PRINCIPAL RESULTS OF SCIENTIFIC RESEARCH AND EXPERIMENTAL DESIGN WORKS ON DEVELOPMENT OF R744 HEAT PUMPS

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Abstract

This article contains the results of works aimed at development of carbon dioxide (R744) heat pumps carried out by experts of a minor scientific organization, SIF "EKIP" and leading Russian technique universities, MSUEE and MEI (TU).

KEYWORDS

Heat pump, Carbon Dioxide, R744, COP, Sources

1. INTRODUCTION

Currently about 40% of the total volume of fuel burnt in Russia is spent for providing heat supply. Besides a devaluation of heat energy takes place during this heat supply process, as the heat generated at the level of 100…140 ºC is sent to consumers at the level of about 80 ºC [1].

One of the ways for qualitative improvement of this situation is introducing heat pumps (HP) which are one of the low potential energy systems [2]. The heat pumps involving reverse thermodynamic cycle derive heat energy from a low potential source (5…40 ºC), increase its temperature level and heat up the source of high potential heat sent to the consumer to the temperature of 60…80 ºC. Thus, the heat pumps consuming mechanical energy for their drives produce heat energy substituting the organic fuel burnt for such purposes.

According to signing of international agreements signed on coolants for refrigerating machines and heat pumps, the most preferable are so-called *natural refrigerants* (ammonia, carbon dioxide, hydrocarbons, water and air) [3].

Carbon dioxide (CO_2, R744) is the most universal for use in heat pumps. R744 is non-toxic, uninflammable and features thermophysical characteristics allowing for construction of carbon dioxide heat pumps (HPCO2) both of smaller, medium and high heating capacity up to 20 MW and more in one unit [3, 4].

Despite the high energy efficiency of HPCO2, its use in various heat pump classes: *smaller* HP (10…100 kW), *medium* HP (100…1000 kW) and *large* HP (up to 20 MW and more in a single unit) is not obvious due to high working pressures [4].

The analysis of available components manufactured for HPCO2 has shown that so far the cost of them is much higher (2…3 times) than the cost of similar components for other working media.

Manufacturing of medium-class HPCO2 is complicated by high volumetric heating efficiency of carbon dioxide which impedes use of centrifugal compressors. Screw compressors are also hardly implementable due to high pivotal forces.

Both machine classes require creation of environment-safe uninflammable mixtures based on carbon dioxide that will allow lowering working pressures and introducing the vapor-liquid

thermodynamic cycle. This will also provide a possibility to use centrifugal compressors in medium-class HPCO2 due to lower volumetric heating efficiency of the working media.

The most perspective area of use of carbon dioxide as HP coolant is large heat pumps with centrifugal compressor. This machine class is aimed at providing heat supply for major industries and residential districts. The metal consumption for manufacture and sizes of such machines are substantially lower than of their analogies with different working media. The cost will also be much lower provided their serial manufacturing.

2. HPCO2 DEVELOPMENT WORKS

In years 2002–2006 in Russia the Scientific & Industrial Firm "EKIP" (SIF "EKIP"), the Moscow State University of Environmental Engineering (MSUEE) and the Moscow Energy Institute (Technical University) (MEI (TU)) in cooperation with other co-executors have completed a number of scientific research, experimental design and projecting works on development of new generation carbon dioxide heat pumps (HPCO2) within the framework of Federal target scientific research program "Research and development in priority branches of science and technology in 2002–2006" (Federal Agency of Science and Innovations of Russia – ROSNAUKA).

The development included two HPCO2 classes: smaller HPCO2 and large HPCO2. The smaller HPCO2 are aimed at use in individual heat and hot water supply of detached houses [5–7]. This type machines have become common in Japan jointly known as ECO-CUTE. They are based on a Norwegian technology and use outside air as the source of low potential heat (SLPH). In Russian conditions this variant is only implementable in southern regions. In central areas the SLPH are soil, underground water, water of rivers and lakes, etc. Besides the design of principal heat exchange units of ECO-CUTE is not optimal for the Russian conditions.

The growing lack of organic fuel and the rise of its price will eventually demand utilizing of all man-caused emissions, primarily from heat and atomic power stations and power-consuming industries. Increased share of atomic power plants in total energy production and development of hydrogen power engineering will only increase this necessity. Presently the use of secondary energy resources in the industry does not exceed 20% [8]. One of the solution for the mentioned problem is the use of high capacity HPCO2.

The following works have been completed within the framework of HPCO2 development project:

- determined the conditions of HPCO2 efficient use;
- carried out theoretical calculation research of HPCO2 thermodynamical cycles, developed simulators and computer programs for calculation, analysis and optimization of schemes, parameters and cycles;
- completed theoretical calculation and experimental research of heat exchange processes in gas coolers (GC), evaporators (E), regenerative heat exchangers (RHE), developed simulators and computer programs for calculation and numerical research of the characteristics of these devices;
- selected design solutions and determined optimal working parameters of the basic equipment of HPCO2: compressors, expanders, GC, E, RHE;
- all principal technical solutions protected by patents [9];
- designed, manufactured and studied the following scientific and technical equipment.

2.1. Thermotechnical test bench for HPCO2 study

A thermotechnical test bench was created at the Department of Refrigeration and Cryogenic Engineering (MSUEE) that allows conducting experimental research of processes in HPCO2 without oil content in the working media flow [10, 11].

Developed a special heat exchange unit of co-axial design allowing consider the substantial non-isothermality of phase conversions in HP elements. This unit was a prototype of an actual machine and allowed developing a reliable method of calculation of this type of machines [12].

The test bench allows study processes in heat pumps with not only carbon dioxide but also with environmentally safe mixtures on its basis in a wide range of working pressures and temperatures.

2.2. A test prototype of small HPCO2

On the basis of the data acquired at the thermotechnical test bench and HPCO2 parameters calculation computer programs developed thereupon a heat pump with the capacity of 20 kW (Fig.1) for two-level heat and hot water supply for a detached house with total area of up to 300 m^3 was developed, built and tested [5]. The designed scheme of regulating and the design of heat exchanger units based on NPO Geliymash technology have demonstrated their high efficiency [12].

Fig. 1. HPCO2-20 within a test bench of NPO «Geliymash»

Fig. 2. HPCO2-15 within the heat and power central of MEI (TU)

***Thermothechnical characteristics of* HPCO2-20:**

Total heating capacity, kW…… 20
Maximum temperature of heat carrier heat-up, ºC…… 85
Temperature of discharge heat source, ºC……. 5–12
COP, at least…….. 3

2.3. Large HPCO2 prototype

To develop large HPCO2 a prototype with heating capacity of up to 15 kW (Fig.2) was developed with the scheme of its incorporation into the MEI heat and power central and working parameters fully identical to actual. The acquired results allowed starting works on the development of a heat pump with heating capacity of 23 MW [4].

***Thermothechnical characteristics of* HPCO2-15**

Total heating capacity, kW…… 15
Maximum temperature of heat carrier heat-up, ºC……. 75
Temperature of discharge heat source, ºC…….. 20–28
COP, at least…… 3.5

3. CONCLUSION

Currently SIF "EKIP", MSUEE and other co-executors within the framework of Federal target program "Research and development in priority branches of science and technology in 2007-2012" are involved in preparation of scientific research and experimental design works aimed at development of an experimental-industrial prototype of a carbon dioxide HP with unit capacity of around 20 MW.

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