Centrum Rzeczoznawstwa Budowlanego

Inżynieria Bezpieczeństwa
Obiektów Antropogenicznych 2 (2023) 7-16
https://inzynieriabezpieczenstwa.com.pl/

Inżynieria Bezpieczeństwa Obiektów Antropogenicznych

Research the stability of refrigerant overhating

Sebastian ŚNIEGOWSKI*[1], Krzysztof GASZEK[1], Zuzanna BURLAGA[1]

[1] Poznań University of Technology, Poznań, Poland

Abstract

The article consists of two parts. The first of them presents an overview drossel elements used in cooling devices. The second part of the article is focuses on the study of the stability of the superheat of the factor. Two expansion valves were compared, the thermostatic one and the electronic one. For this purpose, advanced measuring devices with the possibility of mobile system control were used in the research.

Keywords: refrigeration, expansion valve, refrigerant, overheating the refrigerant

1 Introduction

Refrigeration was initiated by people, who buried food in pits to extend the use-by date of these products. With them, they placed ice and snow in order to receive thermal energy from food. After some time, the underground, darkened cellars were used to store drinks and food. The effectiveness of this solution, however, was not efficient until the first cooling device, called the refrigerator, was invented.

Today, refrigeration is developing very rapidly and is not only limited to cooling food, freezing, storing and transporting food products, but has more extensive applications. In the area of the global economy, refrigeration plays an important role, enabling producers and suppliers to create a supply chain and customers the opportunity to test a wider range of products of higher quality and freshness. Cooling devices are also used in areas such as: materials processing industry, pharmacy, medicine, cryobiology, as well as aviation and cosmonautics. They also play a great role in air conditioning technology, which translates into heating technology for heat pumps.

Almost all cooling devices are equipped with a throttling element present in various solutions. It is the throttling elements that are responsible for the stability and the superheat value of the refrigerant. It is necessary to guarantee the appropriate cooling conditions for a given field and product.

2 Regulation of the operation of refrigeration evaporators

The role of the pressure reducing mechanisms in a refrigeration system is:

- lowering the pressure of the refrigerant from the liquid pressure in the condenser to the pressure in the evaporator,
- control of the flow rate of the refrigerant flowing through the throttle device to the evaporator in relation to the heat load.

* **Corresponding author:** E-mail address: (sebastian.sniegowski@doctorate.put.poznan.pl) Sebastian Śniegowski
https://dx.doi.org/10.37105/iboa.171
Received 14 May 2023
Available online 27 June 2023
ISSN 2450-1859, eISSN 2450-8721
Published by Centrum Rzeczoznawstwa Budowlanego

The function of reducing the pressure of refrigerants in cooling devices is performed by:

- capillaries,
- float valves,
- thermostatic expansion valves,
- electronic expansion valves.

2.1. Regulation of the operation of refrigeration evaporators

The capillary tube creates a resistance to the flow of the refrigerant, which affects the pressure drop from the liquid pressure to the evaporating pressure. It is used in small cooling systems as a choking element, mainly in domestic refrigerators. The inner diameter of the capillaries varies between 0.5 and 2.5 mm and their length ranges from 0.4 to 6.5 m. To obtain subcooling of the refrigerant liquid, the capillary tube is soldered at a certain length to the liquid line of the refrigeration system.

The most important advantages of capillary tubes are: low cost, simple structure, reliable operation. The use of a capillary tube makes it possible to reduce the starting torque of reciprocating compressors, because the compressor starts when the pressure between the discharge and suction side of the compressor is equalized.

The main disadvantages of capillary tubes are: very uneconomical operation of cooling devices during variable thermal loads and sensitivity to fluctuations in the volume of the refrigerant in the system.

2.2. Float expansion valve

Two types of expansion float valves can be distinguished, used only in devices with flooded evaporators, which are distinguished according to the pressure they are subjected to, i.e. low-pressure and high-pressure, as shown in Fig. 1.

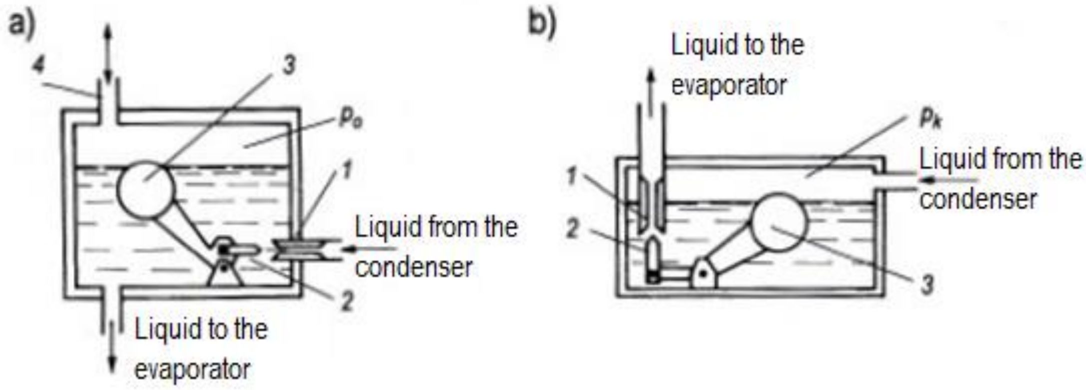

Fig. 1 Float expansion valves: a) low pressure, b) high pressure [2].

where: 1-expansion nozzle, 2-spire, 3-float, 4-steam pipe equalizing pressure with the evaporation pressure: p_o- evaporation pressure, p_k- condensation pressure.

Low-pressure valves are used to regulate a stable level of liquid refrigerant in flooded evaporators or liquid separators, while high-pressure valves are used to throttle the liquid refrigerant coming from the condenser.

As the float descends, the low-pressure valve opens the flow, providing a greater flow rate, but as the float rises to the upper level, the spire closes the nozzle. Low pressure float expansion valves were created in two versions. The first is the one made with the external flow of the throttled liquid by means of a float chamber, and the second with the external flow outside the chamber. Evaporators and liquid separators that require liquid level maintenance can be equipped with this type of valve. These valves have a very big disadvantage, when the float is blocked in the open position, the evaporator will be flooded with liquid. In order to prevent such a failure, a safety float switch is used, whose task is to shut off the liquid line with an electromagnetic shut-off valve.

The high pressure valve opens while the float rises to remove liquid from the condenser. As the float descends to the low level, the nozzle is closed by the spire. These devices are used only in systems with one liquid receiver on the low pressure side. The purpose of this valve is to fill the receiver with a precisely adjusted amount of liquid refrigerant. They are used in aggregates producing water ice and devices equipped with a pumped circulation of the medium.

2.3. Thermostatic expansion valves

Thermostatic expansion valves are elements that function automatically as shown in Fig. 2. The mechanism of their operation is based on the utilization of the pressure difference between the fluid that fills the sensor and the evaporating refrigerant. The pressure in the sensor is analogous to the saturation pressure when the sensor is filled with liquid or the equilibrium adsorption pressure when it is filled with gas. The sensors are filled with the same refrigerant that works in the device, or another factor with a thermodynamic property. The valve sensor is fixed on the outlet pipe from the evaporator, where its temperature can be taken equal to the temperature of the superheated steam behind the evaporator and the pressure assigned to the temperature opens the valve. This process regulates the flow of the refrigerant through a valve which is controlled by the evaporating pressure and the superheat temperature of the refrigerant downstream of the evaporator.

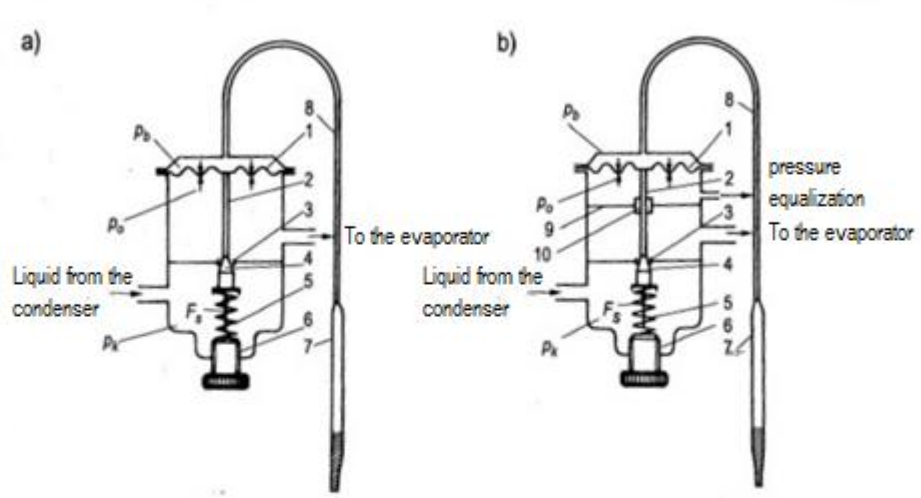

Fig. 2 Thermostatic expansion valve: a) with internal pressure compensation b) with external pressure compensation [2].

where: p_k- condensing pressure, p_0- evaporation pressure, p_b- pressure in the sensor, F_s- spring tension force, 1- membrane, 2- main part, 3- expansion nozzle, 4- spire, 5- regulating spring, 6- adjusting screw, 7-sensor, 8- capillary tube, 9- partition, 10- sealing

While the valve is open, $(p_b-p_0)A_d=F_s$ and when it is closed $(p_b-p_0)A_d<F_s$. Force F_s is caused by the tension of the spring via the adjusting screw. While the force F_s is increased, the pressure p_b needed to open the valve as well, and hence the temperature of the superheated steam downstream of the evaporator as well. Thermostatic expansion valves come in two types with internal and external pressure equalization.

Internal pressure equalization thermostatic expansion valves are used in small single coil evaporators, and external pressure equalization valves are used in multi-section evaporators manufactured from a series of bonded coils. They are fed through a liquid distributor installed between the thermostatic expansion valve and the evaporator.

The pressure of the sensor needed to open the flow of the medium through the valve is each time regulated by the manufacturer and usually has a temperature 5K higher than the standard evaporating temperature contained in the catalog.

The filling of the thermostatic expansion valves can be a liquid-vapor fluid. This filling is called a MOP (Maximum Operating Pressure) type on filling. These valves have a characteristic MOP point marked in fig. No. 3. The filling consists of: helium (hermetic control), inert gas (its purpose is to increase the pressure of the sensor), refrigerant (control). The factor with which the regulation takes place evaporates or condenses in the sensor as a result of changing its temperature, which is analogous to the temperature of the superheated steam behind the evaporator on the suction line.

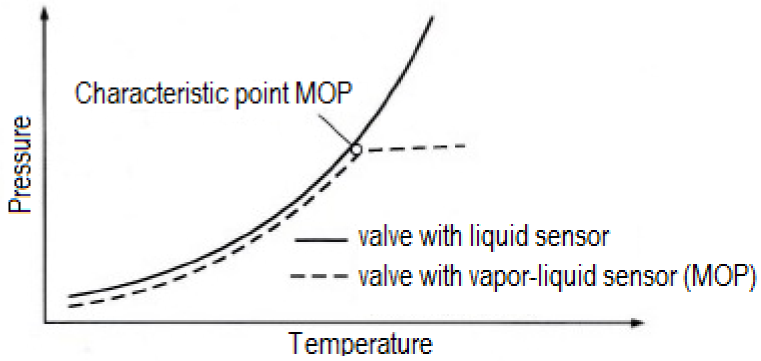

Fig. 3 Comparison of pressure changes in the temperature sensor with liquid filling and liquid-vapor filling [2].

As the temperature decreases, the vapor condenses and the pressure drops. When the set temperature values of the sensor are exceeded, the total amount of the liquid phase will evaporate, which will cause the sensor to be filled only with the volatile phase. As the temperature increases, the pressure will increase imperceptibly.

The unit is exposed to overloads when the compressor motor is started, but the use of a liquid / steam filled thermostatic expansion valve can prevent this problem. While the refrigeration unit is idle, the valve is closed. After the compressor has started, the MOP valve is still closed until the MOP temperature is reached as shown in fig. 4.

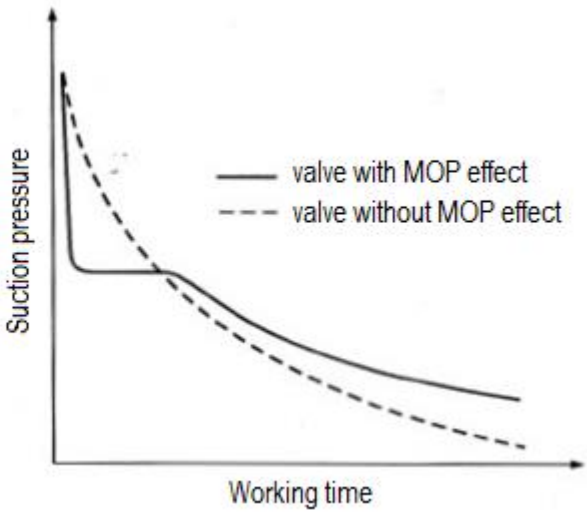

Fig. 4 Summary of the course of changes in suction pressure in a device equipped with a MOP thermostatic valve and without MOP [2].

When the compressor starts, it only sucks the refrigerant vapor from the evaporator, and only after reaching the MOP temperature, the valve will open and it will dispense enough liquid to the evaporator to obtain a constant superheat value. At this stage of operation, the evaporator is not completely filled with refrigerant. When the temperature starts to drop below the MOP, the valve starts to regulate superheat.

2.4. Electronic expansion valves

The role of the electronic expansion valve in a chiller is akin to that of a thermostatic valve. Its purpose is to maintain a stable level of refrigerant superheat at the outlet after the evaporator. Benefits of using electronic control valves:

- constant functionality of the valve at low thermal loads,
- maintaining a stable and low temperature difference of the refrigerant between the inlet and outlet of the evaporator,• electronic testing of pressure and temperature values at the outlet of the evaporator allowing the most advantageous use of the heat exchange surface of the evaporator

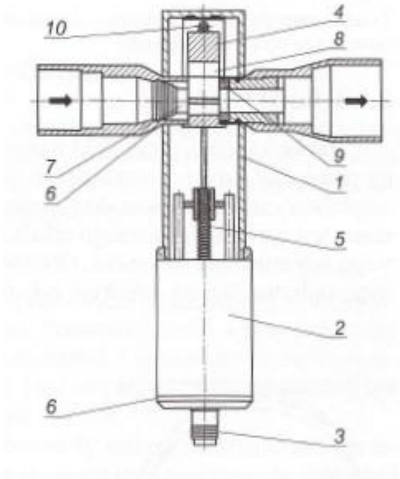

Fig. 5 Construction of the electronic expansion valve [3].

where: 1-stainless steel housing, 2-stepper motor, 3-connection power and control, 4.5-valve stem, 6-connection, 7-inlet ceramic port, 8-ceramic spool, 9-outlet ceramic port, 10-brass ball

The design of the electronic expansion valve is shown in Fig. 5. The driving part of the valve stem 5, which moves the ceramic spool 8, is the stepper motor 2. Using the stepper motor, it is possible to control the valve position in the range from 20% to 100%. This makes it possible to smoothly control the evaporator capacity to a large extent at irregular loads.

The refrigerant superheat control is performed by the controller, the actual pressure and temperature values over a specified time are measured by the pressure and temperature sensors at the outlet of the evaporator. In relation to the read temperature and pressure values, the controller sends a signal to the stepper motor of the electronic expansion valve in order to adapt the valve opening size to the requirements of the evaporator load at the moment.

Stepper motor-controlled valves have found application in other areas than just as expansion valves for filling evaporators with liquid and in various control systems. Examples are: capacity bleed control, superheat control, liquid injection control, crankcase pressure control, condensing pressure control.

3 Research stand

The cooling chamber with the research cooling system have been designed and selected according to the applicable standards. The operating characteristics of the system will be presented in the diagrams. The following parameters will be tested: system operation time, evaporation temperature, pressure on the suction line and superheat.

It was assumed that the chamber should have 0.28 m^3, due to the possibility of placing it in the laboratory and its relocation. Ultimately, the chamber was not insulated in order to obtain the highest possible heat transfer coefficient without additional heat generating sources, such as electric heaters. The refrigerated cabinet is also equipped with a running gear and a base for a condensing unit with fittings and automation.

The condensing unit, which has found a place in the cooling system, works with the R449a refrigerant and is equipped with a reciprocating compressor designed for positive cooling chambers. The selection of an electronic expansion valve was a big challenge, as their capabilities mostly start with higher powers. The second expansion element selected to compare the superheat work was the thermostatic expansion valve without alignment with the 00 nozzle.

Picture 1. Research stand for refrigerant overheating stability

Picture 2. Expansion valves subjected to tests of refrigerant overheating stability

The electronic expansion valve is controlled by a controller that collects signals in the form of temperatures: in the chamber, in front of the cooler, in the radiator and after the cooler, and evaporating pressure using a pressure transducer to dose the exact amount of refrigerant.

The second section, in which the thermostatic expansion valve acts as a choke, is controlled by a classic controller equipped with two sensors: chamber temperature, and the second temperature in the cooler.

The tests were carried out thanks to modern devices, which include: a set of electronic manometers with the possibility of measuring the suction pressure as well as condensation and their temperatures. Manometers based on the selected type of refrigerant from the database have an algorithm that converts pressure to temperature. The next algorithms in this device are superheat and subcooling of the medium. In addition, the manometer is equipped with bluetooth data transmission, which allows you to read data on another device, e.g. a smartphone in an application that allows you to automatically draw graphs and save data at intervals of two seconds.

Research

Medium overheating is the difference between the temperature of the insulated temperature sensor on the suction line and the temperature corresponding to the suction pressure, according to the equation below.

$$\Delta toh = toh - to\ [K]$$

where:

Δtoh - overheating of the refrigerant,

toh - temperature of the temperature sensor on the suction line,

to - temperature corresponding to the suction pressure,

In the first stage of the study, the thermostatic expansion valve was assessed.

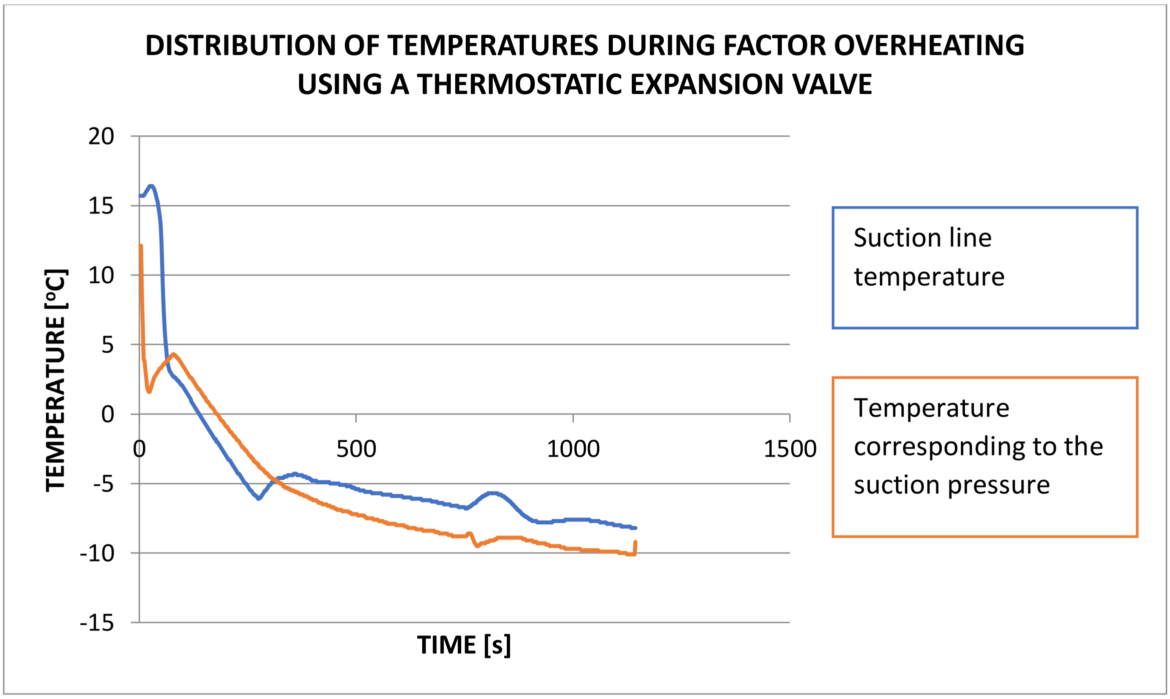

Fig. 6 Temperature distribution during medium overheating Thermostatic expansion valve. Source: own study.

Figure 6 shows the course of the refrigerant temperatures on the suction line of the system. The graph shows large fluctuations and a drop in the temperature of the temperature sensor below the evaporating temperature. This is due to the delayed response of the thermostatic expansion valve to signals from the suction line. The pressure temperature sensor of the thermostatic expansion valve works with a considerable delay. It is influenced by the time of heat conduction between the system suction pipe and the temperature sensor and the gas expansion until the signal is transmitted to the thermostatic expansion valve.

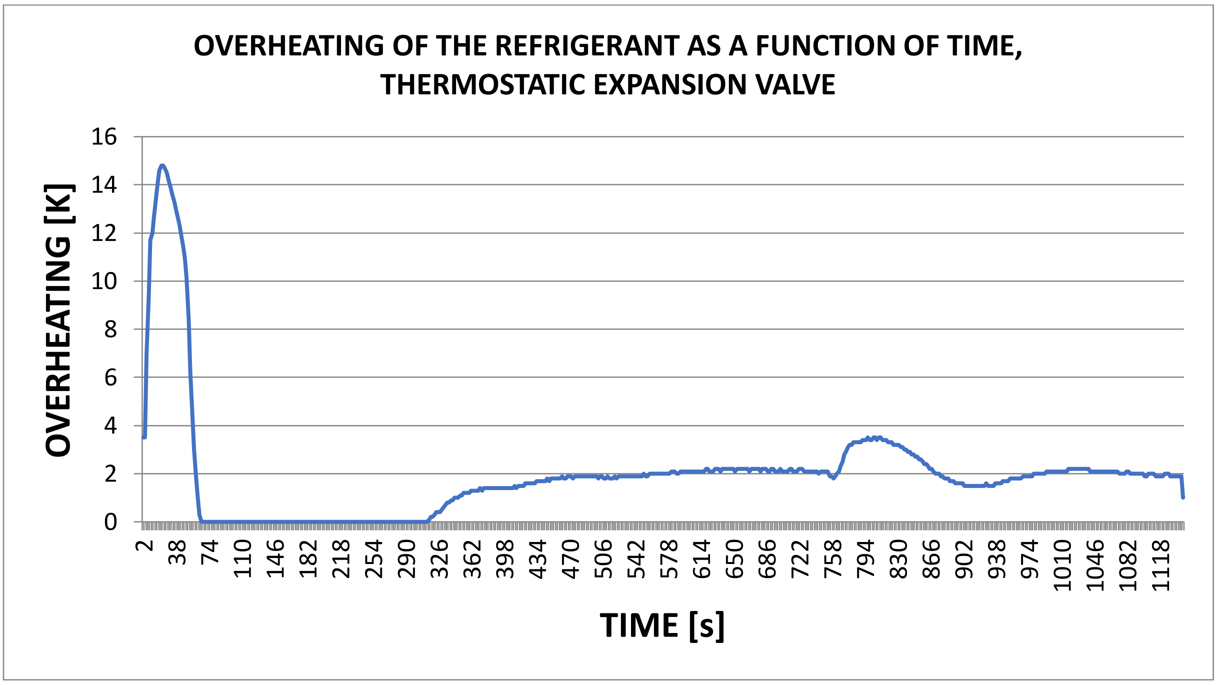

Fig. 7 Overheating of the refrigerant as a function of time, thermostatic expansion valve. Source: own study.

Unstable overheating of the medium in the case of the thermostatic expansion valve was present from the beginning of the system operation. In the initial phase, it grew and decreased very rapidly. Then, the measurement of the medium overheating was impossible due to the disturbance of the measurement of the thermostatic temperature sensor. This detector requires time to stabilize the system temperature.

Similarly, the second stage of the test was carried out with the use of an electronic expansion valve.

The measurements in figures 8 and 9 show the response speed of the electronic expansion valve. The sensor temperature and suction refrigerant pressure signal is quickly sent to the controller and processed in it, which results in accurate and fast refrigerant dosing. This gives the possibility of smooth control of the evaporator capacity in a large range under irregular loads while maintaining stable superheat.

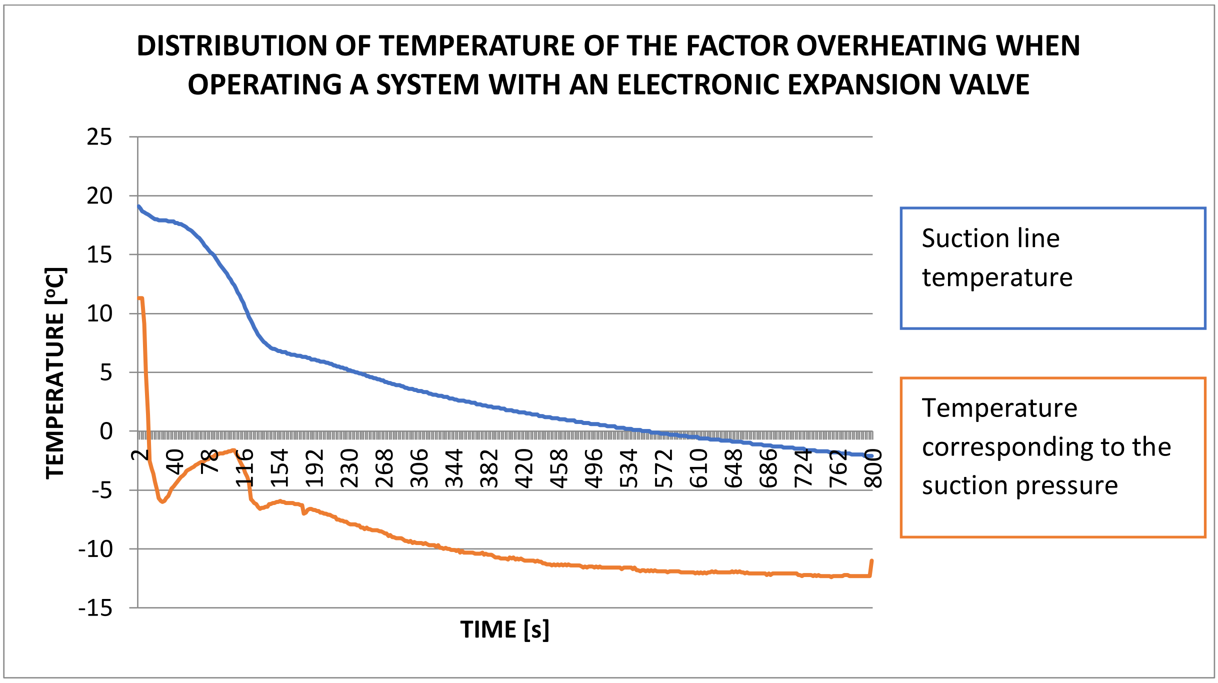

Fig. 8 Distribution of medium superheating temperatures when the system is operated with an electronic expansion valve. Source: own study.

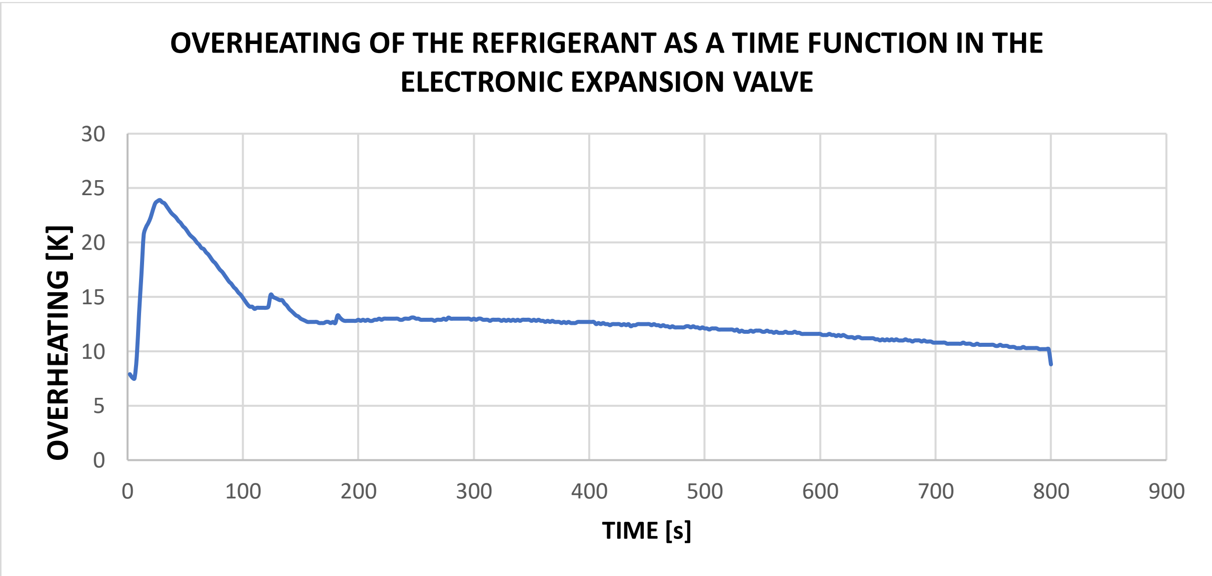

Fig. 9 Overheating of the refrigerant as a function of time in the electronic expansion valve. Source: own study.

4 Conclusions

Refrigeration systems consist of many components, each with a specific task. One of them are throttling elements that can be divided according to their construction and application. They perform the task of reducing the pressure and regulating the dosing of the refrigerant. Depending on the properties, each of them is used to this day, ranging from the simplest capillary, ending with the electronic expansion valve.

In the study of the difference in the stability of the superheat of the refrigerant between the thermostatic expansion valve without external pressure equalization and the electronic expansion valve. Research has highlighted the differences between the two valves. The above charts show the influence of their work on the stability of the refrigerant overheating.

The thermostatic expansion valve is a long-standing throttling element. It fulfilled its function and performs its function in most of the refrigeration systems in the world. Its advantage is simplicity of construction and relatively low price. It is used in a variety of cooling systems, in particular small and medium-sized ones, and in those where the stability of overheating and maintaining the evaporation temperature is not of great importance. Fig. 6 shows that the differences between the temperature of the suction line and the temperature of the suction pressure are disproportionate to each other, and in some moments even the temperature of the suction pressure is higher than the temperature of the suction line. This is due to a very long delay of the mechanism responsible for overheating the refrigerant, and precisely the time when the gas in the temperature sensor of the thermostatic valve of the suction line changes the pressure and this will change the position of the stem responsible for regulating the refrigerant flow.

Electronic expansion valves have been mainly involved in air conditioning, heat pumps and industrial refrigeration equipment for several years. They are doing great. Their advantages include maintaining the temperature of evaporation and overheating despite changing loads, accurate dosing of the medium depending on the heat load. Electronic expansion valves can operate from 20 to 100% of their capacity. This also translates into lower electricity consumption by the cooling system. The only downside of the electronic expansion valve is its price, unacceptable for very small applications and investments. Electronic expansion valves have become established in every field related to refrigeration: vegetable growing, meat processing, air conditioning, heat pumps, chillers and others. On the basis of Fig. 8, the proportional difference and stabilization of temperature corresponding to the evaporating pressure and the temperature of the suction pipe is visible. This is done thanks to the immediate reading of temperature and pressure, which are sent to the controller processing the operation signal for the electronic expansion valve. Data is read, transported and processed immediately without any time delay. This operation allows for precise control, operation of the electronic expansion valve and smooth control of the superheat of the refrigerant.

In summary, there are many differences between valves, ranging from construction, operation, information transport and regulation. The advantage of attributes is on the side of the electronic expansion valve, which was taken into account in the above conclusions. Electronic valves are more and more adopted by companies and installers who want to improve the quality of devices and services sold. The development of electronics has translated into the ability to control each parameter of such a valve, and the ability to accurately test and then calibrate the device. Thermostatic expansion valves, despite the long-stabilized overheating of the refrigerant for the next few years, will be used, heals replaced by electronic ones, in order to improve the quality of refrigeration equipment and energy efficiency.

Bibligraphy

1. Bohdal T., Czarun H., Czap M. „Urządzenia chłodnicze sprężarkowe parowe", Wydawnictwa Naukowo-Techniczne Warszawa 2003, 22-23

2. Gutkowski K. M., Butrymowicz D. J., „Chłodnictwo i klimatyzacja", Wydawnictwa Naukowo-Techniczne Warszawa 2007, 52-60, 228-240

3. Butrymowicz D., Baj P., Śmierciew K., „Technika chłodnicza", Wydawnictwo Naukowe PWN SA Warszawa 2014, 234-241

4. Zalewski W., „Systemy i urządzenia chłodnicze", Politechnika Krakowska, Kraków 2010, 221-226

5. Dyrektywa Parlamentu Europejskiego i Rady 2009/12WE z dnia 21 października,

6. Rozporządzenie Parlamentu Europejskiego i Rady (UE) nr 517/2014 z 16 kwietnia 2014 r. w sprawie fluorowanych gazów cieplarnianych i uchylenia rozporządzenia (WE) nr 842/2006.

7. PN -EN 378: Instalacje ziębnicze i pompy ciepła – Wymagania dotyczące bezpieczeństwa i ochrony środowiska.