

## ENCIT-2018-0109 EXPERIMENTAL ANALYSIS OF THE OPERATION CONTROL OF A REFRIGERATING MACHINE

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**Abstract.** *In a vapor compression refrigeration cycle, the superheating degree is of vital importance for the proper operation of the compressor and maintenance of the system good performance. The purpose of this work was to analyze the superheating degree control in an evaporator of an air-to-air refrigerating machine by means of a thermostatic expansion valve. A temperature step was applied to the secondary fluid surrounding the evaporator by the activation of an electric resistor. A study of the behavior of the main operating parameters of the system was carried out. With the sudden increase in the temperature of the secondary fluid, the refrigerant flow at the evaporator inlet initially decreases. The thermostatic valve responds by increasing the flow imposed by the compressor, thus reducing the machine overheating. With this work, it was possible to analyze the thermostatic valve performance to find a new equilibrium point for the machine, stabilizing the refrigerant flow in the evaporator.*

**Keywords:** *Refrigerating machine, expansion thermostatic valve, superheating degree.*

## 1. INTRODUCTION

Technology has played an important role in the life of society. It is the mechanism that governs human activity. However, before it became accessible for the people, the humanity had to find other means to meet its needs. The refrigeration system is a classic example of the progress of technology. In the past there was no electricity, so the cooling was done naturally, through the ice itself. Subsequently, the man discovered the cryogenic property of gases, which, according to Costa et al. (2013), is a set of techniques for the production and use of very low temperatures.

The first patent for mechanical refrigeration dates back to 1834 in Great Britain and is due to the American inventor Jacob Perkins. The basic principle of operation of modern systems remains the same presented by Perkins, a fluid that changes from the liquid to the gaseous state, lowering the temperature of the objects around it by the withdrawal of energy in the form of heat from the ambient (Welter, 2001). Then, with the advent of electric energy, the improvement of the refrigeration processes began.

Today, the main factor that has led to research in the field of refrigeration is the improvement of this process, since the energy economy is directly linked to the effective operation of its components (Costa et al., 2013).

There is a continuous need to obtain energy efficiently and that does not harm the environment drastically. Energy sustainability presents itself as one of the great challenges of humanity for this century. According to the Inter Academy Council report (2007), the concept of energy sustainability is defined as the imperative to ensure sufficient energy to meet the future energy needs of the entire world population.

For Nunes (2015), the great challenge for the refrigeration industry is to reduce the energy consumption of the systems without compromising the advantages brought about by their use, their productivity and the quality of the installations. This is because, in homes, commercial and industrial facilities, refrigeration systems are widely used in temperature control environments for human comfort, food storage conditions, industrial processes and other utilities.

Through these aspects, the analysis of the components of a refrigerating machine, which obeys the vapor compression cycle, aims to understand the operation of each circuit element and minimize its losses.

Cavalcanti and Filho (2005) analyzed, experimentally, how the performance of a refrigeration unit by vapor compression is affected during its operation in different working regimes. They used a Cooling Unit, which works under the vapor compression refrigeration cycle, and uses the R-12 as the working fluid. The purpose of the study was to analyze experimentally how the performance of this unit is affected under various operation conditions, as well as to evaluate how its efficiency is achieved by the introduction of a heat exchanger between the evaporator and the compressor. They concluded that using a heat exchanger increases the cycle efficiency when the pressure in the condenser is fixed.

Koury et al. (2001) developed two numerical models to simulate the transient and equilibrium behavior of vapor compression refrigeration systems. In such models, the condenser and evaporator were divided into a number of control volumes and the equations used were derived from energy, mass and momentum balances. The expansion valve and the compressor were modeled according to equilibrium state models, since such components have very little thermal inertia. The simulations were carried out with the objective of verifying the possibility of controlling the refrigeration system, as well as the superheating control of the refrigerant gas at the outlet of the evaporator by the compressor speed variation and the thermostatic valve section area reduction. The refrigerant gases applied in such simulations were R-12 and R-134a. The results of the simulation, when compared to the experimental ones, presented a good fidelity, validating the models.

In this study, it is investigated the superheating degree in the evaporator of a refrigerating machine, equipped with a thermostatic expansion valve, addressing different aspects. A sudden increase in the temperature of the air at the evaporator inlet is applied to induce an increase in the evaporation temperature. Therefore, the refrigerant flow at the expansion valve inlet tends to increase. Then, after the system changes have ceased, a certain system temperature will return to the original operation point. Along with the experiment, a search is made to quantify theoretically the mass flow inside the expansion valve.

## 2. VAPOR COMPRESSION CYCLE

A refrigeration system, which operates according to the vapor compression cycle, as shown in Fig. 1, is composed of the following parts: compressor, condenser, expansion valve and evaporator. Before characterizing each stage of the cycle, a small approach to the refrigerant is required, because it is the one that absorbs heat from a substance in the environment to be cooled. It must have specific characteristics to fulfill its function, as condensing at moderate pressures, evaporating above atmospheric, having a small specific volume (less work for the compressor), not being corrosive and, finally, having a reasonable cost (Ferraz, 2008).

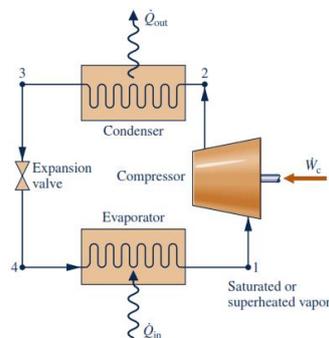


Figure 1. Refrigeration cycle. Adapted from Duarte (2013)

In order to understand the fluid behaviour in the vapor compression cycle, it is necessary to analyze a Pressure-Enthalpy diagram, as exemplified in Fig. 2, which outlines an ideal vapor compression cycle. The cycle begins at the compressor (point 1), whose purpose is to increase the pressure of the intake fluid, absorbing it at low pressure and compressing it towards the condenser at high pressure and consequently high temperature. The compression (line 1-2) is

isentropic (thermodynamic transformation carried out with constant entropy) in which the saturated vapor passes from  $P_{\text{evap}}$  pressure to  $P_{\text{cond}}$  pressure and from enthalpy  $h_1$  to  $h_2$ , consuming mechanical work (Vargas, 2010).

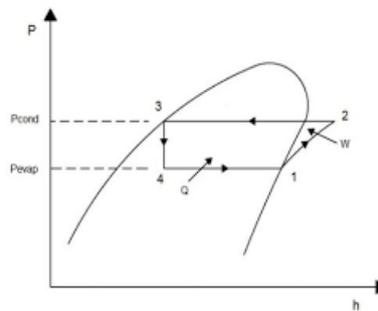


Figure 2. Diagram P-h of an ideal refrigeration cycle (Mandal and Roy, 2014)

The fluid then reaches the condenser (point 2) and undergoes the condensation process (line 2-3), losing heat, from the refrigerant to the cooling medium, at constant pressure, from superheated steam to saturated liquid (Stoecker and Jabardo, 2002).

The expansion valve (point 3) performs an important function, which is to reduce the fluid pressure (line 3-4). It receives high pressure compressed liquid from the condenser and converts it into a mixture of liquid plus low pressure vapor that is directed to the evaporator. It is an isenthalpic process (irreversible expansion at constant enthalpy), from  $P_{\text{cond}}$  condensation pressure to  $P_{\text{evap}}$  evaporation pressure (Venturini and Pirani, 2005).

At the end of the cycle, the evaporation of the fluid in the evaporator occurs (line 4-1), as it receives heat from the environment as the refrigerant flows through it, process that occurs under constant pressure, from humid steam to the saturated vapor state. Thus, the fluid is sent to the compressor, initiating the cycle again (Lima, 2015). Then, a refrigeration cycle absorbs heat through the evaporator, and supplies heat to a medium through the condenser. It is necessary to reinforce that the cycle described, referring to Fig. 2 is an ideal cycle, that is, were not considered the superheating degree at the evaporator outlet, the subcooling at the condenser outlet, the load losses in the heat exchangers, the heat losses in the compressor, among others.

In practice, the compressor inlet is represented in the superheating region (points 1-1'), according to Fig. 3, which depicts the main differences between the actual and theoretical cycle of refrigeration by vapor compression. A certain temperature increase is intended to ensure that the fluid enters fully into the vapor state, ensuring the safety and operation of the compressor (Stoecker and Jones, 1985).

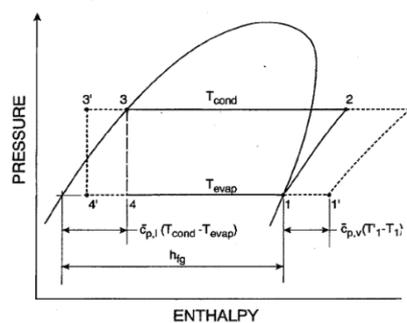


Figure 3. Differences between the ideal and the real cycles. Adapted from Barbosa and Medeiros (2009)

Another difference is the subcooling (points 3-3') of the refrigerant at the condenser outlet, which is a very important process, since it has the purpose of avoiding steam in the condenser outlet. Two common sources of irreversibility are the friction between the flowing fluid and the walls of the system components (causing small pressure drops in the system) and heat transfer with the surrounding environment (Alves, 2016).

### 3. THERMOSTATIC EXPANSION VALVE (TXV)

According to Lima (2015), changes in the nature of the refrigerant can modify the condensation and evaporation pressures. The volumetric capacity of the compressor, the mass flow of refrigerant and the power of compression are

parameters dependent on the evaporation and condensation pressures. Thus, the expansion devices play an important role in the balance of these pressures, being essential for the best cycle performance.

Therefore, a component of this cycle denoting certain peculiarities is the thermostatic expansion valve (TXV), symbolized by Fig. 4.

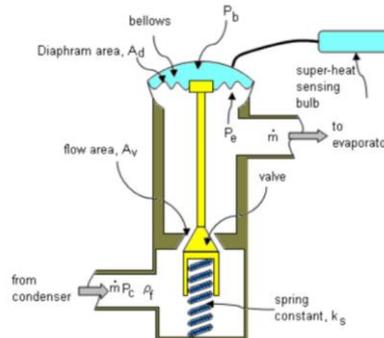


Figure 4. Operation of a thermostatic expansion valve (TXV) (Eames et al., 2014)

It performs the essential function of regulating the refrigerant flow to the evaporator. It controls the flow so as to maintain, at the evaporator outlet, an approximately constant superheating. When the superheating at the end of the evaporator increases, due to a thermal load increase, the TXV intensifies the refrigerant flow until there is a normalization in the superheating level. The inverse also happens. With that, the evaporator remains almost completely active in almost all operation conditions. Therefore, such feature helps to avoid the compressor be compromised and prevents a decrease in system performance.

According to Mesquita (2009), the fluid used in the reservoir is called power fluid. The feeler bulb is partially filled with liquid from the same refrigerant that is used in the system and is attached to the evaporator outlet so that the power fluid reservoir assumes the same temperature of the compressor suction gas. The pressure of the power fluid presses the top of the diaphragm, and the pressure of the evaporator pushes the bottom of the diaphragm. A spring exerts a slight force on the valve, which keeps it closed until the low pressure of the diaphragm exceeds the force of the spring. For the pressure above the diaphragm to become larger than the lower pressure, the power fluid needs to have a temperature above the saturation temperature in the evaporator. The suction gas must be overheated so as to be able to take the power fluid to the pressure switch, which opens the valve. To overcome the spring force, a larger force, which is developed by increasing the overheating, must be progressively applied by the power fluid to further open the valve.

#### 4. METHODOLOGY

For the experiment, the behavior of a thermostatic expansion valve, which belongs to a refrigeration cooling system, is examined and supplied by R-12 refrigerant. It consists of a diaphragm, a spring, a stem and a bulb, and there is a capillary tube that connects the bulb to the diaphragm.

When superheating is above the set temperature, the bulb tends to warm up, and the gas present in this compartment is restricted to the capillary tube and the diaphragm. As a result of the high temperature, the fluid is prone to expand, pushing the diaphragm down, then the rod is also pushed, so the passage to the fluid becomes a little more open, relieving the restriction (by passing a higher mass flow). Figure 4 illustrates this description.

When the superheating is below the set temperature the inverse process occurs, the bulb tends to cool, consequently there is a contraction of the fluid, pulling the diaphragm upwards, so the stem is also drawn, then the passage to the fluid becomes narrower, and there is a restriction (by passing a lower mass flow). It is worth mentioning that, for the bulb to capture temperature variations, it must be covered with a thermal insulation and must be in direct contact with the evaporator discharge.

The aim of this work is to observe the performance of a thermostatic expansion valve, acting in a refrigeration cycle. An investigation of the superheating degree in the evaporation of the refrigerating machine is carried out, when a temperature step is applied to the evaporator with an electric resistor.

##### 4.1 Determination of parameters inside the compressor and the thermostatic valve

In the analysis of a refrigeration cycle, it is extremely relevant to know the properties of the compressor in question, since this is the element that dictates the mass flow of refrigerant fluid. A certain subject has been addressed in several studies.

Currently, several papers use the equations described in Koury et al. (2001) that determine the mass flow rate at the expansion valve outlet (evaporator inlet) and at the compressor suction side (evaporator outlet). Eq. (1) relates the flow

at the compressor inlet, Eq. (2) deals with the volumetric efficiency of the compressor and Eq. (3) shows the flow imposed by the thermostatic valve.

$$\dot{m}_{comp} = NV\rho_{asp}\eta_v \quad (1)$$

$$\eta_v = 1 + c - c \left( \frac{P_{cond}}{P_{ebul}} \right)^{\frac{c_v}{c_p}} \quad (2)$$

$$\dot{m}_{exp} = C_d \sqrt{(P_{cond} - P_{ebul})\rho_{ent}} \quad (3)$$

Where, in Eq. (1),  $\dot{m}_{comp}$ ,  $N$ ,  $V$ ,  $\rho_{asp}$  and  $\eta_v$  are, respectively, the compressor mass flow, rotational speed, displaced volume, specific mass at compressor suction side and volumetric efficiency. From Eq. (2),  $c$ ,  $P_{cond}$ ,  $P_{ebul}$ ,  $c_v$  and  $c_p$  are, respectively, the dead space coefficient, the condensation pressure, the boiling pressure, the specific heat at constant volume and the specific heat at constant pressure. From Eq. (3),  $\dot{m}_{exp}$  is the mass flow imposed by the TXV,  $C_d$  is the characteristic constant of the TXV (cross section area times an adimensional friction coefficient) and  $\rho_{ent}$  is the specific mass at the TXV inlet.

## 4.2 Experimental procedure

In order to analyze the behavior of the variables influenced by the operation of the TXV, the following variables were measured: evaporator inlet and outlet temperatures and refrigerant flow rate. All data were recorded at controlled time intervals.

An electric resistor was placed at the evaporator air intake (a finned tubes type with crossed air flow forced by a fan), what allowed the execution of a temperature step signal in the evaporator, that changed the fluid temperature. The temperature variations at the evaporator inlet T1 and outlet T2 over time were recorded in Tab. 1 and Tab. 2, which reproduce, respectively, the values measured with the electric resistor on and off.

Table 1. Data measured with the electric resistor on

Tempo (s)	T <sub>1</sub> (° C)	T <sub>2</sub> (° C)	ΔT <sub>sa</sub> (° C)	Vazão (Kg/h)
0	4.7	8.4	3.7	38.1
10	5.3	9.9	4.6	35.4
20	5.1	12	6.9	35.4
30	5	13.7	8.7	36.7
60	5.4	15.5	10.2	38.1
90	6.2	15	8.8	39.5
120	6.9	14.7	7.8	40.8
150	7.5	14.7	7.1	40.8
180	8	14.7	6.6	40.8
210	8.4	14.8	6.4	42.2
240	8.6	14.8	6.3	42.2
270	8.8	15	6.2	42.2
300	9	15	6	42.2
330	9	15	6	42.2
360	9.2	15	5.8	42.2
390	9.2	15	5.8	42.2
420	9.3	15.1	5.8	42.2
450	9.3	15	5.7	40.8
480	9.4	15.1	5.7	43.5
510	9.5	15.2	5.8	43.5

Table 2. Data measured with the electric resistor off

Tempo (s)	T <sub>1</sub> (° C)	T <sub>2</sub> (° C)	ΔT <sub>sa</sub> (° C)	Vazão (Kg/h)
540	9.5	15.2	5.7	43.5
550	9.2	14.9	5.7	46.3
560	8.9	12.3	3.4	47.6
570	9.1	7.5	-1.6	43.5
600	7.3	7.1	-0.2	38.1
630	5.8	9.9	4.1	38.1
660	5.6	9.7	4.1	38.1
690	5.5	9.3	3.8	38.1
720	5.4	9.4	4	38.1
750	5.3	9.4	4.1	38.1
780	5.3	9.1	3.8	38.1
810	5.2	9	3.8	38.1
840	5.1	9.4	4.3	38.1
870	5.1	9.4	4.3	38.1
900	5.1	9.3	4.2	38.1
930	5.1	9.2	4.1	38.1
960	5.1	9.4	4.2	38.1
990	5.1	9.5	4.4	38.1
1020	5.1	9.4	4.3	38.1
1050	5	9.1	4.1	38.1

## 5. RESULTS

In the possession of all measured data, graphs were obtained referring to the behavior of the variables affected by the control device (TXV). A graph of the compressor flow rate is shown in Fig. 5 and another one related to the evaporator temperatures is shown in Fig. 6, where ΔT<sub>sa</sub> is the difference between the two temperatures obtained in the evaporator.

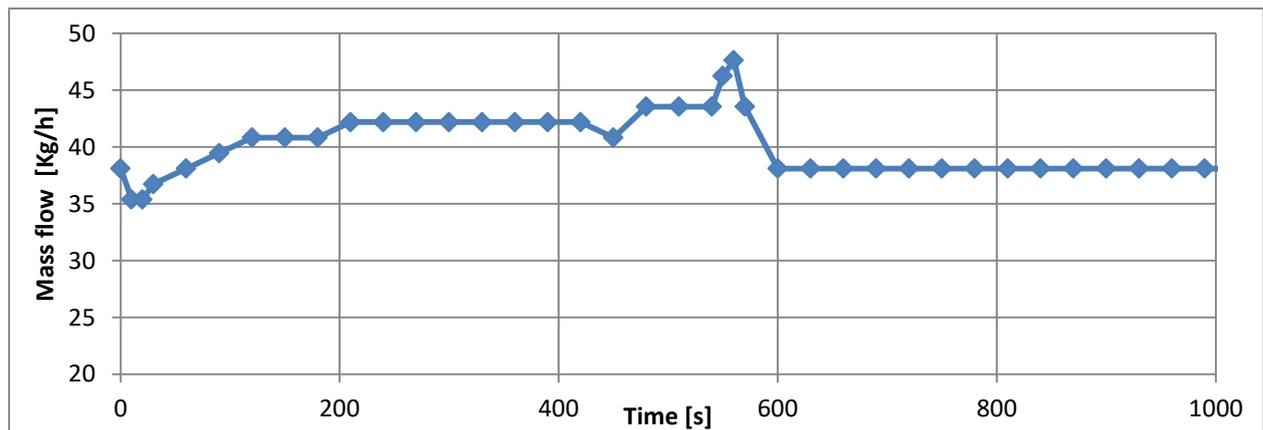


Figure 5. Compressor mass flow versus time

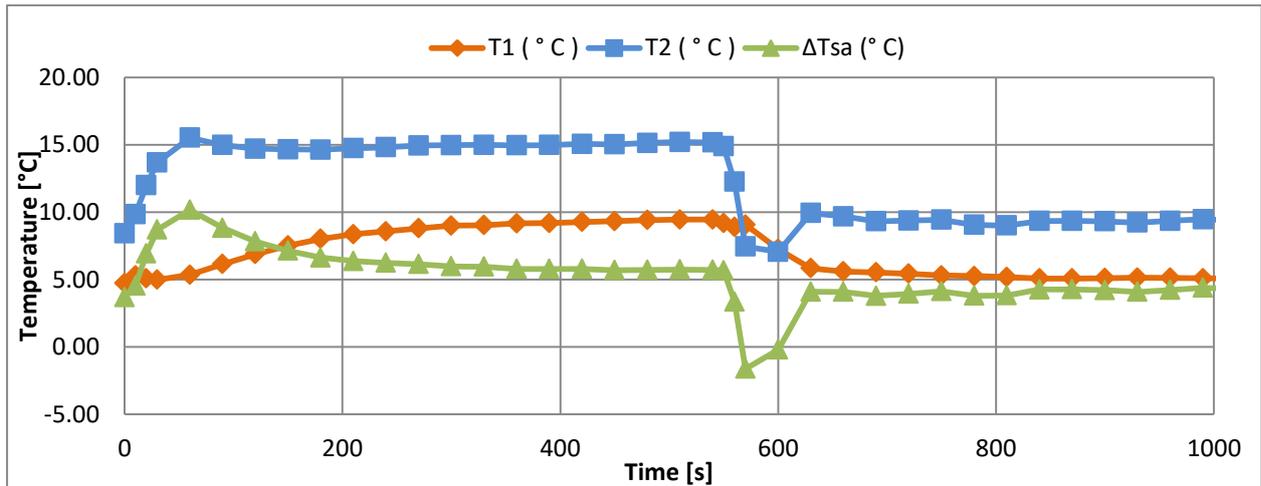


Figure 6. Evaporator temperatures versus time

By increasing the temperature of the secondary fluid surrounding the evaporator with the electric resistor, the superheating degree is changed, thereby increasing the boiling temperature according to Fig. 6. With this increase in the temperature of the secondary fluid, a rise in temperature and evaporation pressure was achieved. As a consequence, the evaporator inlet flow decreased, as analyzed by Eq. (3). Then, with the expansion of the evaporation pressure, the volumetric efficiency increases, according to Eq. (2) and the flow imposed by the compressor also increased, according to Eq. (1), and is depicted in Fig. 5. As the system is very sensitive to any kind of variation, the growth of the evaporation pressure implies a progress of the specific mass of the fluid at the compressor inlet, collaborating in this way to increase the flow imposed by the compressor. Soon, the evaporator begins to be emptied, which causes a growth in the superheating degree. Then, the fluid inside the bulb acts on the diaphragm, widening the thermostatic valve passage section, allowing a flow supply at the valve inlet, as described in Eq. (3). The evaporator is then filled with refrigerant fluid, which causes the superheating to decrease to the setting value. At the end, the system stabilizes at a new operation point.

However, the superheating degree at this new operation point is the same before the change in the system. If the secondary fluid temperature decreases, the system will respond inversely. Fabris (2006) developed similar work and came to conclusions as characterized above. Similar results were drawn by Brandão (2008), who established a numerical model for the purpose of the simulation of refrigeration systems by vapor compression.

## 6. CONCLUSION

The vapor compression cycle is very common in many equipments, and its knowledge adds to the user better ways to take advantage of the full potential of this cycle. Refrigerating machines are of extreme importance for the industrial and residential environment today, and every day new mechanisms that can improve them have been researched.

The study was based on the principle of understanding the superheating degree of a refrigerating machine by analyzing a thermostatic expansion valve. The experiment used an electric resistor, increasing the air temperature in the entrance of the evaporator, and consequently increasing the evaporation temperature. It can be seen that, with the change in operation regime of a cooling system, exciting it with a temperature step, the air temperature tends to follow the excitation behavior, however, with a gradual and non-instantaneous mode variation. On the other hand, it can be seen that the response of the thermostatic expansion valve, when it comes to a permanent regime is, in some way, equivalent to the compressor mass flow, demonstrating its importance in the process which, according to the evaporator outlet temperature, acts on the refrigerant flow rate, stabilizing the cycle.

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