HEAT PUMPS AS A RESOURCE FOR ENERGY EFFICIENCY ON RAILWAY FACILITIES

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ABSTRACT

Since the microclimate in the workplace cannot be considered separately from a number of assessment factors (criteria), the authors justify the choice of heat pumps as a possible alternative to heating from environmental, energy and exergoeconomic viewpoints. This reasoning system is directly related to the specificity of objects of railways and to a set of technological safety factors, justifying reliability of the proposed options.

Keywords: *heat power industry, heat pump, railways, exergonomics, ecology.*

Background. *Heating of industrial premises, in particular remotely located from a central source, suggests the possibility of an alternative heating method. One of such methods is the use of heat pumps.*

Installations for heating are designed to ensure the required indoor temperature at any ambient temperature during the heating season. Typically, the heating system of production facilities is decentralized, and the room temperature may vary slightly from the outside temperature, under these conditions the use of heat pumps is very promising. Given the nature of technological processes implemented at the enterprises of JSC Russian Railways, vapor compression heat pumps correspond to their specifics mostly.

Studies [1–3] show that the potential for energy savings due to reconstruction and introduction of heat pump technology is about 60% of total energy consumption. However, realization of this potential requires, among other things, the use of modern methods of complex analysis and diagnostics of thermotransformation systems, on basis of which it is possible to get the maximum energy-saving effect with minimum financial expenses.

Objective. *The objective of the authors is to consider heat pumps in its application for heating of industrial facilities and as a resource for energy efficiency.*

Methods. *The authors use engineering methods, comparative analysis, mathematical apparatus, economic evaluation.*

Results. *To date, the efficiency of individual components of heat pumps in some cases reached such a level that an improvement in their designs does not have a significant impact on improving the efficiency of the entire system of thermotransformation. The main reserve of energy saving becomes a general improvement of structural and parametric characteristics, taking into account the relationship and mutual impact of elements of the scheme.*

The essential requirements for effective use of heat pumps are presence of sufficient resources of low-grade heat and the lack of restrictions on their accession to the electricity grid.

At this stage there is no technical limitation on the use of a heat pump, both by type and power, and a type of the used low-grade heat. Their choice for heating of production facilities is substantiated by technical and economic calculations, depending on the magnitude of the heat load of buildings, conditions of their placement, accessibility and low-grade heat source parameters.

Currently there is no single criterion (evaluation factor), on the basis of which it would be possible to uniquely identify the feasibility of the use of heat pumps. Three factors affect the decision: environmental, energy and economic.

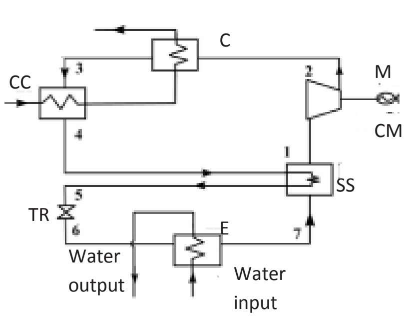
The ecological factor is based on the analysis of emissions in the atmosphere of heat and pollutants – CO_2, N_2O, NO_x, CO and other hydrocarbons that affect global warming. Note that this factor has been proposed for the environmental assessment of refrigeration and heat pumping equipment and therefore it is based on the analysis of the harmful effects of substances on the working environment when they hit the atmosphere. It can be concluded that the heat pump system (operating in failsafe mode) has no emissions into the atmosphere, and therefore is environmentally friendly for the user.

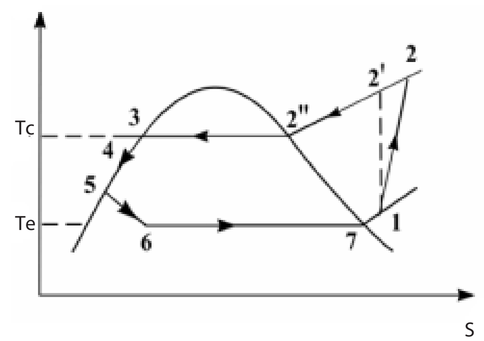
The energy factor for many years was the only really formalized and widely used estimate. For traditional heating systems – it is the efficiency (η), for heat pumps – heat pump conversion factor (μ). If we consider that the value of the efficiency in the most general case varies in the range $0<\eta<1$, and the other value varies in the range $1<\mu<\infty$, then it is unnecessarily to explain the incorrectness of their use in a comparative analysis of various heating systems.

Using the exergy efficiency it is possible to objectively evaluate the effectiveness of any of the heating systems, $e=\frac{E_{PS}}{E_F}$, *where E_{PS} is exergy of system's product (heat produced), E_F is exergy of fuel of the system (primary fuel consumed) [4].*

With the appearance of thermoeconomics (exergoeconomics) as a tool, analyzing and optimizing decision-making on the rational use of heat pumps are significantly facilitated, since the merger of the energy and economic factors reduced the dimension of the problem being solved and made it possible to formulate a definite answer about the effectiveness of this or other heating systems.

Conversion factor of the ideal Carnot cycle for heating during the heating season when the mean outside temperature is 277˚K and temperature inside the room is 293˚K is $\varepsilon_к=18{,}66$. Heating systems with heat pumps have a significantly lower conversion rate. They cannot work with traditional heating devices (radiators), using in most cases hot water with a temperature 90˚–110˚C. Heat pump heating systems with hot water temperature of 55˚C have a conversion factor, which is below the maximum permissible values of cost-effective application. Therefore, the economic effect of the use of heat pumps in heating systems can only be achieved by using low-temperature systems.





Pic. 1. Schematic diagram of heat pumps and circular process in T, S-charts: CM – compressor; C – condenser; E – evaporator; M – motor; CC – working body condensate cooler; TR – throttle; SS – working body of steam superheater.

Heat pump is a device for transferring thermal energy from low-grade heat source (low temperature) to the consumer (heat carrier) at a higher temperature. Thermodynamically a heat pump is a converted refrigeration machine. If in the refrigeration machine the main aim is to produce cold through heat extraction from any volume by an evaporator and the condenser carries out heat rejection into the environment, in the heat pump the pattern is reverse. The condenser is a heat exchanger, generating heat to the consumer, and the evaporator is heat exchanger, disposing of low-grade heat: secondary energy resources and (or) non-conventional renewable energy sources.

The heat pump operates as follows (Pic. 1). Heat from heat sensor (for example, the thermal energy of ground, safety waste streams or solar power) is supplied to the working agent in the evaporator. As a result of supply of heat the working agent boils in the evaporator at a pressure P_e and a temperature T_e. The steam produced in the evaporator is supplied to the compressor. In the compressor working agent (vapor) is compressed from the pressure P_e to the pressure P_c. The condensation temperature of the steam at the same time, respectively, increases from T_e to T_c.

Because of friction and irreversible heat exchange compression process in the compressor 1–2 does not coincide with isentropic compression 1–2′. Vapor from the compressor enters the condenser (K), where as a result of heat conduction to the heat sink cooling of the working agent, and vapor condensation occur. To improve the efficiency of the cycle internal regenerative heat exchange is sometimes performed between the flow of liquid working body (refrigerant) in front of the throttle and the steam flow in front of the compressor (via the working body condensate cooler CC). As a result of heat transfer liquid working body is further cooled (process 4–5 in Pic. 1), and its saturated steam is superheated (process 7–1). After the cooler the liquid refrigerant passes through the throttle (TR), where as a result of the throttling the pressure of the working agent falls from P_c to P_e and the temperature drops and the liquid agent again enters the evaporator.

The energy efficiency of the heat pump is estimated with a conversion ratio

$$\mu = \frac{Q_c}{L}, \qquad (1)$$

where Q_c is heat flow in the condenser, kJ; L – work, spent in the cycle, kJ.

For an ideal heat pump

$$\mu_{id} = \frac{T_c}{T_c - T_e}, \qquad (2)$$

where T_e, T_c are working body temperatures in the condenser and evaporator, respectively.

The energy efficiency of the heat pump increases with increasing of condensation temperature and with decreasing of temperature difference between the condenser and the evaporator. This difference is determined by the temperature of the evaporator, which in turn is connected to a low temperature source.

Heat flow in the condenser is composed of the heat flow in the evaporator and the cycle operation:

$$Q_c = Q_e + L, \qquad (3)$$

where Q_e is a sum of the heat flow in the evaporator, kJ.

Heat flow in the condenser is backed away with water, which is used for heating and hot water supply. The heat flow for heating of industrial premises is defined as

$$Q_c = k \cdot F \cdot (T_{HW} - T_A), \qquad (4)$$

where k is coefficient of heat transfer, W/m^2, degrees; F is heating surface area, m^2; T_{HW}, T_A are temperature of respectively hot work in the heating system and air in the room.

Thus, it should be noted that in theory 100% of the thermal energy is used, with 25% of the energy consumed by the compressor, and the remaining 75% extracted from low-grade heat source (ground water, sun).

For heating of premises with water with a temperature characteristic of the heat pump (50–55˚C) a developed surface of radiators or underfloor heating pipe system are necessary. Another possibility of the use of hot water, generated by heat pump installation, is its use as a coolant in air heating of the premises.

The decisive argument in justification and design of heating systems with heat pumps is a selection of a low-grade heat source, its location and parameters.

Low-grade heat sources for heat pumps can be: exhaust air, outdoor air, soil, wastewater, groundwater and surface water and secondary thermal energy sources of various origin.

The temperature of outdoor air *as a source of low-grade heat is characterized by seasonal and short-term fluctuations in temperature, which results in fluctuations in the heat pump mode, which reduces its effectiveness. The average level of the ambient temperature effects the transformation ratio – the lower is the temperature, the lower is transformation coefficient.*

Groundwater *has a constant temperature and high thermal characteristics. Using them as a low-grade heat source seems to be preferable in view of availability and apparent ease of the circuit of low temperature (up to 50°C) heating, which consists in supplying water to the evaporator of the heat pump and its return through the corresponding holes. But if the water is stagnant, mixing of cooled and ground water can happen, i.e., degradation of thermal energy source until the complete exhaustion.*

Exhaust air *is an effective and affordable for use as a low-grade heat source in heating systems of individual residential buildings. Exhaust air temperature is stable during the heating season and averages 18°C. The volume of exhaust air depends on the purpose and the area of ventilated premises.*

The soil *of the upper layers of the ground, as well as the outside air, is a heat accumulator of unlimited capacity. The effectiveness of the use of ground heat is mainly determined by the temperature mode of soil in the annual cycle and depends on its composition, humidity, air temperature, etc. Heat extraction systems of the soil with the use of heat exchangers made of plastic pipes of different diameters: horizontal version (snake, hinges, etc.), stacked with a deep of 1,5–2,0 m into the ground and vertical (probes) – in the boreholes of different depths are technically possible. For estimations value of the specific heat flow equal to 45 W per 1 meter length of the probe is assumed. Due to the fact that every year the cooled ground array area will increase, there is a question of the extent of this process and its impact on the environment.*

Soil temperature relaxation time is approximately equal to the soil cooling time used as a low-temperature energy source for the heat pump system. For example, if for the summer period (May-September) to completely eliminate extraction of heat from the ground, i.e., stay without hot water, then almost complete relaxation will happen by October.

Wastewater *is very promising, but so far little used for heating low-grade heat source, because of its biological and corrosive aggression, uneven flow regime in the sewer network. However, we must distinguish between the waste water of industrial origin, the composition of which is more predictable, and the wastewater of biological treatment. The volume and temperature of industrial wastewater depends on the technological process and the tap water temperature. Therefore, the minimum temperature of wastewater, to which it is allowed to reduce it via waste-heat exchangers must not be lower than the temperature at which the mixed wastewater enters the treatment plant in compliance with regulations. Leaving with wastewater heat waste can effectively be transferred with the help of heat pumps to a useful temperature level. Wastewater with a temperature below 30°C is of particular interest for this purpose.*

Water of recycling water supply*. In most cases, it serves to extract heat from technological equipment. Of great importance is the choice of location in the water circuit where the water is cooled so that the manufacturing process is improved and thus it is the heat source for heat pumps. Cooling with circulating water is used in technological processes: in tower-coolers to cool the condensers of refrigerating machines, compressors, condensers of power plants, etc.*

Solar energy *is used as a source of low-grade heat through the use of concentrated and directly absorbing solar flux solar collectors (panels). In case of concentration of solar radiation high heat flux density and correspondingly high temperature of the heated body are received. However, the use of solar collectors in winter and transitional periods in the territory of the Russian Federation is very limited because of low density of solar radiation, cloud cover, low ambient temperatures, snowpack.*

Conclusions. *After examining the main provisions of the application of heat pumps for heating and hot water supply, as well as capacity and availability of low-grade heat sources, it can be argued that the effectiveness of the use of heat pumps, all other things being equal, essentially depends on the ratio of the cost of electricity and thermal energy in the region. With a low cost of electricity and high cost of thermal energy the use of heat pumps in heating system is perspective.*

Thus, heat pumps are an economical way of heating of industrial facilities. Expensive heat pipelines are not required. As a result, with only electricity and water, using the heat pump it is possible to provide completely autonomous development and maintenance of the required microclimate at an industrial site.

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