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DEVELOPMENT AND PERFORMANCE ANALYSIS OF A COMPRESSION REFRIGERATION CYCLE

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Abstract. Due to the rising search for cooling systems, which are used in many areas on a daily basis, such as air conditioning and food preservation, like, cooling and freezing, there is currently a strong worldwide trend to invest in research and development studies to optimize refrigeration cycle. Therefore, focusing on verifying and analyzing the multiple variables, which may affect a cooling system, a vapor-compression cycle workbench was built, and its components were analyzed. The R22 was used as working fluid. Even though, this fluid has a moderate GWP rate (1700), it has a low chlorine concentration in its structure, resulting in a nearly zero ODP rate. The system is composed with a hermetic compressor, a cooled by forced air convection condenser, standard direct expansion evaporator and a capillary tube. The performance analysis made resulted in COP values varying from 3,15 to 4,64. The fan responsible for the forced convection on the condenser had its speed varied in order to evaluate its influence on the system's COP. It was possible to obtain an outlet air temperature ranging from 15 to 0°C.

Keywords: Coefficient of Performance; Compression Refrigeration Cycle; Energy.

1. INTRODUCTION

According to EPE (2012), energy efficiency is an important vector on meeting the demand, thus contributing to energetic safety, reasonable fares, economic competitiveness and reduce emission of gases with high greenhouse effects. In this way, many researches such as Wani *at el.* (2016) are aim to analyze and optimize refrigeration cycle performance. The work of Wani, *at el.*, (2016), for instance, has increased the system's COP by 10,35% just by adding an ejector into the conventional refrigeration cycle.

As it is known, cooling systems can be defined as an equipment which allows an efficient heat transit in a direction that is opposed to its natural order, that is, it transfers heat from a low temperature reservoir to a high temperature one (Ferreira, 2010). These system's applications are such as air conditioning, food preservation associated with air conditioning units or refrigerators, among many other systems that has already become essential to today's society.

Between the main cooling technologies, such as absorption refrigeration, refrigeration by air, jet refrigeration, thermoelectric refrigeration, thermoacoustic refrigeration, it is possible to highlight the compression refrigeration cycle due to its simplicity, high efficiency and broad field of application (Duarte, 2013). Figure 1 shows a basic compression refrigeration system.

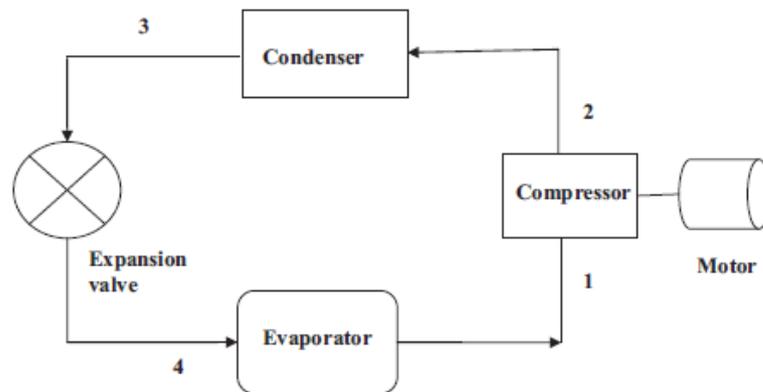


Figure 1. Schematic diagram of a vapor compression refrigeration system.

To choose which working fluid should be used in such cooling systems is still a huge challenge. Ever since the Montreal's Protocol, Kyoto's and most recently Kigagli's amendment in, 2016, it was determined that the CFCs, HCFCs and HFCs fluids must be replaced in the medium to long term. According to Douglas *et al.* (1999) several criteria must be considered when selecting replacement refrigerants, including: chemical stability, safety, environmental, and thermal performance.

Therefore, despite the R22, which is used at the present work, being a HFCF with a moderate GWP (Global Warming Potential), its ODP (Ozone Depletion Potential) is nearly zero (0,055). In addition, it is nontoxic, non-inflammable and it also has a great cooling capacity.

Recently, a study done by Shirvastava and Choudhari (2016) has shown that the R22 is the most used fluid in air conditioning cooling systems and many other industry applications. The authors made a comparison between the R22 and HC-290. Despite having many similar thermodynamic properties, the R22's COP was about 15% higher in almost every case analyzed compared to the HC-290.

In the research of Elgendu, Hassanain and Fotouh (2015), it was analyzed the refrigerant fluid R438A as a candidate for a retrofit on a R22 based system. However, the results obtained for a refrigeration cycle with direct expansion were still better using the R22. The cooling capacity and COP using R22 were, respectively, 11% and 12,5% higher than those using R438A.

In the experimental work of Deshmukh and Mali (2015), the R22, operating in a refrigeration compression cycle, has also obtained a higher COP (3,18) compared to many other fluids such as R134a, R290, R600A, R1270, R290/R600A (40/60), among others.

Reis and Seidel (2015), in a study of simulation and comparison between various fluids, have obtained values for the R22's COP of 3,123, thus being higher than those ones from R134a and R410A. Furthermore, the study demonstrated that the cooling cost using R22 is also lower.

Thereby, this work approaches the design, assembly and energetic efficiency analyzes of a refrigeration cycle operating with R22 for air cooling. Additionally, this work has aimed to evaluate the influence of the forced convection through the modulation of the electric motor coupled to a fan directed to the condenser.

2. METHODOLOGY

The present work was developed at Thermodynamics and Heat Transfer Laboratory in Itaúna's University. The project of workbench refrigeration cycle started by designing and specifying the components and thermic devices, which would be necessary to its composition, as well as analyzing the ideal R22 refrigeration cycle. The thermic devices were installed in the way to minimized the heat loses and the cargo loses. They were connected using copper tubes and isolated with proper material. Supports were fabricated to attach the forced convection electric motors. The propellers were coupled to the electric motors using keyed joints and elastic bolts. The duct where cooled air would flow was fabricated and painted in the laboratory. In each one of the four device's outlet, manometers and thermocouples were installed. Another thermocouple was also installed on the cooled air outlet duct. Figure 2 shows a 3D image of the initial design used to assemble the refrigeration workbench, developed using the software *Inventor 2010*.

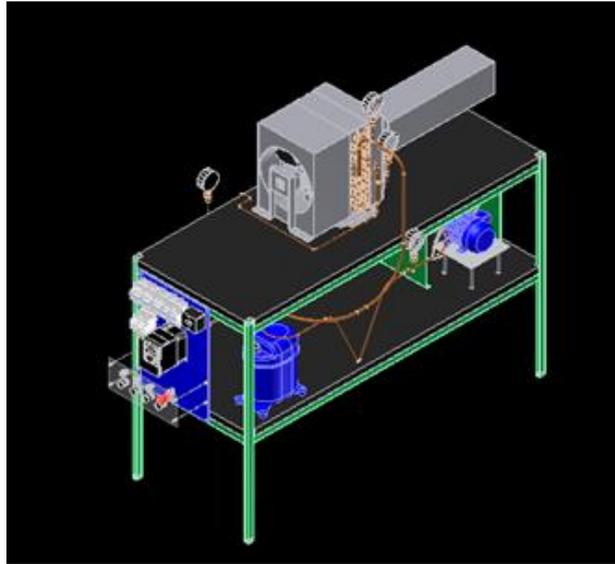


Figure 2. Design used to assemble the refrigeration workbench

The *LabVIEW* system design software was implemented to collect the experimental data. In an addition, instrument's uncertainty were analyzed to calculate and evaluate the COP of the system.

As the workbench was being assembled, efficiency optimization was aimed through developing the best possible layout for its thermodynamic devices. The elements, which operate at high temperature, were disposed on different height levels from those elements that work at low temperature to minimize heat transfers lost.

A Schneider variable-frequency drive has been installed in order to control the rotation of an electric motor's shaft, which is coupled to a propeller that is responsible to force convection through the condenser, so its influence on the system's COP could be evaluated.

3. RESULTS AND DISCUSSION

The assemble of the workbench containing 610 grams of R22 ran as well as expected. The system operated cooling the air from 30 to 0°C. Figure 3 shows the workbench successfully operating.



Figure 3. Compression refrigeration cycle workbench operating

All the proprieties of the refrigerant was obtained from EES (*Engineering equations solve*). That way, by the First Law of Thermodynamics calculated the real COP of the system analyzing the other energy spent with the compressor and motors losses. It was studied all the work and heats transfer involved in the system. Some measurements of the variation frequency of the electric motor's speed are demonstrated in Tab. 1, when the temperature of the air was 23°C.

Table 1. Measured data.

Hz	T1(°C)	P1(Mpa)	T2(°C)	P2(Mpa)	T3(°C)	P3(Mpa)	T4(°C)	P4(Mpa)	T (air outlet)
36	88,3±1	2,106±0,145	46±1	2,057±0,145	0±1	0,517±0,116	0±1	0,474±0,116	4±1
48	86±1	1,812±0,145	35,3±1	1,719±0,145	-2±1	0,459±0,116	3,5±1	0,429±0,116	2±1
60	78,3±1	1,616±0,145	31±1	1,534±0,145	-3,7±1	0,435±0,116	7±1	0,4±0,116	0±1

Note: Point 1 corresponds to the compressor's outlet, point 2 to the condenser's outlet, point 3 to the capillary tube's outlet and the point 4 corresponds to the evaporator's outlet.

In Figures 4, *Pxh* diagrams of the complete refrigeration cycles can be seen, for fan frequency of 60Hz previously mentioned in Tab.1, also made using the software EES.

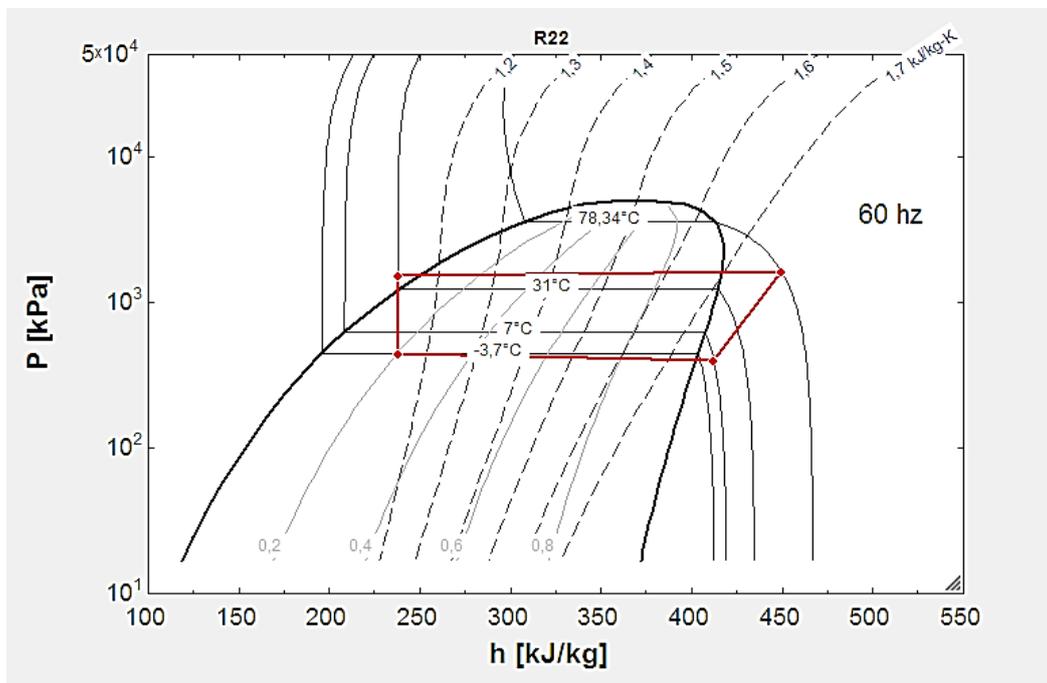


Figure 4. *Pxh* diagram for 60Hz

As shown in Figure 5, the COP values vary between 3,15 and 4,64. As expected, the highest COP value was obtained when it was applied the nominal frequency of 60Hz, which corresponds to a fan speed of 1720 rpm, and its value was $4,63 \pm 0,154$. This is the effect of a more efficient heat exchange on the condenser: since the electric motor that drives the fan was at its maximum speed, the convective heat transfer coefficient was increased due to it being an air's speed function; therefore, the heat exchange was increased as well.

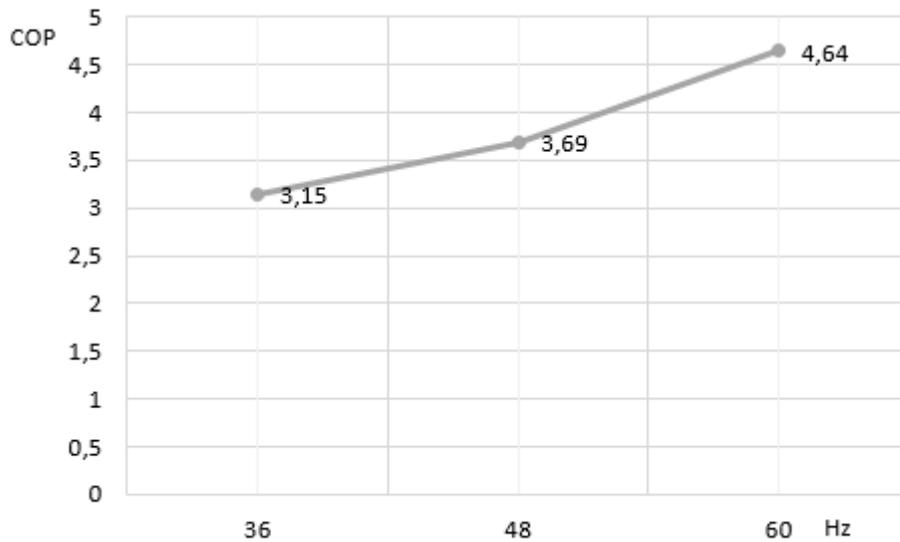


Figure 5. COP values versus fan's motor frequency.

The measured COP values were considered very satisfactory when compared to other papers that evaluated similar refrigeration systems, available on the literature. The study from Bona, et al (2006), operating using the same work fluid, R22, reports that the highest COP value obtained was 4,11. Deshmukh e Mali (2015), operating a simple compression refrigeration cycle, reported a COP of 3,18 using R22; this being the highest COP value compared to other refrigerant such as the R134a and R290, fluids analyzed on this study as well.

Additionally, the COP was evaluated as a function of the evaporation temperature and its corresponding electric motor's frequency, as it can be seen in Figure 6.

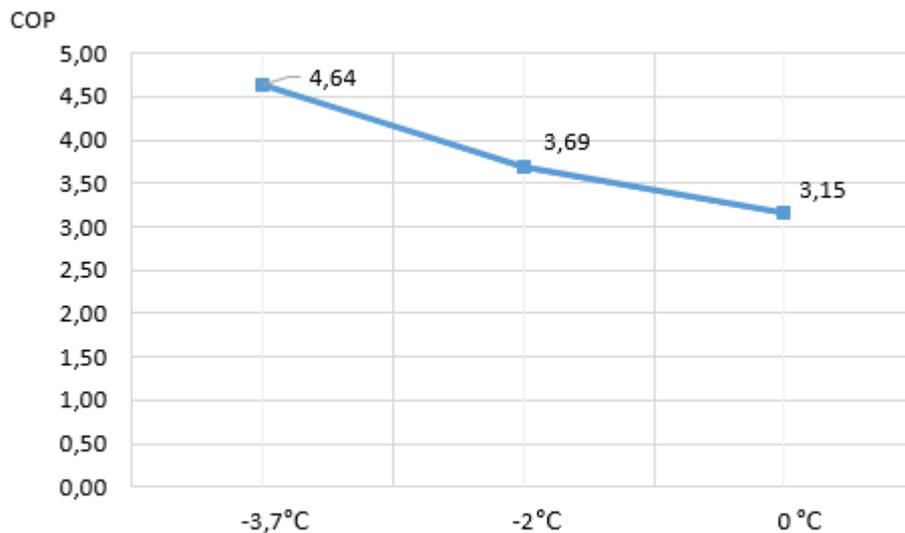


Figure 6. COP analysis versus evaporation temperature and its corresponding frequency

As it was to be expected, the higher the frequency of the motor that drives the fan responsible for the forced convection, the lower the evaporation temperature of the fluid is, thus, higher the system's COP gets, increasing the air cooling capacity.

4. CONCLUSIONS

The workbench's assembly was satisfactory especially when compared to other works that are in the literature, as it was possible to obtain favorable COP values. As expected, it could be noticed that the higher the fan rotation speed, the higher are the COP values, as well as, the lower the evaporation temperature is. Future studies aims to improve the

system's COP even further and, due environmental matters, refrigeration fluids that are capable of replacing and perform as well as the R22 are also being researched, and researches using the new HFO-1234yf fluid and/or natural fluids (HCs) could be performed in the near future.

5. ACKNOWLEDGEMENTS

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