)$$

where m_w - mass of water, kg (l)

c_w - heat capacity of water, kWh / kg ºC

T_3 - initial temperature of milk, ºC

T_4 - temperature of milk after heating, ºC

The amount of energy required for the second phase – heating of 100 liters of water from 55 º C to 85 º C.

$$Q_w^{II} = m_w \cdot c_w \cdot (T_5 - T_4) = 100 \cdot 0.0011 \cdot (85 - 55) = 3.3\ kWh \qquad (3)$$

The total amount of heat thus will be:

$$Q_w^{total} = Q_w^{I} + Q_w^{II} = 16.56 + 3.3 = 19.86\ \ kWh \qquad (4)$$

We propose technology for simultaneous cooling of milk and heating of water by the use of heat pump of "liquid - liquid" type (A & K Medium 57 / 49.1). Heat pump, unlike traditional technologies of heating and cooling, uses the internal energy production processes (Fig. 1) [8, 10, 12-15].

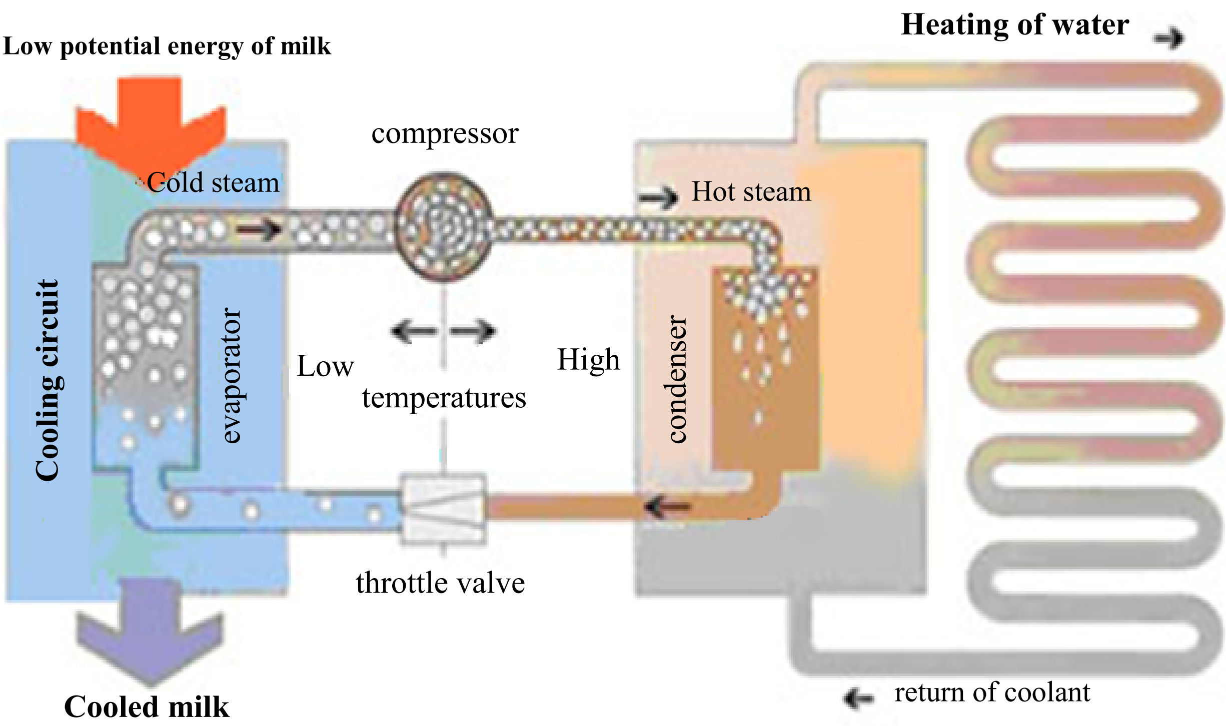

Fig. 1. The operation principle of heat pump in the manufacturing process of primary milk processing

At this stage of heat pumps development, given their technological features, efficiency of heating to temperatures higher than 55 º C is significantly reduced. Therefore, to improve the efficiency of total heating system and to increase speed of water heating, we propose the following scenario: 350 liters of water will be heated from 12 º C to 55 º C using heat pumps of "liquid - liquid" type. In the second stage, separated 100 liters of water will be additionally heated from 55 º C to 85 º C in a separate boiler by thermal electric heaters (Fig. 2).

For the system a heat pump of "liquid - liquid" type was designed (A & K Medium 57 / 49,1). Coefficient of effectiveness is the ratio of the sum of useful energies (of water heating and cooling of milk) to electricity (P_{el}) actually spent to drive the compressor for actual time of milk cooling to the desired temperature (t_{cool}). During the experiment, it was determined that the average value of amount of spent electricity is equal to 11.2 kW, and the average time of milk cooling in conditions of the farm is 2.3 hours.

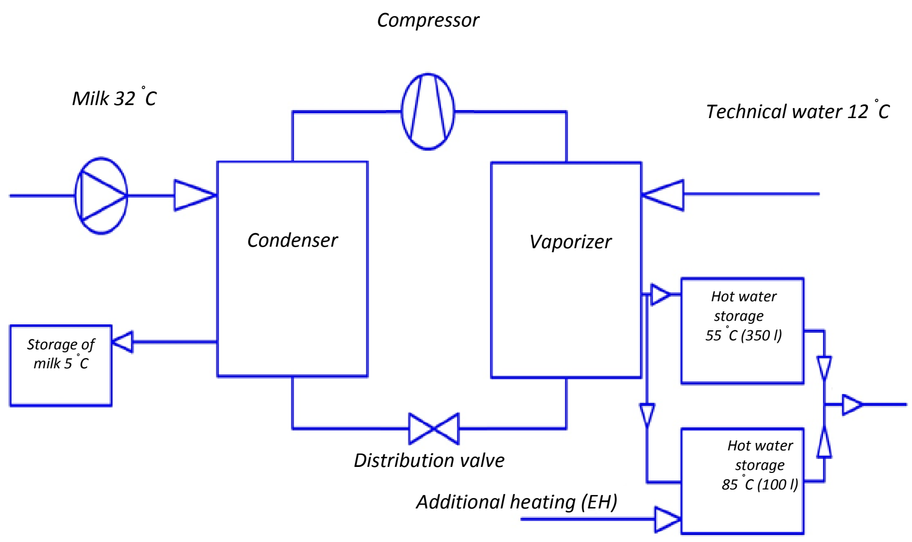

Fig. 2. Technological scheme of the proposed system

$$K_{efficiency} = COP + EER = \frac{Q_{milk} + Q_w^{total}}{P_{el}^f \cdot t_{cooling}^f} = \frac{103{,}05 + 16{,}56}{11{,}2 \cdot 2{,}3} = 4{,}64 \quad (5)$$

COP (coefficient of performance) – is the ratio of produced heat to the consumed electrical power;

EER (energy efficiency ratio) – in cooling mode is used to assess the effectiveness.

Analysis of the results.

Expenses using traditional technology.

To cool the milk obtained per one milking, with the efficiency of refrigeration equipment 85%, it is spent:

$$E_{el}^{tr} = \frac{Q_{milk}}{\eta} = \frac{103{,}08}{0{,}85} = 121{,}27\ kW \quad (6)$$

With the traditional technology to heat 350 liters of water we need

$$Q_w = Q_w^I + Q_w^{II} = 19{,}86\ \ kWh, \quad (7)$$

where Q_w^I – energy for water heating in the first stage, Q_w^{II} – in the second stage.

Totally $E_{el}^{tr} + Q_w^{total} = 121{,}27 + 19{,}86 = 141{,}13\ kWh$ electricity per one milking, that will be *282,25 kWh* per day.

For current prices for electricity company spends ≈302 UAH per day, which is almost 110 thousands UAH a year[1].

Expenses using new technology.

With the use of heat pumps, electrical energy required for simultaneous milk cooling and water heating in the first stage was:

$$E_{el} = P^{act}_{el} \cdot t^{act}_{cool} = 11{,}2 \cdot 2{,}3 = 25{,}76\ kWh$$

[1] All calculations were made as of September 2013.

For additional heating of water in the second stage $Q^{II}_w = 3,3.\ kWh$

Total expenses $E_{el} + Q^{II}_w = 25,76 + 3,3 = 29,06\ kWh$ per one milking or *58,12 kWh* (62.19 UAH) per day. Annual costs – 22.7 thousand UAH.

Daily saving of electricity with new technology

$$E_{daily} = 282.25 - 58.12 = 224.13\ kW \text{ or } 239.82 \text{ UAH.}$$

Annual savings – 87.53 thousand UAH.

Pump cost was 132 thousand UAH, thus the payback period was only 18 months.

Conclusion. In our work two methods of primary milk cooling and water heating for technological needs on a dairy farm are compared: standard and non-standard (combined heat and cold production using heat pumps).

Found that the use of the heat pump in bi-directional heat flow (cooling and heating) in industrial processes of agricultural companies is the most effective use of this type of equipment.

With traditional technology for milk cooling and water heating it is totally consuming up to 180 kilowatts of electricity per day. For current prices for electricity company spends ≈302 UAH per day, which is almost 110 thousands UAH year.

With the using of heat pumps, electrical energy required for simultaneous milk cooling and water heating in the first stage, was approximately 25 kW, the for heating water in the second stage 3.3 kW total ≈29 kW per milking or 58 kWh per day, that is ≈ 62 UAH. Annual spending – 22.7 thousand UAH.

Daytime saving makes 224.13 kW or almost 240 UAH per day, or 87.5 thousand UAH a year. It should be noted that the value of the used pump is 132 thousand UAH so the payback period is only 1.5 years.

Found that through the use of heat pump type "liquid - liquid" system allows to maintain high precision temperature control of technological processes, thereby improving the quality of dairy products. In addition, the use of non-traditional approach to the heat energy production can reduce emissions of CO and CO_2 by reducing the use of traditional energy sources.

Thus, the use of heat pump equipment on a dairy farm of Ltd. "Bilahro" in Velykobahachansky region (Ukraine) has considerable technological, economic and ecological effects. The system was designed based on the technical task of dairy farm Ltd. "Bilahro" and is in the process of implementation.

Використана література:

1. Аюпов А.А. Применение теплонасосной установки для охлаждения и пастеризации молока / А. А. Аюпов, Н. А. Мухитдинов, И. Д. Ибрагимов // Холодильная техника. – 2008.
2. Бродянский В.М. “Эксергетический метод и его приложения” / В.М. Бродянский и др. // М.: Энергоиздат. – 1986.
3. Быков А. В. Холодильные машины и тепловые насосы. (Повышение эффективности) / А. В. Быков. – М. : Агропромиздат, 1988
4. Девянин Д.Н. Тепловые насосы. Разработка и испытание на ТЭЦ –28 / Д.Н. Девянин, С.И. Пищиков, Ю.Н. Соколов // Новости теплоснабжения. – №1. – 2000.
5. Каплан А. М. Тепловые насосы, их технико-экономические возможности и области применения. / А.М. Каплан. // Работы ЦКТИ. – Кн. 4, вып. 1. - М.- Л.: Машгиз, 1947.
6. Мартынов А.В. Использование ВЭР на предприятиях химической промышленности на базе ТНУ / А.В. Мартынов, Ю.В. Яворский // Химическая промышленность. – №4. – 2000.
7. Офіційний сайт Інституту відновлюваної енергетики НАН України [Електронний ресурс]. – Режим доступу: http://www.ive.org.ua.
8. Офіційний сайт "Компанія В.Д.Е. – Україна" [Електронний ресурс]. – Режим доступу: http://vde.com.ua/
9. Офіційний сайт "Науково-виробнича фірма ЕКОТЕПЛО" – Електронний ресурс. Режим доступу: – http://www.ekoteplo.com/ua/19.html
10. Офіційний сайт "ООО Тепловые насосы". [Електронний ресурс]. – Режим доступу: – http://teplonasos.ua/uk/teplonasosy-gruntovye/princip-raboty-gruntovyh-teplonasosov/
11. Попель О.С. Тепловые насосы – эффективный путь энергосбережения / Попель О.С. // Проблемы энергосбережения. – № 1. – 1999.

12. Billy C. Langley. Heat Pump Technology / Billy C. Langley // Prentice Hall. – 2001.
13. Cantor J. Heat Pumps for the Home / John Cantor // Crowood Press. – 2011.
14. Energy Efficiency and Management in Food Processing Facilities Lijun Wang // CRC Press. – 2008.
15. Official site of Hotfoot The Warm Floor Store UFH & Heat Pumps [Електронний ресурс]. – Режим доступу: http://www.hotfoot.ie/heat-pumps-dairy-sector/
16. Potential applications for heat pumps in the dairy and brewing industries [Електронний ресурс]. Journal of Heat Recovery Systems. – Vol. 3, Issue 3. – 1983. – Режим доступу: http://www.sciencedirect.com/science/article/pii/0198759383901145
17. Tytko R. Odnawialne źródła energii / R. Tytko, – Warszawa: OWG, 2011.

REFERENCES

1. Ayupov A.A., Mukhitdinov N. A., Ibragimov I. D. Application of the heat pump system for cooling and pasteurization of milk [Primenenie teplonasosnoy ustanovki dlya okhlazhdeniya i pasterizatsii moloka]. *Kholodil'naya tekhnika – Refrigeration*, 2008.
2. Brodyanskiy V.M. Exergic method and its applications [*Eksergeticheskiy metod i ego prilozheniya*]. Moscow, Energoizdat, 1986.
3. Bykov A. V. Chillers and heat pumps. (Improved) [*Kholodil'nye mashiny i teplovye nasosy. (Povyshenie effektivnosti)*]. Moscow, Agropromizdat, 1988.
4. Devyanin D.N., Pishchikov S.I., Sokolov Yu.N. [Teplovye nasosy. Razrabotka i ispytanie na TETs –28]. *Novosti teplosnabzheniya – News of heat supply*, 2000, No. 1.
5. Kaplan A. M. Heat pumps, their technical and economic possibilities and applications [Teplovye nasosy, ikh tekhniko-ekonomicheskie vozmozhnosti i oblasti primeneniya]. *Raboty TsKTI – Works CKTI*, 1947, Vol. 4, No. 1.
6. Martynov A.V., Yavorskiy Yu.V. he use of RES in the chemical industry on the basis of TNU [Ispol'zovanie VER na predpriyatiyakh khimicheskoy promyshlennosti na baze TNU]. Khimicheskaya promyshlennost' – Chemical industry, 2000, No.4.
7. The official website of the Institute of Renewable Energy National Academy of Sciences of Ukraine [*Ofitsiynyy sayt Instytutu vidnovlyuvanoyi enerhetyky NAN Ukrayiny*]. Available at: http://www.ive.org.ua.
8. Official Site "Company V.D.E. - Ukraine" [Ofitsiynyy sayt "Kompaniya V.D.E. – Ukrayina"]. Available at: http://vde.com.ua/
9. Official Site "Scientific and Production Company EKOTEPLO" [Ofitsiynyy sayt "Naukovo-vyrobnycha firma EKOTEPLO"]. Available at: http://www.ekoteplo.com/ua/19.html
10. An official site "Heather Pump LTD" [*Ofitsiynyy sayt "OOO Teplovyye nasosy"*]. Available at: http://teplonasos.ua/uk/teplonasosy-gruntovye/princip-raboty-gruntovyh-teplonasosov/
11. Popel' O.S. Heat pumps - an effective way of energy saving [Teplovye nasosy – effektivnyy put' energosberezheniya]. *Problemy energosberezheniya – Problems of conservation*, 1999, No. 1.
12. Billy C. Langley. Heat Pump Technology. Prentice Hall, 2001.
13. Cantor J. Heat Pumps for the Home. Crowood Press, 2011.
14. Energy Efficiency and Management in Food Processing Facilities Lijun Wang. CRC Press, 2008.
15. Official site of Hotfoot The Warm Floor Store UFH & Heat Pumps, available at: http://www.hotfoot.ie/heat-pumps-dairy-sector/
16. Potential applications for heat pumps in the dairy and brewing industries. *Journal of Heat Recovery Systems*,Vol. 3, Issue 3, 1983, available at: http://www.sciencedirect.com/science/article/pii/0198759383901145
17. Tytko R. *Odnawialne źródła energii*. Warszawa: OWG, 2011.

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