Application of heat pumps in the food industry: purification plant

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Abstract. Furnaces and thermal chambers are created with specific guidelines in mind. These guidelines include using energy in an efficient manner, arranging products closer together to increase productivity, ensuring the direction of air flow is precise, having accurate control over temperature and humidity, making sure the equipment is reliable and convenient to use, and ensuring that any gaseous waste emissions fall within acceptable levels set by regulations. Also, a clear advantage of a heat pump is the possibility of using it at high power enterprises, where it is difficult to use water as a heating coolant. Heat pumps are also able to reduce the risk of bacterial growth, as they can maintain a safe and consistent temperature throughout the entire process. Heat pump processing is an effective and efficient method for meat products because it can achieve a high level of product uniformity with minimal product degradation.

1 Introduction

At the enterprises of the thermal industry, heat treatment is carried out during heating and cooling of media, thickening of solutions and juices, condensation of vapours, evaporation of moisture during drying of materials and many other processes [1]. All these operations are connected with the transfer of heat to the product or the removal of heat from it and can occur only if there is a temperature difference between the heat-exchanging media. Industrial food ovens are used in many food processing industries to cook, bake, and dry a wide range of food products [2]. The operation of these ovens is critical to ensuring the quality, safety, and efficiency of the food processing operation [3, 4]. There are several reasons why it is important to optimize and improve the operation of industrial food ovens. Product quality: The quality of the finished product is often closely tied to the operation of the oven. If the oven is not operating optimally, it can result in uneven cooking or drying, leading to variations in product quality. By optimizing the oven operation, it is possible to achieve a more consistent product with better texture, colour, and flavour. Food safety: Properly cooked or dried food is essential to ensure food safety. If the oven is not operating at the correct temperature or humidity levels, there is a risk of undercooked or overcooked

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food, which can lead to food borne illness. Optimizing the oven operation can help ensure that the food is cooked or dried to the correct temperature and time, minimizing the risk of food borne illness. Energy efficiency: Industrial food ovens are often energy-intensive operations, and optimizing the operation can help reduce energy consumption and costs. By improving the insulation, air circulation, and other factors that affect energy efficiency, it is possible to reduce the amount of energy required to operate the oven. Production efficiency: The operation of the oven can also have a significant impact on production efficiency. By optimizing the oven operation, it is possible to reduce processing time, increase throughput, and reduce downtime for maintenance and cleaning [5, 6].

Optimizing and improving the operation of industrial food ovens is critical to ensuring product quality, food safety, energy efficiency, and production efficiency. By focusing on these factors, food processing companies can improve their operations and remain competitive in the marketplace. Two types of devices are used for the heat treatment of meat products: devices using liquid heat carriers and devices using gas and vapor heat carriers. In the second type of devices, the following are used as a heat transfer medium: air, smoke-air mixture, hot steam and steam-air mixture. One of the variants of such devices is a baking oven, where a coolant temperature of 150°C is required. It can be achieved by using a heat pump. A heat pump is a mechanism that moves heat from a lower temperature area to a higher temperature location through the use of a refrigerant cycle. Heat pumps are generally powered by electricity and include a compressor, condenser, evaporator, and expansion valve to enable the transfer of heat [7, 8].

2 Materials and methods. The principle of operation of the technological scheme. Scientific novelty

Meat roasting is carried out with hot air in rotary ovens with gas or electric heating, in standard ovens and auto coppers, but at the appropriate temperature of the processing medium. For the operation of rotary kilns used in industrial drying of various products, including food, it is necessary to ensure air purification. This is necessary in order to get rid of contaminants that can negatively affect the quality and safety of products, as well as to increase the productivity of the drying process. Air purification can be carried out by various methods, including mechanical, physical and chemical filtration. In order to ensure the safety and quality of products, as well as to increase the productivity of the drying process, it is necessary to ensure effective air purification. This can be done both by installing appropriate filters, and by using special drying technologies using purified air or odor suppression. An example of a purification plant scheme is shown in Figure 1. Air filtration and purification are processes that involve the removal of unwanted particles, gases, and other contaminants from the air using filters. The process typically involves the following steps. Pre-filtration: This step involves the removal of large particles and debris from the air using a pre-filter. This pre-filter is usually a coarse material, such as a mesh or a non-woven fabric that captures large particles before they reach the main filter. Main filtration: The main filter is a more sophisticated material that removes smaller particles, such as dust, pollen, and other allergens, from the air. The filter material is typically made of a fine mesh of synthetic fibbers or other materials that can capture particles as small as 0.3 microns in size. The filter may also be treated with a chemical, such as activated carbon, to remove gases and odours from the air [9, 10].

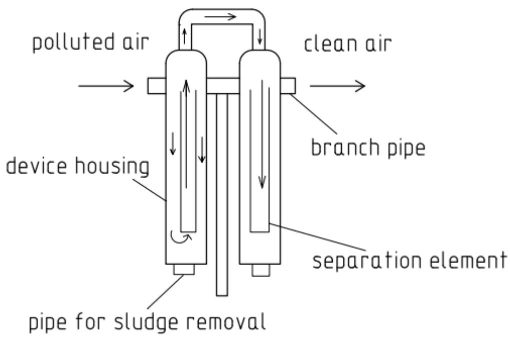

Fig. 1. Scheme of a purification plant.

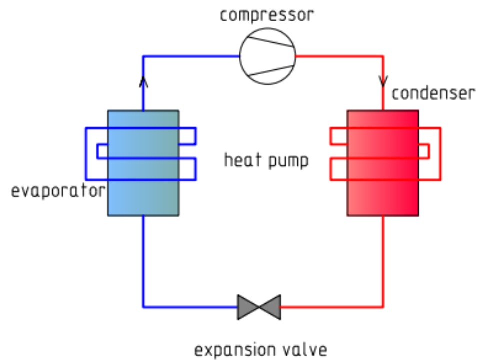

Fig. 2. Scheme of a heat pump.

Purification: After the air has been filtered, it may be further purified using a variety of techniques. One common technique is ultraviolet (UV) light purification, which uses UV radiation to kill bacteria and other microorganisms in the air. Another technique is ionization, which charges particles in the air and causes them to stick to surfaces, removing them from the air. Maintenance: To ensure that the air filtration and purification system continues to function effectively, regular maintenance is required. This may include replacing the filters, cleaning the system, and checking the airflow and other parameters. Smoking-baking is done with an air-smoke mixture. Consider the principle of operation of a rotary kiln with a heat pump instead of a heater. Figure 2 shows a scheme a heat pump. The heat exchange process in rotary kilns involves several mechanisms, including conduction, convection, and radiation. Conduction: In a rotary kiln, the material being processed is heated by contact with the hot walls of the kiln. Heat is transferred from the kiln walls to the material by conduction. The rate of heat transfer by conduction depends on the thermal conductivity of the material being processed and the temperature difference between the material and the kiln walls. Convection: The material being processed is also heated by convection. As the material moves through the kiln, it is exposed to hot gases that flow in the opposite direction. Heat is transferred from the hot gases to the material by convection. The rate of heat transfer by convection depends on the velocity and temperature of the gas, the surface area of the material, and the convective heat transfer coefficient. Radiation: The material being processed is also heated by radiation. The walls of the kiln emit thermal radiation that is absorbed by the material. The rate of heat transfer by radiation depends on the temperature of the kiln walls, the emissivity of the kiln walls, and the distance between the kiln walls and the material [11, 12].

Overall, the heat exchange process in rotary kilns is a complex interplay between these different mechanisms. The efficiency of heat transfer depends on the design and operation of the kiln, as well as the properties of the material being processed [13, 14].

The rotary kiln itself consists of a thermally insulated housing inside which the rotor rotates. The rotor has 3 sprockets on which the cradles for the product are suspended. A rotor drive and a heat pump are installed on the upper panel of the chamber, which replaced the heater unit. A heat pump consists of a compressor, a fan and a condenser. The compressor pulls in air from the surrounding environment [15, 16]. This increases the temperature and pressure of the air reaching the furnace and thus ramps up the efficiency of the baking process. Additionally, the fan is used to move air through the furnace in order to further increase the temperature and pressure. Finally, the condenser helps to manage the discharged air, taking the heat from the furnace and releasing it outdoors to be reused. The heated air flows through the side box into the perforated cylinders. From there, the streams of hot medium enter the product, are sucked off by a fan and sent to recirculation. Part of the medium is discharged into the atmosphere through a pipe. The product is in motion all the time, which ensures uniform processing throughout the entire volume of the chamber. The furnace drive consists of an electric motor connected by a coupling to the first worm gear, which is connected to the second gear. Further, by means of a chain transmission, the gearbox is connected to a shaft on which sprockets with fingers and cradles are fixed. The power of the electric motor is 0.6 kW, the power of the heaters is 43 kW. One-time loading of the product into the oven is 300 kg. The furnace operates in a periodic mode, its capacity can reach 110 kilogram per second.

3 Results. Practical significance

Here are some potential impacts of introducing a heat pump into the scheme of food rotary kilns. Increased energy efficiency: By using a heat pump to extract waste heat from the kiln exhaust gases and transferring it to the incoming air, the overall energy efficiency of the system can be increased. This can result in lower energy consumption and reduced greenhouse gas emissions. Improved temperature control: A heat pump can help maintain a more consistent temperature profile within the kiln, which can improve the quality and consistency of the food being processed. Faster heating rates: With a heat pump, it may be possible to achieve faster heating rates within the kiln. This can lead to shorter processing times and increased throughput. Reduced heat loss: By using a heat pump to recover waste heat, less heat is lost from the system. This can help reduce energy costs and improve the overall thermal efficiency of the process. Overall, the introduction of a heat pump into the scheme of food rotary kilns can have significant benefits for the thermal processes involved in the kiln operation, resulting in increased energy efficiency, improved temperature control, faster heating rates, and reduced heat loss. Replacing the heater unit with a heat pump has a number of practically significant advantages, considered by the example of the K7-FP2G rotary kiln. Increased Efficiency: Heat pumps are much more efficient than standard heater unit, particularly in industrial settings. Heat pumps have the potential to effectively transfer more heat energy thin electric heating. This means that you can reduce the energy bill of industrial furnace, as less energy is required to achieve the same level of heating power. Heat pumps are an excellent option for situations where low noise levels are necessary since they produce much less sound than heating units. Additionally, heat pumps require less maintenance than their heater unit counterparts as they are less complicated. This means that they require less maintenance and repair over the course of their life span. Environmentally Friendly: Heat pumps are a great choice for businesses trying to reduce their carbon footprint. By using less energy, heat pumps can help to reduce greenhouse gas emissions. Introducing an air purification system before feeding into a heat pump can offer several benefits. First, it can improve the quality of indoor air by removing harmful contaminants such as dust, pollen, and mold spores. This can lead to better health outcomes for individuals who suffer from respiratory conditions or allergies. Second, a clean air filter in the air purification system can help improve the efficiency of the heat pump by reducing the amount of debris and particles that can clog or damage its components. This can lead to a longer lifespan for the heat pump and fewer maintenance requirements. Third, removing pollutants from the air can help reduce the workload on the heat pump, which can translate into lower energy bills over time. Fourth, a clean air filter can also help reduce the amount of noise produced by the heat pump, which can make for a more comfortable living or working environment. Fifth removing excess moisture from the air can help prevent the growth of mold or mildew, which can be damaging to both the building and its occupants. Sixth, removing pollutants from the air can help protect sensitive electronic equipment from damage caused by dust or other contaminants.

4 Discussion

Heat pumps are essential to the food industry as they are capable of extracting thermal energy from the environment and then using this energy to heat the heat carriers used in food production. By using a heat pump, heat can be efficiently transferred from a low temperature heat source to a high temperature heat source, making it possible to reduce the amount of fuel used to heat the heat carriers. This helps to reduce the industry's reliance on fossil fuels and, in turn, reduce the amount of greenhouse gas emissions associated with the industry. Furthermore, heat pumps also provide a more reliable and consistent temperature in the heat carriers, helping to improve the food quality and safety. By using heat pumps, the food industry can achieve cost savings, reduce its environmental impact and maintain his food standards.

Using an air purification filter for heat pumps in rotary food ovens can provide several benefits. Firstly, the filter can remove any impurities, odors, or contaminants from the air before it enters the oven, ensuring that the food being cooked remains clean and free from any unwanted flavors or smells. Secondly, the filter can help prevent any debris or particles from entering the oven and sticking to the food, which can cause it to burn or affect its texture and taste. Thirdly, the filter can help increase the lifespan of the oven by reducing the amount of buildup on its internal components, such as heating elements and fans. This can reduce the need for maintenance and repair, saving time and money in the long run. Fourthly, using an air purification filter can improve the energy efficiency of the oven by reducing the amount of debris and dust that accumulates on the components, thus reducing the workload of the oven. Fifthly, the filter can reduce the amount of noise generated by the oven, creating a more comfortable working environment for those operating it. Sixthly, the filter can help prevent the growth of bacteria and mold within the oven, which can be beneficial for food safety and hygiene. Seventhly, using an air purification filter can help meet the regulatory requirements for food production facilities, which require strict adherence to food safety standards.

The heat pump transfers the waste heat to a heat exchanger, where it is used to heat up the incoming air that is used to fuel the combustion process of the kiln. This process of utilizing the waste heat significantly reduces the amount of fuel required to maintain the high-temperature environment required in the kiln. Furthermore, the heat pump can also provide additional benefits by increasing the efficiency of the kiln. By using the waste heat to preheat the incoming air, the combustion process is improved, and less fuel is required to maintain the same temperature. This leads to a reduction in the consumption of both fuel and electricity, which can result in substantial cost savings.

5 Conclusion

Furnaces and thermal chambers are created based on fundamental principles that include efficient energy usage, higher productivity resulting from compact product placement, complete precision in the direction of airflows, accurate regulation of temperature and humidity, utmost reliability and convenience, and gaseous waste emission falling within the permissible standard limit. To follow these principles, a competent technical solution is to include a heat pump in the circuit diagram of industrial food equipment. Also, a clear advantage of a heat pump is the possibility of using it at high power enterprises, where it is difficult to use water as a heating coolant. The introduction of a heat pump into the scheme of rotary kilns can save fuel, electricity, and money by utilizing the waste heat generated during the cooling process of the kiln. The heat pump is a thermodynamic cycle device that pumps heat from a lower temperature source to a higher temperature sink, by using electricity as an input. In this case, the waste heat from the rotary kiln is utilized as the low-temperature source, and the heat pump upgrades the temperature to a level suitable for use in the process, which can significantly reduce the amount of energy required for heating.

In summary, the introduction of a heat pump into the scheme of rotary kilns allows for the utilization of waste heat, reducing the amount of fuel and electricity required for heating. This results in significant cost savings, while also improving the efficiency of the kiln. The introduction of filters for air purification in the operation of food ovens is an important step towards maintaining a healthy and safe work environment. These filters can effectively remove harmful particles and contaminants from the air, reducing the rise of respiratory problems and other health issues for workers. Additionally, by reducing the amount of contaminants in the air, these filters can help improve the overall quality and safety of the food being processed. Ultimately, the use of air purification filter is a wise investment for food processing companies, as it can lead to improved worker health, increased productivity, and better quality products.

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References

1. R. Klimov, A. Pododnia and A. Morozovskaya, Coll. of sch. papers of DSTU (Tech. Sci.) **2(41)**, 133-138 (2022)
2. A. N. Shishkov, K. V. Osintsev, *Proceedings of IOP Conf. Ser.: Mater. Sci. Eng.* **1064**, 012033 (2020)
3. V. I. Chalov, *Territorial-industrial complex: problems of formation and management* (Russia: Thought, 1983)
4. A. B. Tchicaya Loemba, B. Kichonge, T. Kivevele, En. Sci. and Eng. **3**, 1326 (2022)
5. C. Tunckal, A. Yuksel, S Coşkun, En. Sour., Part A: Recovery, Utilization and Environmental Effects **44(3)**, 6777-6792 (2022)
6. O. V. Tolstoy, *Proceedings of International scientific and practical conference* (Prague, 2016)
7. A. Drannikov, T. Tertychnaya, A. Shevtsov, N. Zasypkin, Storage and processing of agricultural raw materials **246**, 132-145 (2021)
8. K. Protopopov, I. Zhirebny, S. Garanov, News of higher educational institutions. Mech. Eng. **12(657)**, 76-83 (2014)
9. V. Volodin, V. Kuntysh, S. Filatau, Refrigeration, heating engineering, energy saving **3**, 145-151 (2015)
10. V. Gorshkov, Handbook of industrial equipment **2**, 47-80 (2004)
11. A. Andryushchenko, D. Novikov, Problems of power engineering **11-12**, 17-25 (2004)
12. S. Luneva, A. Chistovich, I. Emirov, TTPS **4(26)**, 10-12 (2013)
13. I. Khakimzyanov, P. Kainov, R. Khasanshina, Bulletin of Kazan Technological University **18(2)**, 253-256 (2015)
14. I. Gataullina, Scientific progress – creativity of the young **2**, 101-104 (2019)
15. O. Ostapenko, V. Leshchenko, R. Tikhonenko, VNTU **2**, 12-16 (2015)

16. V. Chernyshova, *Proceedings of International Scientific Conference* (Kazan, 2020)