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Thermodynamic Principles and Properties of Heat Pumps

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ABSTRACT: This article emphasizes the ability of a heat pump today to absorb energy from the environment and the features that distinguish it favourably from other heat generators, their ability to transfer all heat losses to the atmosphere along with combustion products.
Calculating the efficiency of a steam compressor heat pump is a very difficult task that can be solved taking into account certain operating conditions.

KEYWORDS: heat pump, refrigerant, condenser, compressor, evaporator, heating coefficient, cooling coefficient.

I. INTRODUCTION

Today, if we look at the dynamics of the economies of countries around the world, energy conservation is one of the most pressing problems, as well as the rise in prices for fossil fuels and their economical use.It is known that we see that most of the world's population needs to be heated in winter. 90% of the energy used in the national economy is thermal energy. This amount is constantly growing, and in recent years the share of heat consumption in the national economy has increased significantly. In turn, the issues of saving fuel and energy resources are a factor in increasing production efficiency. There is currently no industry that does not use the heat associated with human production. Space technology, metallurgy, transport, energy, agriculture, chemical industry, food production - all these are the main areas of the national economy that require solutions to scientific, engineering and technical issues related to heat.At the same time, in some cases, attempts are made to create such processes and equipment, in particular, in which the maximum amount of heat is released and useful results are obtained. In some cases, this is done in reverse order, ie to minimize the negative impact and generate less heat [1].

II. MATERIALS AND METHODS

The ability of a heat pump to extract energy from the environment distinguishes it favourably from other heat generators, which emit all heat losses into the atmosphere along with combustion products (Fig. 1). For a heat pump to receive energy from the environment at a relatively low temperature, it must be supplied with mechanical energy, which in most cases is converted into electrical energy.

Typically, heating a heat pump requires about three times less electricity than, for example, electric radiators than directly converting electricity to heat. However, such a comparison is not entirely accurate, because electricity is generated in thermal power plants with very low efficiency, and it is correct to calculate the efficiency of a heat pump based on the amount of primary fuel energy consumed to produce a unit of consumed heat. The energy flow diagram for heating the heat pump is shown in Figure 2. As mentioned above, a heat pump (HP) is one of the heat transformers - a device that transfers heat from one body to another at different temperatures.

Heat transformers can be enhanced if they are designed to transfer heat to high-temperature bodies and lower if they are designed to transfer heat to high-temperature bodies. Thermodynamic cycles of thermal transformers are combined into forward and reverse cycles [2].

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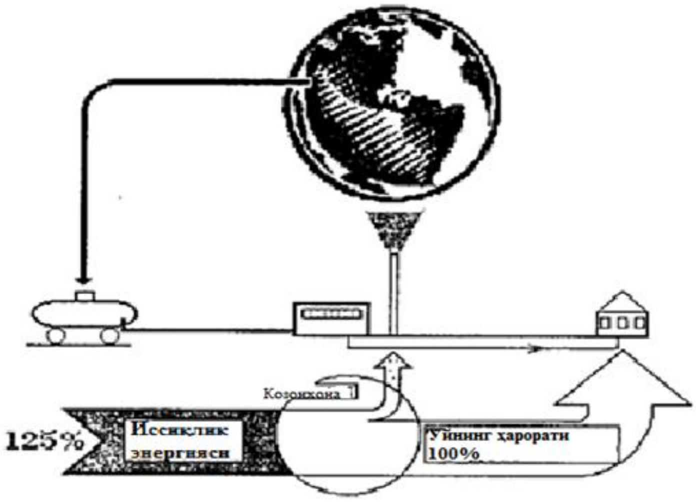

Figure 1. Diagram of energy flows during heating in the boiler

The heat pump is one of the amplified thermal transformers, which transfers heat from the outside environment to the high-temperature body as shown in Figure 2.

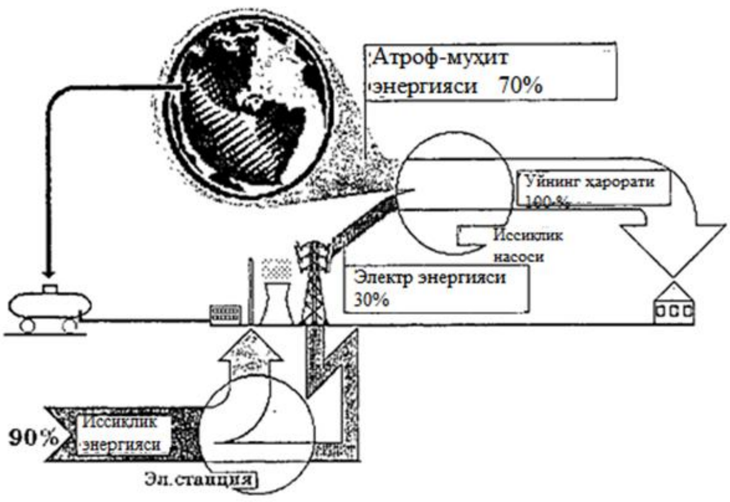

Figure 2. Energy flow diagram for heating a heat pump

The principle of operation and the main features of heat pumps. It can be seen that there is no fundamental difference in the performance and design of refrigerating machines and heat pumps. The only difference is that it depends on the purpose of the heat received and the temperature level. The refrigerator is designed to generate heat below ambient temperature. That is, the production of cooled heat carrier (saltwater, antifreeze, air, water) leaving the evaporator. The purpose of the heat pump is to generate heat (in the form of a heat pump with compressed steam, in the form of a heated refrigerant (water, air) leaving the condenser).The principle of operation of a steam displacement heat pump. In fig. 3 shows its scheme and thermodynamic cycle ("temperature-entropy") on the T-s diagram. The heat pump is driven by mechanical work supplied to the compressor, which is driven by an electric or heat motor. The pressure of the working fluid in the vapour state in the compressor increases from P_1 to P_2 (process 1-2).Then the working substance is condensed in the condenser under constant pressure (2-3 processes).The heat obtained during condensation is transferred

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to the consumer at a temperature T_2, for example, by heating the water supplied to the heating system.With the partial evaporation of gaseous substances (process 3-4), P_1 expands to pressure.

Also, the working substances are completely evaporated in the evaporator at temperature T_1, where heat is taken from its source, for example, from heated ventilation air or combustion products.

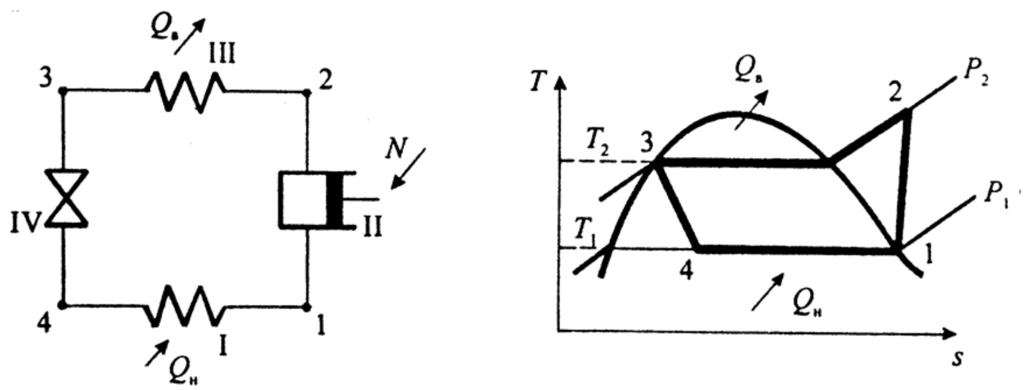

Figure 3.Diagram of a heat pump that displaces steam and a diagram of its cycle.
I - evaporator, II - compressor, III - condenser, IV - suffocator.

The main characteristics of a heat pump are the heat conversion (conversion) coefficient, thermodynamic efficiency and unit cost, that is, the costs associated with the heat output of the heat pump. [3]

The heat conversion factor is the ratio of the heat energy received to the power expended to drive the compressor. This depends on the temperature of the suddenly increased, significantly cold heat source T1 and the temperature of the resulting hot heat carrier T2. As a result of the operation of the heat pump, it is possible to obtain approximately 2-8 times more heat than in the case of heating the refrigerator directly by the electric heater.

$$\varepsilon_T = \frac{Q_B}{N} = \frac{T_2}{T_2 - T_1} \qquad (1)$$

For people not familiar with the operation of heat pumps, this situation seems to be a violation of the first law of thermodynamics. In fact, this is not the case, and in this case, we only convert the heat of potential into the heat of high potential, that is, the coefficient of conversion of the temperature of another temperature level is not the efficiency of the heat pump installation. It is known that the quality of one type of energy depends on its ability to switch to another type of energy. If in an ideal process mechanical work can be converted into a completely different kind of energy, then heat, even in an ideal process, can be partially converted into mechanical work.The rate at which heat is converted into work is characterized by the efficiency or exergy of the heat flux, and we can see that the heat flux depends mainly on the temperature level as well as the ambient temperature. Thermodynamic perfection of a heat pump is determined by its exergy efficiency. This can be calculated as follows:

$$\eta_e = \frac{Q_B \omega}{N} \qquad (2)$$

There, w is the temperature function or coefficient of thermal efficiency.

$$\omega = \frac{T_2 - T_{OC}}{T_2} \qquad (3)$$

As you can see, the exergy efficiency of a heat pump is always less than one.

Approximate temperature dependence of the heat transfer coefficient As can be seen in Figure 4, if the temperature difference between the evaporator and the condenser is small, the conversion ratio can reach large values.In practice, at the current level of equipment and energy costs, it is recommended to use heat pumps with a transformation ratio of at least 2.5.

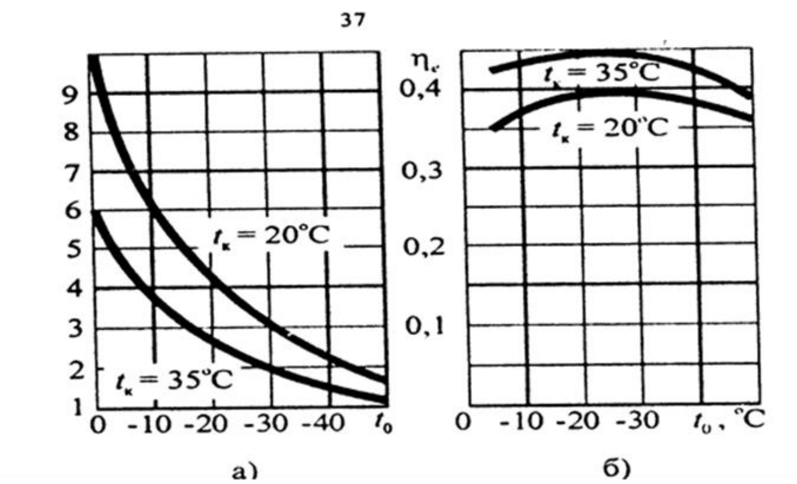

Figure 4. Dependence of performance coefficient (a) and energetic efficiency (b) on condensation and evaporation temperature.

The cost of heat pumps from foreign companies is slightly higher; we should expect a decrease in the unit cost of heat pumps as the number of local manufacturers increases. The performance of a heat pump mainly depends on the operating medium used .In this opportunity, various freons, derivatives of saturated hydrocarbon refrigerants, are often used. Freons such as R-22, R134a, R-407 are used, as well as easily safe R-142B freons. The use of R-22 freon was allowed only by the Montreal Convention until 2005.The characteristics of freons mainly determine the heat conversion coefficient and, therefore, the efficiency of the heat pump .For example, the thermophysical and thermodynamic properties of freons. Heat pumps are widely used for heating and cooling in heating and hot water supply processes [4].

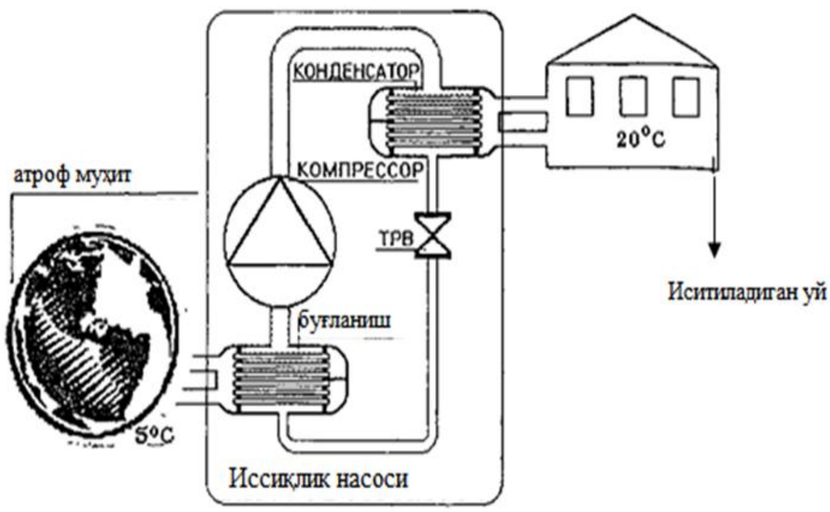

Figure 5. Diagram of natural energy conversion in a heat pump

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The same principle of operation of chillers and heat pumps allows the production of cold and heat in one unit, providing a simultaneous supply of heat and cold to the consumer. This combination is usually cost-effective. The heat source for a heat pump used for heating can be air, water or soil.If the temperature of the heat source changes in a room with radiator heating (for example, the daily change in air temperature), then the efficiency of the heat pump will also change. Thus, when using a heat pump, more useful heat can be obtained (several tens of per cent) than is available in the fuel used for its production, which can lead to significant economic efficiency. There are many types of heat pumps, the most common of which is the vapour-liquid compressor. It consists of four elements: a compressor, an evaporator and a thermostatic expansion valve (shown in figure 5).

All heat pump units are filled with low boiling point refrigerant, for which the ambient temperature is so high that the liquid refrigerant begins to boil in the evaporator. The resulting vapours are absorbed by the compressor. When the compressor is compressed, the temperature of the refrigerant vapour rises so much that the vapour liquefies in the condenser, which is flushed with the coolant, and the heat of the condensate is transferred to the cooling heat and then heated.

On its way to the evaporator, the liquid refrigerant passes through a thermostatic expansion valve, where the pressure of the liquid drops sharply, after which it begins to boil in the closed-loop evaporator.

III. CONCLUSION

In conclusion, it should be noted that the ratio of the heat energy produced to the work done in the compressor is the conversion factor of the heat pump. Depending on the temperature difference between the EPR sources, we can see that if the difference is small, then the conversion coefficient reaches high values. We can say that it decreases with a significant temperature difference.

It is believed that the efficiency of a heating heat pump is achieved through three or more conversion factors. Calculating the efficiency of a heat pump is one of the most difficult tasks that can be solved taking into account specific operating conditions.

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