Experimental Mixed Refrigerant Low-Temperature System: Development and Trial

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Abstract. The article introduces a low-temperature system operating on a mix of refrigerants R134a/R23, as well as its operating scheme, structural diagram, and appearance. The design proved operable, reliable, and efficient. The system needed three hours for the temperature to drop as low as -70°C. The operating temperatures and pressures endowed the system with a reliable, stable, and long-time performance. The device can be used for low-temperature processing and storage of biotechnological materials, as well as in pharmacy and environment testing.

1 Introduction

Refrigerations systems of various configurations and designs provide low-temperature processing and storage of foods, raw materials, and biotechnological materials [1]. Each case requires a particulardesign determined by various factors, e.g., cooling capacity, temperature, safety requirements, etc. [2].

Depending on the required temperature, vapor-compression refrigerators are divided into single-stage, two-stage, and cascade ones [3]. The required temperature also determines the type of refrigerant used as a working fluid. Currently, about forty refrigerants are used in low temperature technology. The use of one or another refrigerant is determined by conditions of use and other reasons. At the same time, part of the refrigerants are azeotropic and non-azeotropic mixtures of substances [4].

To obtain low temperatures - usually below -40° C, it is often necessary to use more complex schemes of low-temperature systems. These can be two-stage refrigerating machine or cascade refrigerating machine. Both cases are accompanied by a complication and rise in the cost of the design, a decrease in reliability. The use of a refrigeration machine with a mix refrigerant consisting of easily separable components makes it possible to obtain significantly lower temperatures without significant complication of the construction [5].

Non-azeotropic mixtures of refrigerants, the components of which have a significant temperature difference at the same pressure (this difference should be from 40 ° C or more). The use of such mixtures allows the use of a substantially single-stage type of chiller, while allowing significantly lower temperature levels to be achieved. Freons R13, R23, as well as ethylene (R1150) are used as low-temperature components of such mixtures. High-temperature components of such mixtures can be freons R134a, R134f, R22, R12, R114, as

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well as butane and isobutane (R600, R600a). The low temperature system on these worker blends is affected by refrigerating machine blowout, but they still achieve single stage compression. The refrigerating machine on R134a/R23 mixture with serial connection of components allows to obtain the temperature level in the evaporator up to -90°C [6].

Currently, in order to achieve a temperature level of -50°C and below, single-stage low-temperature systems using non-azeatropic mixtures of refrigerants with sequential condensation of components are becoming more and more in demand [4].

In accordance with international agreements on climate and ozone layer protection, ozone-safe refrigerants [5] should be used in the design of such systems , for example, R134a, R134f, R600, R600a, R1150, R23, etc. [7].

The aim of the study was to develop a low-temperature system based on a mixture of refrigerants with sequential condensation of components for the temperature level -45÷-70°C..

2 A mixed-refrigerant low-temperature system: operation principles

Fig. 1 illustrates a scheme for a new low-temperature refrigerator operating on a mix of refrigerants. R134a was the high-temperature component while R23 served as the low-temperature one. Essentially, a low-temperature system is a cascade refrigeration machine with a hydraulic circuit filled with two refrigerants in a certain proportion. The refrigerants move together as a mix through a section of the hydraulic circuit. After that, they separate to perform certain functions and then mix again.

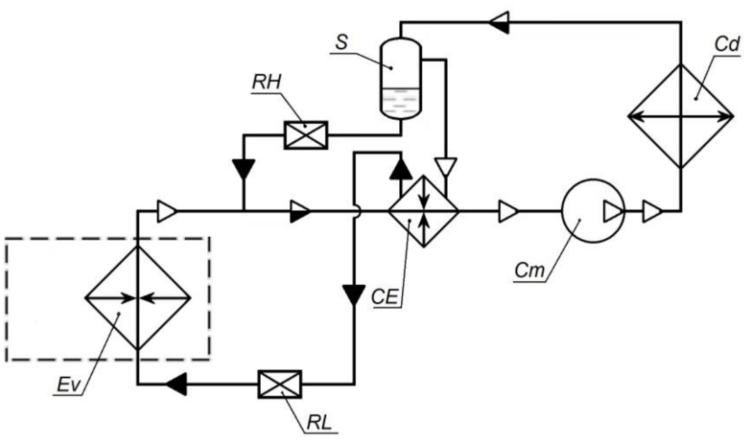

Fig. 1. Principle scheme of a low-temperature system on a mixed refrigerant with sequential condensation of components

Ev–evaporator; *RH* –restrictor for high-temperature refrigerant, *S*– separator; *Cd*–condenser; *Cm*–compressor; *CE*–condenser-evaporator; *RL* –restrictor for low-temperature refrigerant

Compressor compressed the mix of low-temperature and high-temperature components. The discharge pressure depended on their ratio, which also determined the temperature of the discharged refrigerant. The discharge pressure should be (11÷14 bar). To maintain this discharge pressure in an air-type condenser at an ambient temperature of≤27°C, the ratio of R134a/R23 was about 70% to 30%. At this ratio, the temperature of the injected steam stayed below 120°C.

From the compressor, the refrigerant mixture enters the high temperature refrigerant condenser, where R134a is condensed. Next liquid R134a and gaseous R23 is separate into the separator. The liquid R134a throttled in restrictor *RH* to the suction pressure. Then, it mixed up with the return flow of the vapored R23 coming from evaporator. This low-temperature mix entered condenser-evaporator. The low-temperature component vapor direct into condenser-evaporator from separator. In the condenser-evaporator R134a at low temperature and pressure removes heat from R23, therefore R23 condenses and R134a passes into a vapor state.

The refrigerant vapor is direct to the compressor and the liquid R23 throttled restrictor *RL* to the suction pressure. It also lowers the temperature R23. From the restrictor *RL* R23 enters the evaporator installed in the cooled volume.

3 The device of a low-temperature system with sequential condensation of components mixed refrigerant

The low-temperature scheme (Fig. 1) is made in the form of a refrigerated chest (Fig. 2).

Fig. 2. Low-temperature refrigerating chest with a mixture of refrigerants with sequential condensation of components

The design of a low-temperature system based on a mixture of refrigerants with sequential condensation of components is shown in fig. 3.

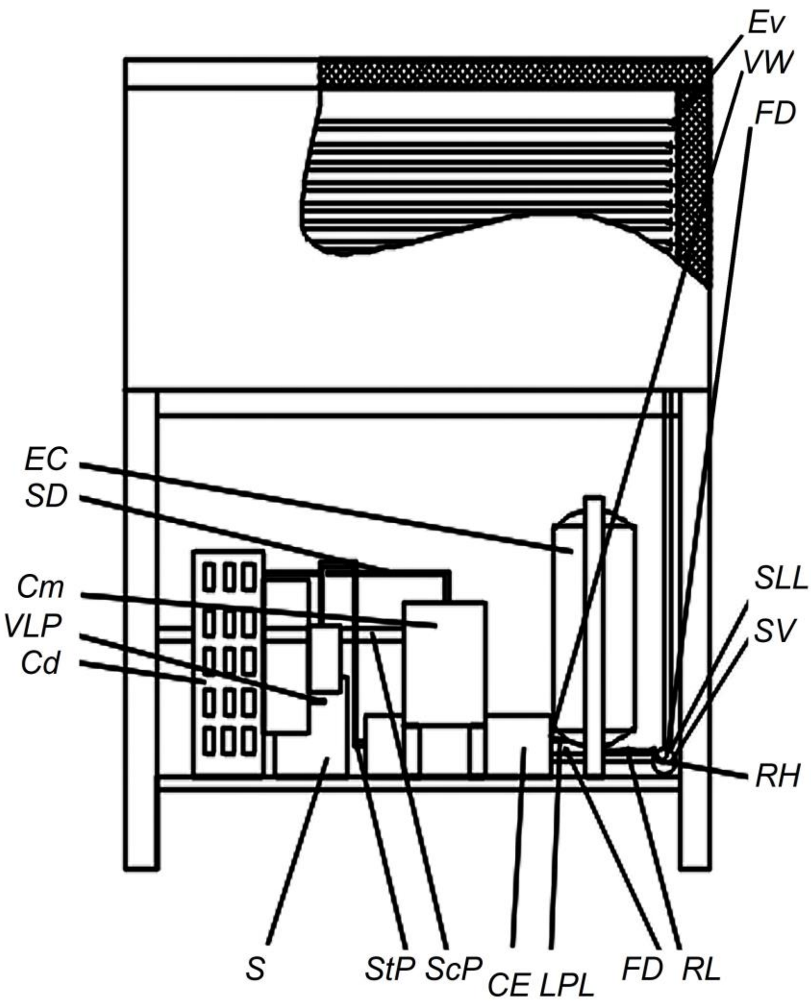

Fig. 3. The device of a low-temperature system with sequential condensation of components mixed refrigerant

Ev–evaporator; *VW*–viewing window; *FD*–filter drier; *CE*–condenser-evaporator; *RL*–restrictor R23; *FD*–filter drier; *SLL*–suction pipeline R23; *SV*–shut-off valves; *RH*–restrictor R134a; *EC*–expansion capacity; *LPL*–liquid pipeline R23; *ScP*–suction pipeline; *Cm*–compressor; *SD*–steam discharge pipeline; *Cd*–condenser; *StP*–steam pipeline R23; *VLP*–vapor-liquid pipeline; *S*–separator

A Cubigel GX18TB low temperature compressor was used to compress and circulate the refrigerant, which is highly reliable at high pressure drops and high refrigerant discharge temperatures.

The filter driers were placed on the lines for supplying liquid components directly in front of the restrictors. The main function of the filter-drier is to dry the refrigerant from water and clean it from mechanical impurities.

A 1 mm thick copper pipe was used to circulate the refrigerant. On the suction side, a pipe with a diameter of 8 mm was used. On the discharge side, a pipe with a diameter of 6 mm was used.

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Overall dimensions of the low-temperature chest: 1200x500x600 mm, internal volume 250 liters. The evaporator was made of a copper pipe with a diameter of 8 mm.

The condenser-evaporator in this unit is designed to condense the R23 refrigerant by boiling the R134a refrigerant. A double-circuit brazed plate heat exchanger was used as an evaporator-condenser.

The refrigeration plant on a mixture of refrigerants (Fig. 3) operates as follows.

From the heat exchanger, the refrigerant vapor is sucked into the compressor, which pumps the compressed refrigerant into the condenser. R134a condenses in it. The mixture of liquid and vapor phases leaves the condenser and enters the liquid separator, where the phases are separated. R134a is throttled in the restrictor to the boiling pressure, mixed with the R23 vapor flow coming from the evaporator, and sent to the evaporator condenser to cool and condense the vapor phase R23 coming from the liquid separator. Pairs of R23 from the liquid separator are sent to the condenser-evaporator and condense in it. Further, the liquid is throttled in the restrictor and enters the evaporator. In the evaporator R23 boils, taking heat from a heat source with a low temperature, evaporates and at the outlet of the evaporator before the evaporator condenser mixes with R134a. In the condenser-evaporator, the mixture overheats and is sucked into the compressor.

Expansion vessel is necessary to protect the chiller from excessively high pressure when the chiller is stopped when the temperature of the refrigerant in the entire system is equal to the ambient temperature. When the compressor is started, the refrigerant is pumped out of the expansion vessel, the pressure in which during operation will correspond to the boiling pressure.

4 Low temperature system trial with refrigerant mixes

The low-temperature system was tested on a refrigerant mix. The temperature measurements took place in the cooling chamber, as well as at the inlet and outlet to and from the evaporator of the low-temperature refrigerant. The measurements involved a measuring complex with chromel-copel thermoelectric converters, a TPM-138 controller, an AC-4 interface converter, and the Aries software. Fig. 5 illustrates the trial results.

The discharge gas temperature and the suction and discharge pressures created by the compressor are important factors in low-temperature systems. Fig. 5 shows the results of the discharge temperature measurements.

Fig. 6 illustrates the pressure measurements, which involved a BM2-6-DS-CLIM Refco. The measured values are given in excess values.

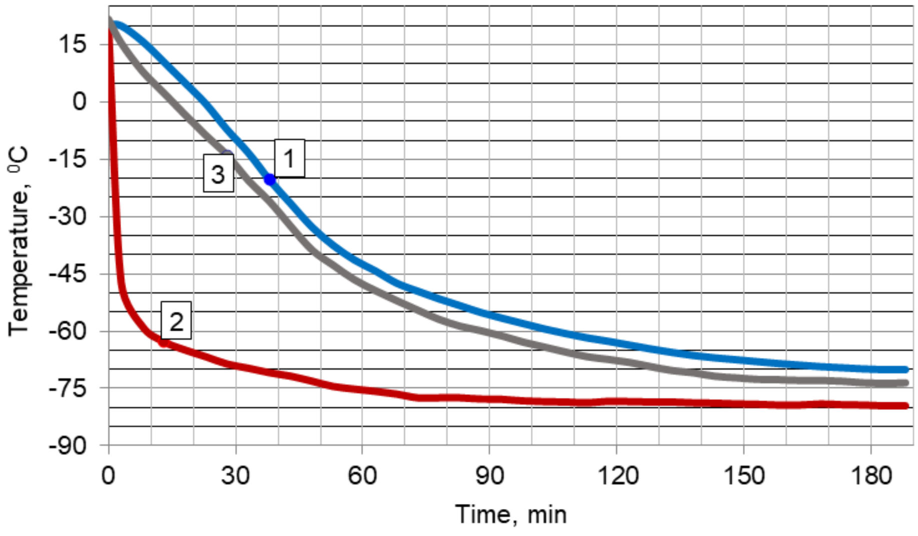

Fig. 4. The low-temperature mixed refrigerant system with sequential condensation of components temperatures

1 - temperature in the cooled volume; 2-R23 at the evaporator inlet; 3-R23 at the evaporator outlet

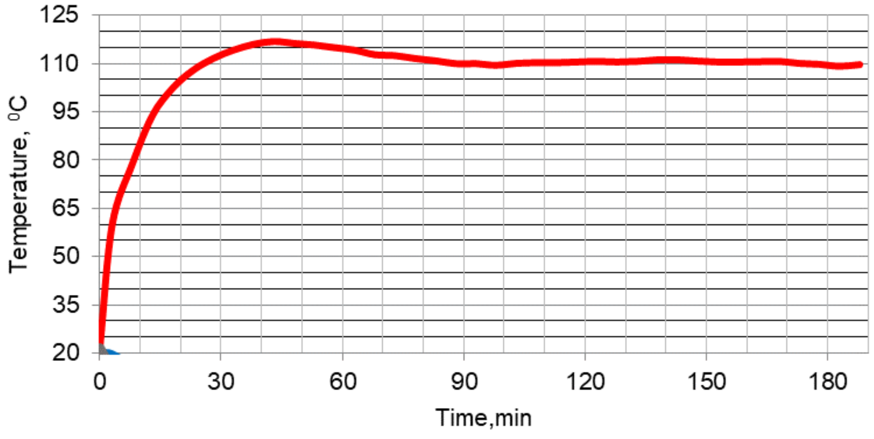

Fig. 5. Compressor outlet temperature

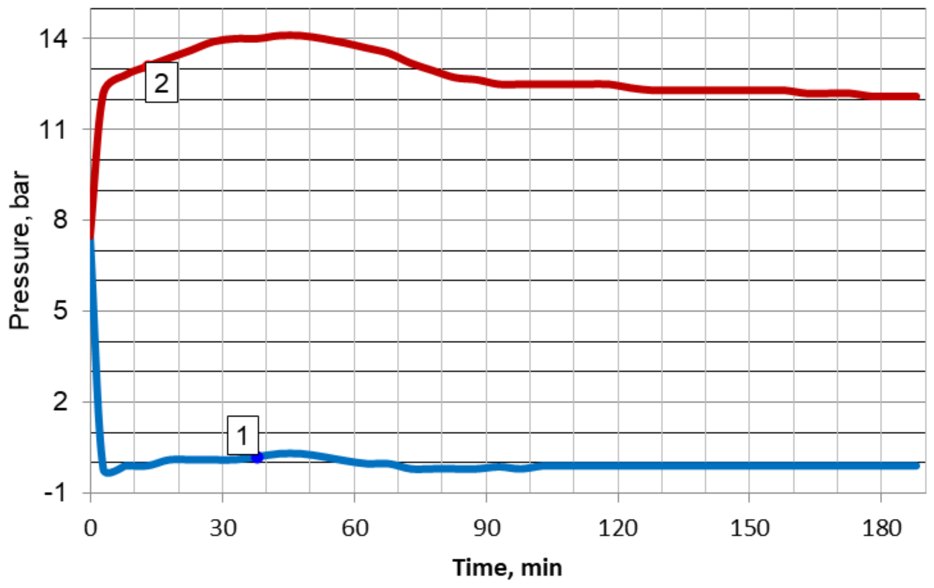

Fig. 6. Refrigerant pressures, in a low-temperature mixed refrigerant system with sequential condensation of components

1–to the compressor; 2–after compressor

5 Conclusions

The experiment yielded a scheme and design of a low-temperature refrigeration system operating on a refrigerant mix of R134a and R23 at a safe and stable operation ratio.

The trial showed thatit took the refrigerator three hours to reach -70°C in the cooling chamber. The discharge temperature during operation was below 120°C while the excess discharge pressure during operation stayed below 15 bar.

Thus, the new scheme can be used for commercial production of low-temperature systems for low-temperature processing and storage of biotechnological materials [8], as well as enzyme and endocrine raw materials in biotechnology, food industry, and pharmacy [9]. Also, the scheme can be applied in climate tests for various purposes [10].

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