Adaptation of Heat Pump Operation to Cold Climate Conditions

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Abstract

Freon-based air conditioning systems are widely used throughout the world and are used to provide heating and cooling year-round. Since the RA regions are divided into warm, temperate and cold climate zones and even into warm zones, the design air temperature in winter is below -10 ℃, so it is necessary to use such systems that can operate at low temperatures. conditions. The article discusses options for making heat pumps work efficiently in cold climates.

Keywords: *heat pump, condenser, conversion factor, vapor indicator, extension valve*

1. Introduction

Along with the development of construction in Armenia, market relations are also developing, as a result of which a wide variety of cooling systems, the cheapest and the most expensive modern air conditioning systems, are imported into Armenia The fact is that most cooling equipments are not adapted to the climatic conditions of the Republic of Armenia. In the northern regions, the demand for local air conditioners (split systems) has decreased due to unfavorable climatic conditions. The average air temperature in summer is approximately + 28°C[1], which is close to optimal comfort conditions. The use of local air conditioners in order to provide comfortable conditions in residential premises is economically more profitable compared to other types of air conditioning installations.

In the newly built buildings of RA, is mainly organized a centralized the heating systems, but in transition periods, when the north faced rooms need heating, the central heating systems are not yet connected, and it is inconvenience among the residents. Therefore, the most widely used types of air conditioners are those models that can also work in heat pump mode Thus, by installing such systems, two problems can be solved at once: to cool the room on hot days and to heat it in transitional periods. Moreover, heating with a heat pump during the transition period is energy efficiently.

In non residential spaces, where there is also a huge excess of heat in winter, the use of local air conditioning systems is not very advisable. In such buildings, centralized air conditioning systems are mainly used: VRF, VRV systems. These systems come in varieties that are capable of simultaneously providing both heating and cooling in different rooms [2-4].

2. Materials and Methods

The calculated air temperature in Yerevan in winter is -19°C, which is below the lower limit of the working temperature of many air conditioners. Using local air conditioners in winter is not very advisable. The use of these systems leads to increased wear and reduced service life, in addition, the non-return valve (4-step valve) begins to work not properly.

The efficiency of heat pumps decreases significantly as the outside air temperature decreases. Figure 1 shows the dependence of the conversion factor for R134a, R410a freons on the outdoor temperature for a reciprocating compressor when the condensing temperature is +45°C.

The working principles of the heat pump and chiller are the same, that is, the technical characteristics of the heat pump can be found by analyzing the operation of the chille.

The changes in the thermal productivity of heat pumps are realized in the same way, regardless of the type of heat source, but it is worth noting that heat pumps with an airflow heat source have a larger range of operating temperatures. The absolute maximum and minimum values of air temperature in different regions of Armenia vary from -36°C to +43°C. The compressor suction pressure varies over wide ranges, while the discharge pressure remains almost constant.

It should be noted that the productivity of the heat pump decreases depending on the decrease of the evaporation temperature (pressure), because the density of the vapor refrigerant, the compressor's thrust coefficient and the specific cooling capacity decrease in this case.

The conversion factor of the heat pump is determined by the following formula: $\mu=(1+\varepsilon)$ (1).

The operation of the heat pump is considered effective if the heat coefficient $\mu \geq 3$ [5-7. As the outside air temperature decreases, the power used by the compressor also decreases. However, it is not a fact that heating with heat pumps is relatively cheap. At relatively lower temperatures of outside air, the heat pump develops a relatively low productivity. In addition, compressor wear is greater in cold weather.

Analyzing the operation of air conditioners when the temperature of the cooled room is higher than the outdoor temperature, we see that it is not so appropriate The use of split air conditioners for year-round cooling of rooms is caused solely by the insufficient availability of appropriate equipment on the market and partly by incorrect professional solutions.

At outdoor temperatures of +10°C and below, the so-called artificial methods of obtaining cold can be abandoned by using the natural transition of heat from a higher potential to a lower potential.

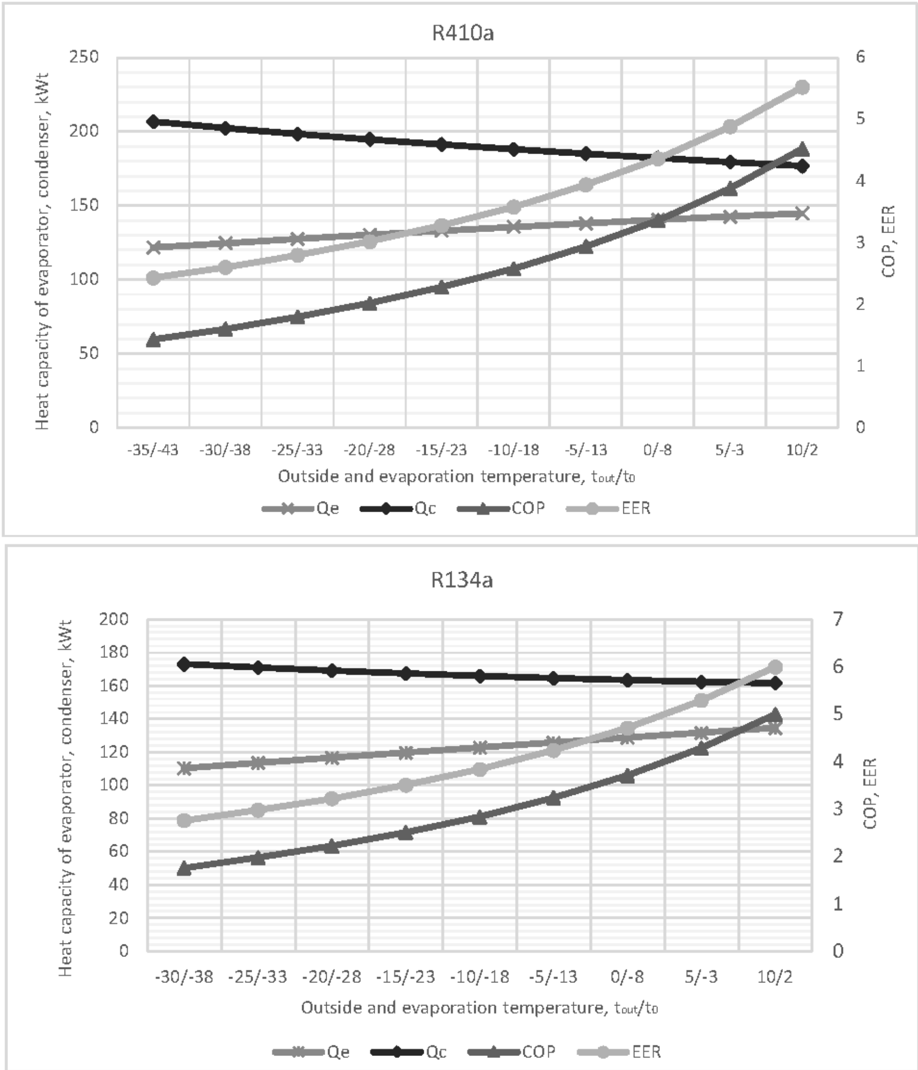

Fig.1. Dependence of COP on external air and evaporation temperatures

In practice, it can be implemented in different ways, for example, using a ventilation system (the temperature of the air in the room is regulated by the amount of air introduced). Refrigeration systems, which use a circuit with intermediate antifreeze (ethylene glycol) in winter, have recently become widespread. When, the heat transfer is carried out by the fluid in the heat exchanger outside. Electrical energy is spent only in the pump and fan nodes, at the same time extending the life span and reliability of the entire system.

To make the problem more visible, let's consider the operation of the air conditioner in the conditions considered above, when the temperature of the cooled environment is higher than the temperature of the outside air [8,9].

The refrigerant flow through the evaporator valve is expressed by the following well-known dependence:

$$G_{XA}=X\cdot F\sqrt{(2*(P_K-P_0)*\rho)},$$

where: F- the area of live section of the opening; X-flow coefficient; ρ is the density of coolant.

Thus, the cost through a evaporator device (capillary tube) depends on two variables: pressure drop and refrigerant density.

In winter, as the outdoor temperature decreases, the condensing pressure decreases (cooling operation). This results in an increased pressure drop across the expansion device, meaning less refrigerant is delivered to the evaporator.

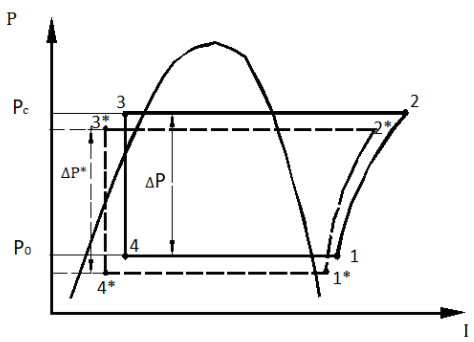

Fig. 2 Heat pump operation at low outdoor temperatures (self-regulating mode)

A further decrease in the amount of refrigerant in the evaporator leads to an increase in refrigerant in the condenser, a decrease in the effective internal heat transfer surface and a slight increase in condensation pressure. At the same time, the pressure on the suction line also decreases (Fig. 2). Thus, the pressure drops in the capillary tube increases. In addition, supercooling of the expentonling liquid refrigerant leads to an increase in flow through the capillary tube due to an increase in density, the so-called "self-regulation of the system" occurs. But the installation becomes less efficient, since as a result of a decrease in outside air temperature, the evaporator is not completely filled, which leads to a decrease in cooling capacity. It is also important that in severe frosts the suction pressure may be lower than the design pressure, and as is known, such operating modes are undesirable for refrigerators, since returning oil to the compressor becomes difficult.

When the air conditioner operates in this mode, we have to talk not about the condensation temperature, but about the condensation pressure Pk, since it is determined by the hydraulic resistance in the expention valve and pipelines, and not by the outdoor temperature.

When the system is turned off, the refrigerant returns from the evaporator through the capillary tube to the condenser, where it cools.

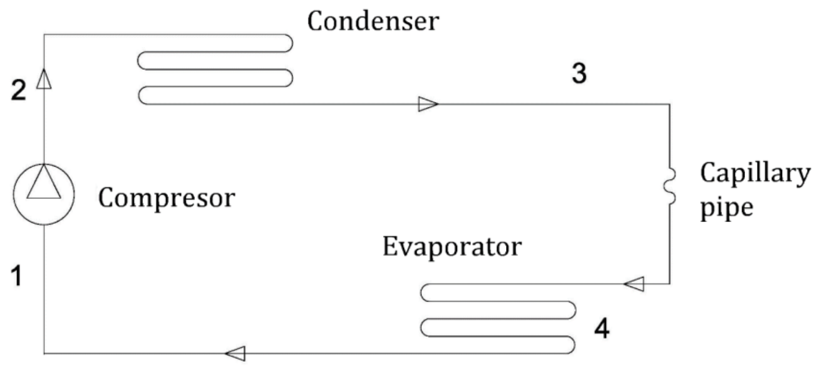

Fig. 3. Schem of heat pump with a capillary tube

From the above it follows that the system equipped with a capillary tube (Fig. 3) shows low efficiency at low outdoor temperatures. Insufficient performance of the evaporator is also an important factor. When the air conditioner is overcharged during cold periods for maintenance reasons, this can lead to hydraulic shock and equipment failure when the weather warms up.

The problem is more easily solved when the systems are equipped with a thermoregulating valve, when in case of a slight drop in the outdoor temperature, the evaporation pressure is regulated by increasing the living cross-sectional area of the thermoregulating valve. Starting from certain values of the outdoor temperature (0°C for refrigerated vehicles), the thermostatic valve opens fully and a further decrease in the outdoor temperature, and therefore also the condensing pressure, leads to a drop in the boiling pressure, as in the case of a refrigerated vehicle equipped with a capillary tube. If there is a liquid refrigerant line receiver in the system, the "flooding" of the condenser does not occur and the system is shut down by the low pressure sensor relay. In practice, several methods of maintaining the condensing pressure in heat-compressor refrigerating machines with an air-cooled condenser are used when the outdoor air temperature is low (this is important for the operation of refrigerating machines). For example, by flushing a part of the heat transfer surface of the condenser with liquid refrigerant. In this case, the effective heat transfer surface on the refrigerant side decreases and the condensing pressure increases[10, 11].

Nowadays, inverter-controlled motors are also widely used, which allow the condenser fan speed to be continuously varied, thereby regulating the cooling air flow and condensing pressure.

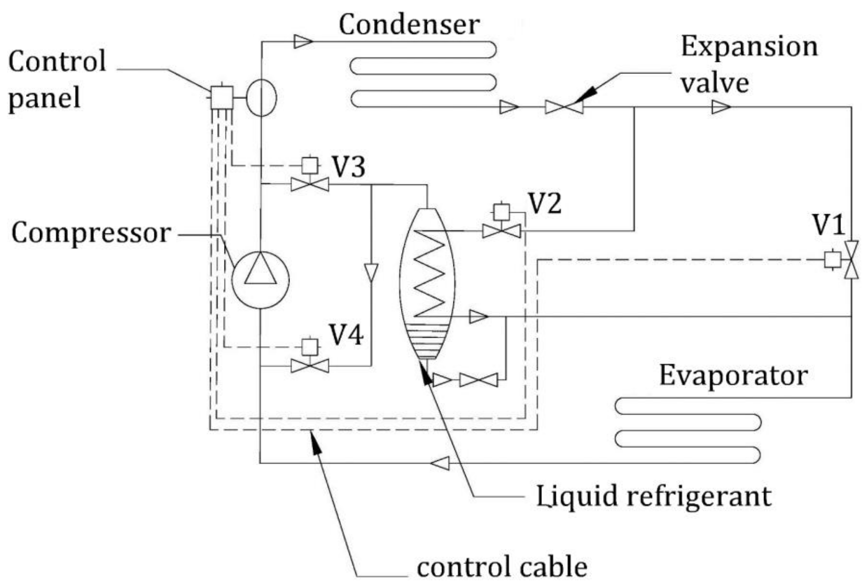

Fig. 4. Heat pump with condensing pressure regulation (by the non-condensable gas method)

3. Results and discussion

We proposed the following method of maintaining the condensing pressure (Fig. 4), according to which, when the pressure in the condenser decreases, a certain amount of non-condensable gas is supplied to the evaporator Accumulating in the condenser, it increases the pressure in accordance with its own partial pressure, which is also the reason for the reduction of the effective heat transfer surface. At the same time, the pressure drop across the throttle valve increases, which is sufficient for the normal supply of evaporative refrigerant.

In the solution offered by us, the system is complete: compressor, condenser, throttle valve, evaporator, non-condensing refrigerant tank, V1 valve (solenoid valve), non-condensing gas removal line, its V3 valve, non-condensing gas supply line, its V4 valve, cooling of the removed mixture from the line with V2 valve, from the accumulator tank, from the refrigerant emptying line, from the control device for response to pressure changes in the condenser.

The heat pump works in a classic cycle. In the self-regulating mode, the pressure in the condenser, which is measured by the pressure sensor of the control system, corresponds to the specified one. With a significant decrease in the temperature of the air cooling the condenser, the condensing pressure and the pressure drop across the expansion device fall, as a result of which the refrigerant consumption and the cooling capacity of the machine also decrease. In this case, based on the signal received from the pressure sensor of the control device, a certain amount of non-condensable gas from the tank is given to the low-pressure side of the refrigerant circulation through V4.

The non-condensable gas is compressed with the refrigerant in the compressor and is pumped to the condenser and stored. The pressure in the condenser increases. The pressure difference between the suction and discharge sides increases. As a result, the refrigerant flow through the expansion device increases, providing the necessary cooling capacity. During the further decrease in the temperature of the air cooling the condenser, the next portion of the non-condensable gas is given to the refrigerant circulation. As the temperature of the air cooling the condenser rises, the non-condensable refrigerant is returned to the tank.

Based on the signal received from the pressure sensor of the control device, V1 is closed, V2 is opened, and the refrigerant, after the throttle valve, passes through the non-condensing gas tank, cooling it. Valve V3 opens briefly and transfers a certain amount of non-condensable gas and vapor refrigerant mixture into the tank. In this case, the vapors of the refrigerant pumped from the condenser to the tank, together with the non-condensable gas, are liquefied. Refrigerant from the valved non-condensing gas tank is returned to the refrigerating machine circuit. Valve V2 closes and V1 opens, the installation works in normal mode. With a further increase in air temperature, the procedure is repeated.

During the warm period of the year, when the cooling air temperature is high enough for normal operation of the heat pump, all non-condensable gas is returned to the storage tank and the control device is switched off. The proposed control device can be used in conjunction with a device that partially or completely disables the forced flushing of the condenser with cooling air.

At low temperatures, the process of releasing the compressor becomes difficult. The oil becomes too viscous and the compressor runs dry. In addition, at low temperatures, the solubility of freon in the oil increases, so the saturated oil-freon mixture accumulates in the oil sump. As the heat pump discharges, the refrigerant boils in the sump, the oil becomes less viscous, and the compressor may fail [12].

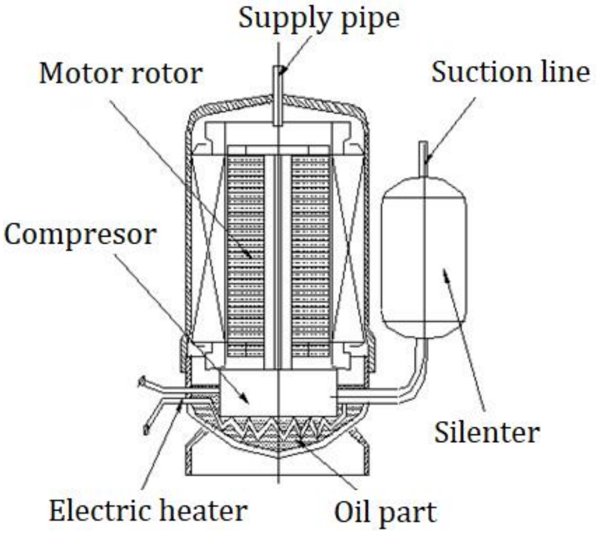

Fig.5. Electric heating of oil tank

All air conditioners intended for use in Armenia must be equipped with oil sump heating, which will operate automatically before turning on the compressor and when operating in negative temperatures. For newer air conditioners, this may be a heating element built into the cartridge (Fig. 5). For existing air conditioners, the above can be obtained using a homemade method.

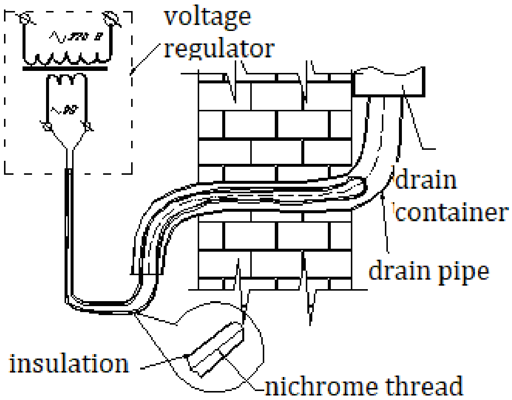

Fig. 6. Condensate removal pipe heating

One of the problems in the operation of air conditioning systems is the freezing of the condensate, which can freeze even after passing a short distance at temperatures below 0°C, and if the system works in the cooling mode, the condensate will flow into the indoor environment. This problem can be solved by heating the condensate with a nichrome wire (Fig. 6), which should be under a low voltage of 9-12V.

A nichrome wire with a diameter of 0.1-0.15 mm passes through the plastic tube, which serves as an insulator, and is placed in the condensate removal tube.A step-down converter is installed in the outdoor unit of the air conditioner and fed from the compressor power supply so that the duct heating is connected in parallel with the unit. The temperature of the thread should not exceed +80°C, for this a temperature sensor is also placed. The modern level of automation, the widespread use of plate heat exchangers, which makes it possible to reduce the temperature difference between the coolant and the intermediate coolant to 3-4 K, the use of economically advantageous cooling in cold weather, allow us to speak with full confidence about the revival of salt cooling systems. "Cheap" cooling systems with an intermediate coolant (ethylene glycol, etc.) are especially promising for maintaining subzero temperatures in Armenia (ventilation, fruit freezing). storage, beer technologies), because the temperature regime can be maintained for half a year without operation of the refrigeration machine.

4. Conclusion

1. The widespread capillary tube application method in heat pumps at low outdoor air temperatures leads to inevitable disadvantages (reduction of the effective internal heat transfer surface and small increase in condensing pressure, insufficient performance of the evaporator).
2. The use of heat pumps at low outside air temperatures becomes appropriate in the case of partial use of non-condensing refrigerant.
3. In order to ensure uninterrupted operation of the heat pump at low temperatures, it is inevitable to heat the oil sump and the condensate removal pipe.

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