

CONSTRUCTION OF A SIMULATOR OF BASIC REFRIGERATION SYSTEM

Carlisson Arnaud de Azevedo

Caio Luiz de Carvalho Macedo

Yves Alexandrino Bandeira

Leandro Rafael de Moraes Figueiredo

Eraldo Cruz dos Santos

Air Conditioning and Thermal Comfort Laboratory, Institute of Technology, UFPA, Augusto Corrêa Street, N° 1, Guamá, Belém.

carlisson.azevedo@gmail.com

caio.macedo07@hotmail.com

yvesalexandrino.b@hotmail.com

rafaelmoraes00@gmail.com

eraldocs@ufpa.br

Carla Arnaud de Azevedo

Raíssa Cristine Santos de Araújo

carla_arnaud@outlook.com

raissa_tyne@hotmail.com

Laboratory of Chemical Engineering, Institute of Technology, UFPA, Augusto Corrêa Street, N° 1, Guamá, Belém.

Abstract. *The present work is about a development of a simulator of a basic refrigeration system, which works with high evaporation temperature, using R-22 like fluid of the system and a capacity of 18,000 BTU/h. In order to help students to understand better how it works, the circuit is simplified and has some connections that allows measure the pressure and temperature in determined points, where the refrigerant fluid is found in different thermodynamic states, according to the behavior of the system. The collect data shows that the system works, reducing the outlet temperature of the evaporator. The simulator was also used to compare the synthetic fluid R-22 and a natural one, like R-600a. After all the tests made, it can be verified that the R-600a presented itself as a better option to R-22, showing all the parameters and conditions of work, mainly in the aspect of quantity used in the system and energy consumption. Besides that, the recycle of components that once were destined to garbage, make this experimental apparatus a sustainable one.*

Keywords: *Simulator, Refrigerant Fluid, Recycle.*

1. INTRODUCTION

The definitions of compression refrigeration cycles (ASHRAE'S HANDBOOK, 2017) includes the Carnot Cycle, which is the perfect model, with two fixed temperatures and two refrigeration fluids, the theoretical single-stage cycle using a pure refrigerant, this model is more similar to a real system, but uses two compressors, one is a isothermal and another isentropic to keep the characteristics. A negative point in this model is that the use of two compressors is unreliable, because of the cost and, energy consumption, among the two compressors setup, the expander has to be a turbine, increasing even more the cost of the construction and maintenance. To make more practical, the system is considering one simple compressor and a common expansion valve. Still according to this handbook, the actual refrigeration system is different of the ideal cycle for many reasons, for example:

- a) The refrigeration fluid is not only a pure fluid, it is a mixture of the fluid and oil lubricant from the compressor;
- b) Pressure drops caused by long lines of refrigerants;
- c) Condensers or evaporators with bad distribution;
- d) Leakings;
- e) Problems with components as expansion devices, which can cause variations in the evaporation pressure; and
- f) Low capacity or oversized condenser may cause variations on condenser pressure.

Any of this causes mentioned above are irreversibilities, and irreversibilities increase the power consumption of the system, reducing the performance.

Stoecker and Jones (1985) says that the most used cycle in the refrigeration systems is vapour-compression. In this cycle, the vapour receives energy from a compressor, which increases the pressure and temperature above the ambient conditions, this allow the superheated fluid lost energy to external environment. After pass by the condenser, the pressure stay high, but the temperature is low and the fluid is now found at liquid state, at this point the fluid will pass through the expansion device, where the pressure reduce drastically and allows the saturated fluid, with low quality, run by the evaporator, where the saturated liquid will receive the energy from the internal room and will vaporize. Posteriorly, the cycle will start again.

The refrigerants used for the simulator tests were R-22 (synthetic) and R-600a (natural). The R-22 (Dichlorofluoromethane) is one of the most widely used synthetic fluids in refrigeration and air conditioning systems because its working at pressure ranges from negative evaporative temperatures, use in refrigeration systems aimed at product freezing, to higher evaporation temperatures than 0 °C, which are used in ambient air conditioning systems, but because it has chlorine in its composition, the same when coming into contact with the Earth's atmosphere reacts with the ozone molecules and causes the destruction of the Ozone Layer. For this reason, the fluid is in disuse and with the contact days for the end of its commercialization, according to the Protocol of Montreal. It is a fluid compatible with mineral oil, non-flammable and non-toxic (DANFOSS; THE LINDE GROUP).

The R600a (Isobutane) is a substance that presents excellent thermodynamic characteristics together with a minimum environmental impact because it is a natural, being totally non-toxic, however, because it has a high degree flammability, its use requires specific procedures in the handling and safety of the application. This fluid is widely used in medium and high temperature evaporation systems because its working pressure range is low caused by its high critical temperature again when compared to synthetic fluids. One of the downsides to the R600a is its volumetric capacity being at least 50% of the capacity of the synthetic fluids, which indicates that the compressors must be specific for application only with the R600a. In contrast, this fluid is compatible with mineral oil, which facilitates the safe evacuation procedure of not being able to remove the moisture that has adhered to the lubricant in the case of highly hygroscopic synthetic lubricating fluids used in conjunction with some synthetic compatible with mineral oil (TECUMSEH, 2017).

The simulator was built in the Air Conditioning and Thermal Comfort Laboratory at the UFPA, and has as main objective demonstrate how the systems works, showing the components and helping to explain about some aspects of thermodynamics as how the fluid changes his states and how parameters like pressure and temperature affects the performance.

2. METHODOLOGY

In the first part of this paper, it was used a capillary tube like expansion device and R-22 as refrigerant fluid. For the construction of the simulator, the compressor and the evaporator used came from an old 18,000 BTU/h window type air-conditioning, the parts were in a good condition. The expansion device, a capillary tube, and condenser came from an used split type air-conditioning, as shown in the Figure 1. A schematic of the experimental apparatus is shown in Figure 2.



Figure 1. Components used in the simulator.

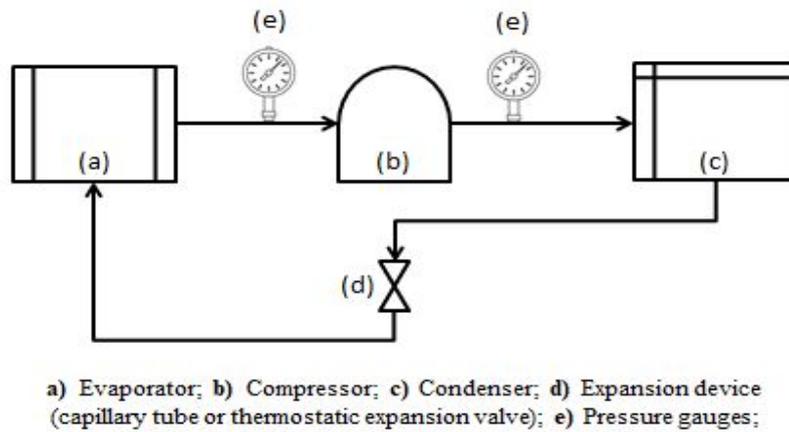


Figure 2. Schematic of the experimental apparatus.

To be possible collect some data of the system and to read the pressure, some pressure gauges were installed in the entrance of compressor, condenser, expansion device and evaporator. In fact, the temperatures in these points are a lot easier to read even using a simple thermometer.

The connections between the condenser unit and evaporator unit was made with copper tube with 1/32" of thickness and 3/16" of diameter in the high pressure side and 5/16" of diameter and 1/16" of thickness in the low pressure side, as exposed in Figure 3.



Figure 3. Pipes and connections.

After all the weldings have be finished, the system was pressurized with nitrogen 99% pure for 12 hours for the purpose to guarantee that the system has not any leaking before the vacuum procedure. The initial pressure was 80 psig, as shown in Figure 4. When the system has the capillary tube expansion device, the low and high side pressure can reach the equilibrium, then, there is no problem in pressurize the system for the low side pressure because, in the beginning, the compressor and evaporator will be pressurized, and slowly, the fluid will flow through the capillary tube until it reaches the condenser.



Figure 4. System pressure after 12 hours.

Before the vacuum procedure, the system reached the equilibrium with about 60 psig, this meant that the system did not have any leaking or bad weld. To the vacuum, the nitrogen was removed until the pressure system reach 15 a 20 psig, then, the nitrogen left was removed with the vacuum pump (Figure 5). The procedure consists in three sets of vacuum, during 20 minutes each, and charge the system with nitrogen between each vacuum.



Figure 5. Vacuum procedure.

The last vacuum reached about 30 inHg (Figure 6) in about 5 minutes after start, reinforcing the idea that the system was perfectly sealed. Then, the system was charged with R-22.



Figure 6. System with almost 30 inHg of vacuum.

After testing the system with the capillary tube as an expansion device, this was replaced by the thermostatic expansion valve type TEX2 externally equalized with orifice 04, with a capacity of 5 kW. In this step, the R-22 and R-600a refrigerants were used, as shown in Figure 7.



Figure 7. Expansion valve installed.

For the replacement of the expansion device, the system fluid was first collected, starting from the high pressure side and then from the low pressure side. When the recovery step was completed, the entire system was pressurized for 24 hours with nitrogen at an approximate pressure of 75 psig. During this period, no pressure drop indicating leaks in the system was noted.

After make sure that there were no leaks in the system, it was possible to install the thermostatic expansion valve. As the valve is externally equalized, it was necessary to install a pressure outlet at the evaporator outlet to supply the valve signal. A flange-type connection was also installed at the condenser outlet and at the evaporator inlet, where previously a filter and a capillary tube were, respectively.

All valve connections were threaded and torque tightened, and again the system was charged with nitrogen to check for leaks. During the time the system was under observation, thermal insulation (Figure 8) was applied to the pipes corresponding to the outlet of the expansion valve to the evaporator, and at the suction line at the perimeter from the outlet of the evaporator to the inlet of the compressor.



Figure 8. Thermal insulation.

Again, it was confirmed that there were no leaks and the first evacuation process was started. After 5 minutes, the vacuum gauge indicated approximately 30 inHg, indicating that a high degree of vacuum had been achieved. The procedure lasted for 20 minutes and then nitrogen was injected to break the vacuum.

3. RESULTS AND CONCLUSION

In the first attempt, the system was charged with about 1.5 kg of the R-22, the original quantity of the window type system was 1.3 kg, but the new condenser is larger than the old one, then, it supports more and received plus 200 g of fluid. With this charge and working for 60 minutes, some data of the system was collect and it is shown in the Table 1.

Table 1. Data collected in the first testing using a capillary tube and R-22.

Time	0 min	30 min	60 min
Low side pressure	150 psig	65 psig	70 psig
High side pressure	150 psig	325 psig	350 psig
Consumption	0 A	10.5 A	11 A
Evaporator exit temperature	25°C	19.6°C	19.9°C

The initial values of pressure were the same because the system was pre-charged with 1.5 kg of R-22 and has been shutting-off in order to achieve the equilibrium in both sides and in this way there would be no problem to start up the compressor.

After 30 minutes of working, the pressure readings were stable, at 65 psig evaporation pressure, the saturation of R22 starts at 3°C, but this pressure depends directly of condensing pressure which is 325 psig, and at this pressure the saturation of the fluid is 59°C, which is a high working temperature, leading to a small capacity of heat transfer and a very high power consumption from the compressor. After 60 minutes, the evaporation and condensing pressure rises, respectively, to 70 and 350 psig, which represents saturations temperature equal 5°C of evaporation, and explain the elevation of the evaporator exit temperature, i.e., the higher the evaporation temperature, the higher the temperature of the fluid in contact with the evaporator, but the system will be able to have better capacity of heat transfer although, the condensing temperature for 350 psig is about 60°C, indicating that overall system capacity is very low.

At the initial values of power consumption, the only equipment added to the system was a fan condenser, so the original had one motor to two fans, but the consumption of the condenser fan is near 0,4 A, and this indicates that the high condensing temperature, high energy consumption of the compressor and overloaded system with fluid were factors that contributed to the high energy consumption.

Table 2. Data collected using an expansion valve and R-22.

Time	0 min	15 min	30 min	45 min	60 min
Low side pressure	150 psig	50-68 psig	55-65 psig	68 psig	70 psig
High side pressure	150 psig	200-230 psig	210-220 psig	225 psig	235 psig
Consumption	0 A	10.4 A	10.3 A	10.4 A	10.7 A
Evaporator exit temperature	24°C	22°C	20°C	19.8°C	19.9°C

It is important that it was a rainy day when the test was made and this explains, in part, the lower condensing pressure if we compare with the experimental data shown in Table 1, perhaps the new expansion device had contributed.

The system was charged with 0.9 kg of R-22 and, after 15 minutes, the system shown significantly instability in both sides, the pressure in the suction side floating between 50 and 68 psig, with saturation temperature between -3.5°C to 4.5°C, and the condensing pressure between 200 and 230 psig, the saturation temperature from 39°C to 44°C. According to Whitman et. al. (2013), both pressures of the system must be constant to guarantee the best working state of the system, with good capacity of heat transfer and low consumption, this phenomenon was called 'hunting'. When this phenomenon is seen in an expansion valve, the valve open and close repeatedly without control and in some cases, this can cause overfeed of evaporator with the possibility of liquid return to damage the compressor. In the case of the

test, the evaporator was poorly feed, causing the low pressure and temperature of evaporation, and high working temperature of the compressor, which is bad for lubrication.

After 30 minutes, the valve adjust was open 1 cycle, the readings get better, the floating decreased from 18 to 10 psig, with the saturation temperature between -1°C to 3°C , and the condensing pressure reduced to 10 psig of variation and temperature between 40.5°C to 42.5°C . But it couldn't continue working with that variation, then the system was charged to 1.0 kg.

After 45 minutes, the valve starts to work properly with a good control of feeding and superheating, and the system was finally working with a constant pressure in both sides. At a pressure of 68 psig, the saturation temperature was 4.5°C , and the temperature of condensing to 225 psig was 43.5°C , those pressures indicates that the system was working good. To test the correct function of the valve, plus 0.1 kg of R-22 was added to the system. In 1 hour of working, 15 minutes with 1.1 kg of charge, the pressure in both sides still constants, after an increase of 2 psig in suction side and 10 psig in discharge side.

The evaporator exit temperature shown that the system with 'hunting' was low capacity, after 30 minutes, in a rainy weather, only could drop 4°C , if the system didn't have this problem, possibly, after 15 minutes the exit temperature will be very close to 20°C . The temperature couldn't drop anymore because de evaporator wasn't well-insulate and the system was overcharged, the excess of fluid cause high pressure in suction side and didn't allow the reduction even after the expansion valve closes to adjust the flux. The overcharged system also can be observed with the increase of 0.3 A in the consumption.

Now, to replace the R-22 for R-600a, all R-22 has been recovered, the system was pressurized with nitrogen, and the vacuum procedure applied three times, to guarantee the total removal of R22. The system was tested exactly the same way, initially with 0.420 kg, which is the amount of 1 bottle, to test the performance of the system and how the valve would work, another bottle was used after 15 minutes of working. The collected data are presented in the Table 3.

Table 3. Data collected using an expansion valve and R-600a.

Time	0 min	10 min	15 min	20 min	30 min	45 min	60 min
Low side pressure	40 psig	13 psig	13,5 psig	13,5 psig	13,5 psig	13,5 psig	13 psig
High side pressure	40 psig	52 psig	56,6 psig	58 psig	59,5 psig	59,5 psig	58 psig
Consumption	0 A	4.1 A	4.6 A	4.5 A	4.6 A	4.5 A	4.5 A
Evaporator exit temperature	27°C	24°C	20.5°C	20.6°C	20.5°C	20.3°C	19.7°C

In the start-up of the system, has been noticed a significant difference of working pressure, the mean temperature that day was 31°C , and the condensing pressure stays above 60 psig, being the saturation temperature close to 39°C , which leads a good level of fluid condensation and sufficient liquid to feed the expansion valve. After 10 minutes the exit temperature already was 24°C , to a suction pressure of 13 psig, the saturation temperature was 5°C , which is a good value of evaporation temperature to a condensing pressure of 52 psig (35°C). After this reading, more 0,210 kg R-600a was added to the system.

In the time 15, 20 and 30 minutes, the suction pressure increase to 13.5 psig (6.2°C), and the condensing pressure was 56.6 psig (37°C), after more 0,1kg, it increased again to 58 psig (38°C), and to 59.5 psig (38.95°C) until the bottle was totally empty. After 60 minutes of testing, the final pressure were 13 psig (5°C) and 58 psig (38°C), with an exit temperature below 20°C , very close to the values obtained using R-22.

Because the low condensing pressure, the compressor, which is the major consumption component, needed much less power to work, leading to a very low consumption of the system, more than 50% of difference for the test using R-22 and the capillary tube. The graph shown in Figure 9 below compares the power consumption with the condensing pressure.

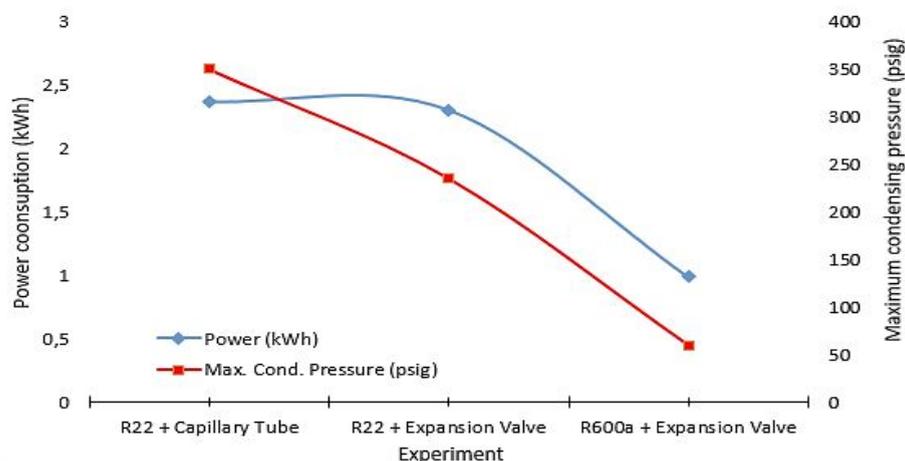


Figure 9. Comparison of the power consumption with the condensing pressure.

As seen above, the condensing pressure is one the most important factor that contribute to the power consumption from the compressor, with a reduction of almost 5.9 times the pressure, the total consumption was reduced in about 2.4 times, without any kind of lost of performance at all.

Finally, although the need of changes, using this experimental apparatus it was allowed to conclude that simulator and the reuse of components e parts of obsolete systems works, as shown in data in Tables 1, 2 and 3, observing the excellent temperature variation. Posteriorly, after replaced the capillary tube for a thermostatic expansion valve, it was possible to control the reduce the mass of fluid in the system. In addition, change the refrigerant fluid makes it possible to evaluate the operation characteristics of a system using a less aggressive to the environment fluid (R-600a).

After all experiences realized, the test with R600a is, by far, the most successful, showing all the parameters and conditions of work seemed a synthetic fluid, even better for the point of view of power consumption, the restrictions of his use must be reduced as soon the new studies and technology are developed

Furthermore, this equipment is accessible and easy to handle, especially in the collection of pressure e temperature data.

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