



Effect of Return Gas Temperature in Reciprocating and Rotary Compressor Performance for Medium and Low Temperature Applications in Commercial Buildings



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Abstract

Energy efficiency in refrigeration and air conditioning vapor compression systems has been focused on the development of modulation methods allowing variation of compressor energy consumption according to refrigeration requirements, or the use of alternative energies for running those compression systems. However, even when a compressor comes with frequency inverter, improper selection can lead the user to spend more energy during low cooling loads; or force the compressor to work under conditions for which it was not designed. Thus, the present article shows how the determination of the return gas temperature of the compressor can affect its performance and may vary according to the type of application. Therefore, the operation of reciprocating and rotary compressors was simulated under the same nominal conditions and determined its cooling effect and its compression capacity. The results show that for the same type of compressor, differences in system capacity are approximately constant regardless of the type of refrigerant used in low temperature applications. The compressor capacity for medium and low temperature systems is independent of return gas temperature using R-22.

Keywords: Refrigeration system; Return gas; Reciprocating compressor; Rotary compressor and superheat

Introduction

Air conditioners, heat pumps, and other commercial refrigeration equipment are widely used in contemporary society. On-off cycling operation is a common way to control the capacity of indoor heating and cooling equipment [1]. Small capacity household or commercial air-conditioners consume tremendous electrical energy in buildings due to its huge holding quantity all over the world. Improving the energy utilization efficiency of small capacity air-conditioners will be the key factor that helps to reduce energy consumption of buildings [2]. Much effort has been devoted in performance improvement of air conditioners, wherein working efficiency enhancement of the compressor is the key technology [3-8].

Although many efforts have been devoted for energy and financial saving of air conditioners, relative few works have been done to reveal the internal leakage characteristics [9,10]. The two key factors that affecting the volumetric efficiency of a rolling piston type rotary compressor are respectively the internal leakage and the oil supply situation [1,8,11]. At present, applications of

new refrigerant as well as variation frequency technology bring new challenges for the development of rolling piston type rotary compressors [12,13]. In addition, according to the adjustment of the Montreal Protocol for Substances that deplete the Ozone Layer, the phase-out progress of HCFCs (hydrochlorofluorocarbon) had been accelerated [14,15].

The use of compressors in commercial and small-scale industrial refrigeration systems has proven to be the most profitable cost-benefit ratio technology over other cooling systems such as absorption; which has the advantage of working with economical energy sources, but with a lower C.O.P [16]. In addition to the conventional cooling systems mentioned above, people have developed multiple options as those addressed by Dieckmann et al. [17]; Canter [18] that replace the compression process with a magnetocaloric effect or Peltier effect; which clearly show the current inability to scale those systems to commercial and industrial scale; so that, vapor compression cooling systems are capable of being optimized through the implementation and

development of new technologies; even more when it's estimated that the percentage of energy required for Industrial cooling and air conditioning facilities is at least 45% [19]. This has led engineers and designers to develop alternative methods to optimize energy consumption and, in some cases, reduce it.

Among some compression systems technologies, it's important to emphasize the one mentioned by Dieckmann et al. [17] about the use of variable frequency compressors to achieve speed control of induction motors according to the cooling load of the system. This technology can reduce high-energy consumption due to the constant stops and starts of the compressor (compressor cycling); however, frequency control can lead to stability problems in the system; because of that, Yiming et al. [20] propose the use of a minimum stable superheating. In Wang et al. [21] is presented a model to optimize the use of scroll type liquid injection compressors to increase efficiency; while Shuaihui et al. [22] studied the performance of a compressor of the same type by using an external structure for cooling. On the other hand, in Douglas & Jekel [23] is evaluated the use of waste heat from cooling systems for its use at industrial level.

Method Description

Determination of return gas temperature

Suction gas, also known as return gas is defined as the gaseous refrigerant, which is at the compressor inlet. This gas is at a temperature that depends on the application (high, medium, low) and the superheating that has collected in the suction line. However, compressor selection software rates equipment performance under "standard" conditions in order to compare compressor capabilities on the same design condition. According to international standards such as ANSI/AHRI 540 and EN 12900, compressor selection is set using return gas at 18.5 °C, when the suction temperature is above -18 °C; which is the temperature obtained for high and medium temperature.

In Maxson [24] and some condensing units manufacturers recommend a total superheat measured at the inlet of the compressor (evaporator+suction line) of 15 to 16 °C to assure the return of dry gas to the compressor; so that the return gas temperature is given by:

$$T_{\text{return gas}} (\text{°C}) = T_{\text{evap}} (\text{°C}) + 15 \text{ °C} \quad (1)$$

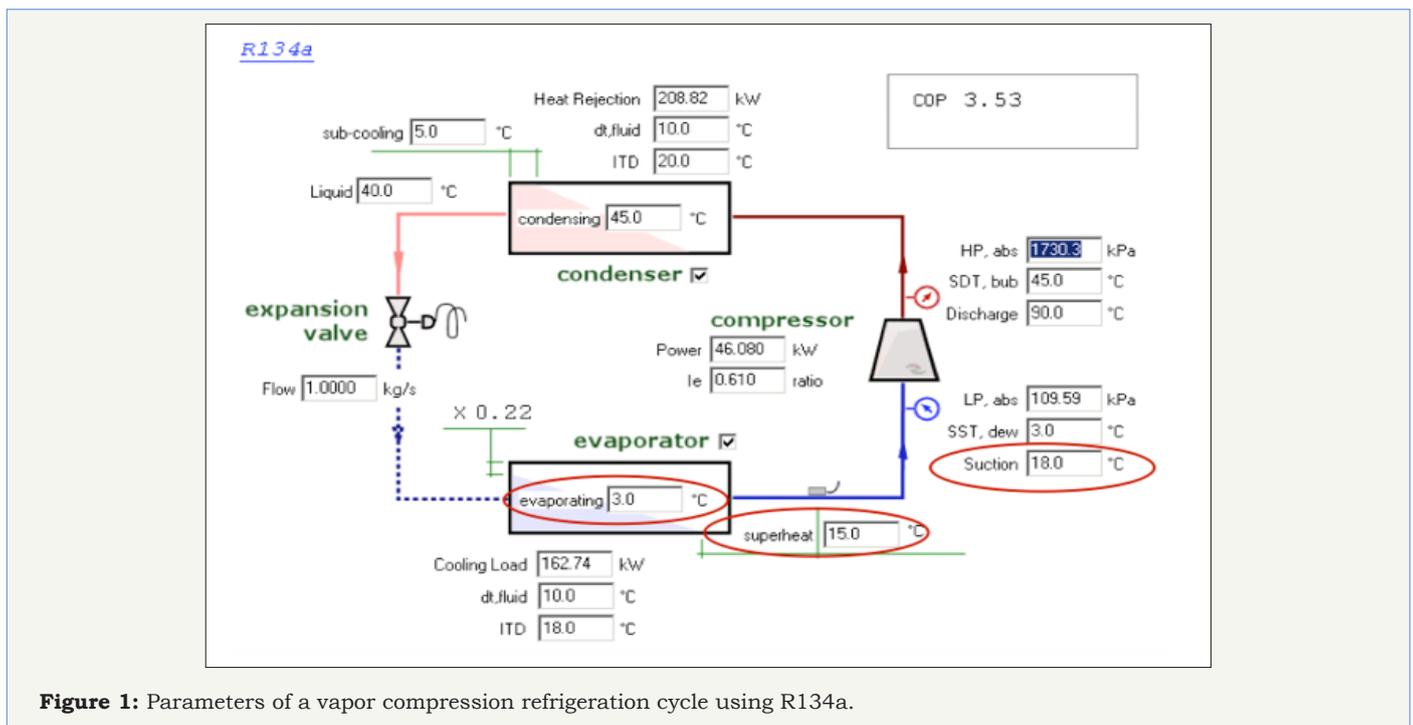


Figure 1: Parameters of a vapor compression refrigeration cycle using R134a.

Figure 1 shows the parameters of a vapor compression refrigeration cycle using R134a. For high temperature applications; where a system can operate with an evaporating temperature of 3 °C, an 18 °C return gas should be obtained; which is the temperature mentioned by AHRI 540. However, assuming an 18 °C return gas in applications of medium and low temperature, may provide a far exceeding expected compressor capacity.

Simulation features

According to return gas temperature set by the standard AHRI 540, cooling capacity was simulated for two types of compressors

at rated capacity of 7½ HP and three refrigerants; one HCFC that although is not being produced, is still present in various refrigeration systems installed, and two HFC having 0 ODP for not having chlorine in its structure. For typical medium temperature applications an evaporation temperature of -5 °C was used, and the return gas was varied from 10 °C to 18,5 °C (Equation 1). In low temperature, where evaporation is generally about -25 °C to -18 °C, return gas temperature was varied from -10 °C to the temperature suggested in AHRI 540. Table 1 shows the conditions under which compressor capacity was simulated for different systems working with R- 22, R -507 and R- 404A respectively.

Table 1: Simulation parameters.

Parameter	Application	
	Medium	Low
Evaporation (°C)	-5	-25
Evaporator superheat (°C)	5	5
Subcooling (°C)	5	5

Description of the high-speed centrifugal steam compressor

To validate our proposed method, a monitoring process was developed during three months. The high-speed centrifugal steam compressor and the monitoring system are installed in a commercial place in the city of Barranquilla, Colombia. This city is located at 10° 57' 50" N, 74° 47' 47" W and averages 27,4 °C of temperature. Table 2 shows the specifications of the high-speed centrifugal steam compressor. The monitoring system was developed using virtual instrumentation and it acquires 1 data per second of temperature, voltage and current and it calculates an average per minute. The

LabVIEW software saves the information daily to a spreadsheet and it is analyzed and compared with simulation results. Figure 2 shows the front panel of the virtual instrument developed in LabVIEW. The user can setup the sampling rate of the monitoring process, select the format of the saved file (.txt or .xls) and create an HTML report of the process.

Table 2: Specification of the high-speed centrifugal steam compressor.

Parameter	Data
Temperature rise of saturated steam (°C)	Jun-16
Mass flow (MVR system evaporation - tons/h)	01-Oct
Efficiency (%)	80-85
Impeller rotation speed (RPM)	5000-40000
Volume Flow (m³/h)	3000-14000
Working stability	Better
Max. Compression ratio	1,8

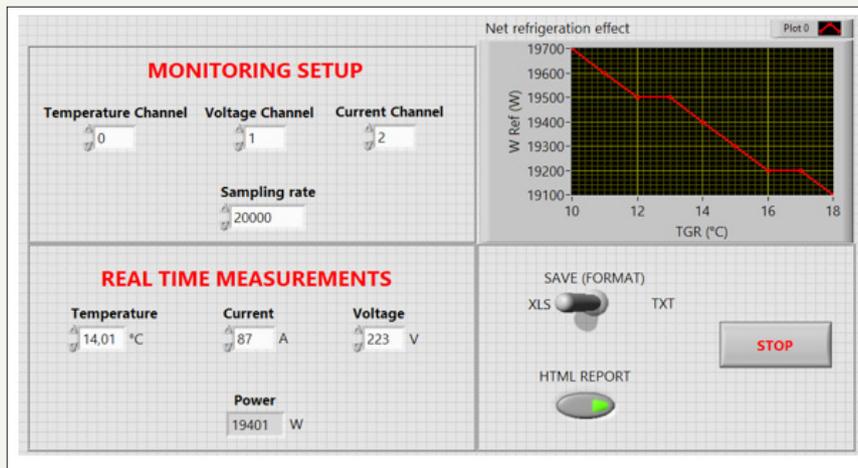


Figure 2: Front panel of the monitoring system.

Results and Discussions

Net refrigeration effect

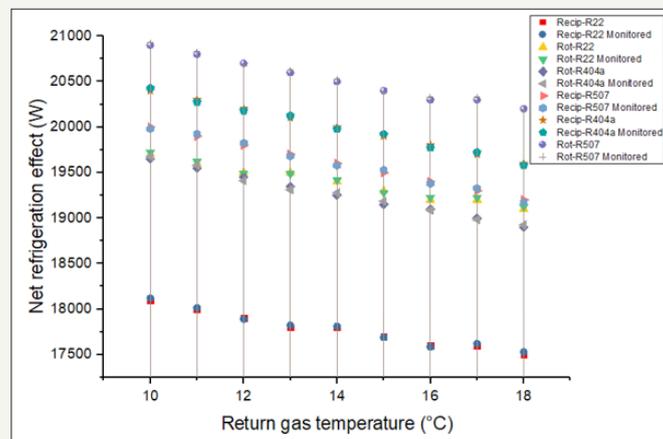


Figure 3: Net refrigeration effect in medium temperature.

Figures 3 & 4 show the results obtained by varying the return gas temperature for medium and low temperature applications respectively. It can be seen that the cooling effect decreases as the return gas temperature increases; this is because when the gas temperature increases, its specific volume increases causing that less refrigerant gas enter the compressor, and consequently is

compressed. This behavior is slightly more evident in reciprocating compressors due to the clearance volume that these compressors have at the top of the pistons and the valve plate; so that, it's important to have an accurate estimate of the return gas temperature while the compressor is running, to prevent compressor selection using nominal conditions.

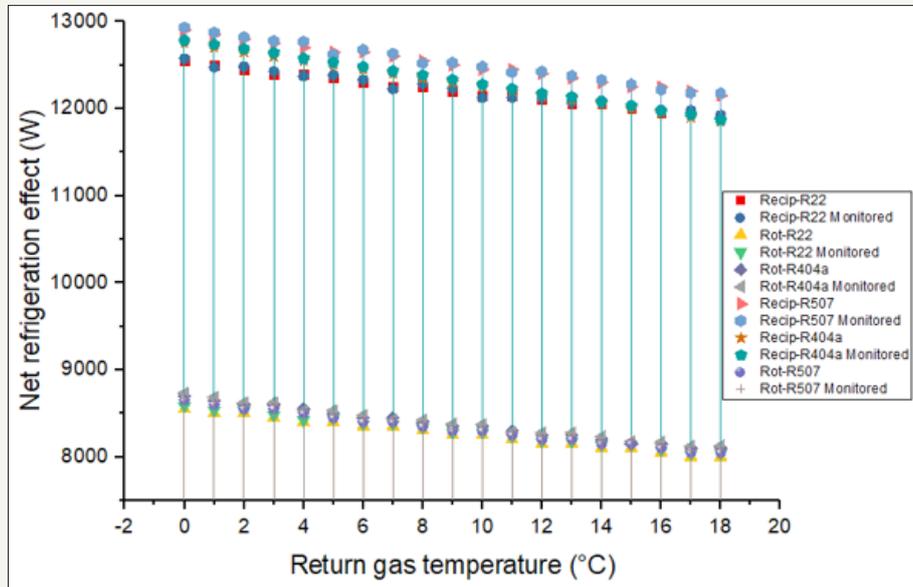


Figure 4: Net refrigeration effect in low temperature.

Compressor capacity

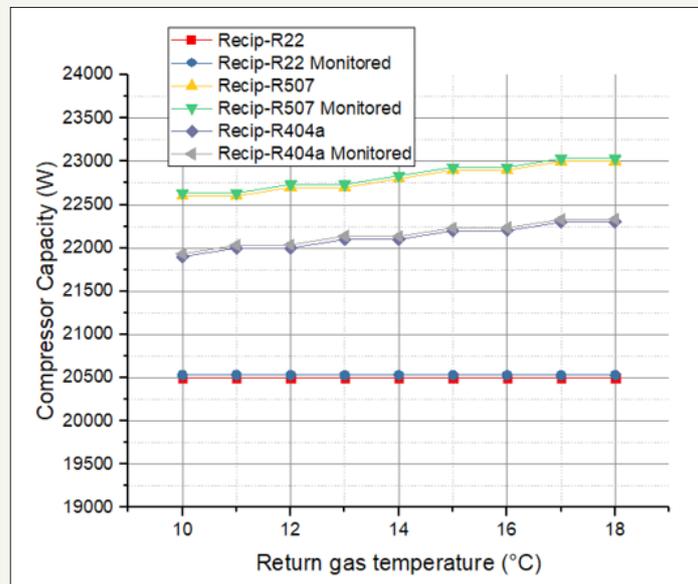


Figure 5: Compressor capacity in medium temperature.

Although the net refrigeration effect decreases as the return gas temperature increases, the opposite behavior happens with compressor capacity as evidenced in Figures 5 & 6. A rise in the return gas temperature increases the compressor capacity; which is clearly notable in reciprocating compressors. This effect is

explained as follows: while the net refrigeration effect decreases, the fact that the refrigerant can absorb more energy in the suction line to reach 18 °C allows sensible heat gain and thus the overall effect is a slight increase in capacity.

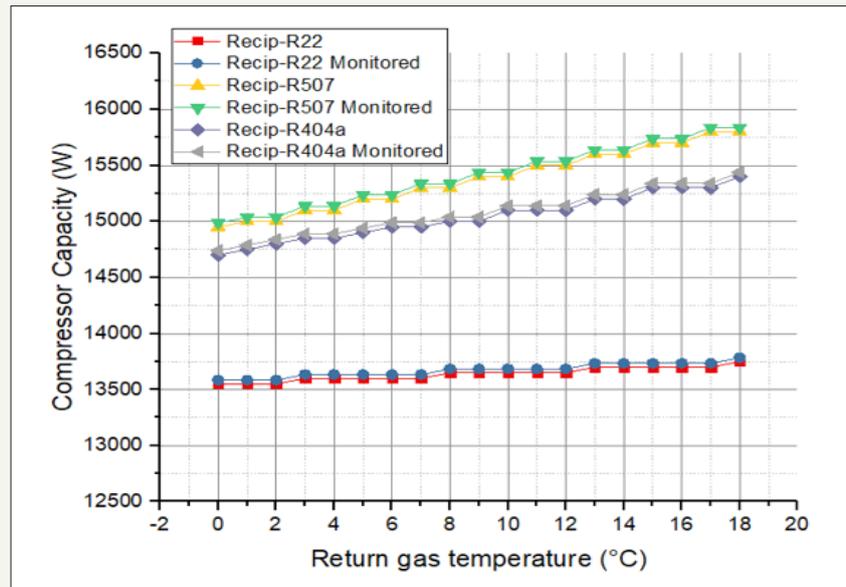


Figure 6: Compressor capacity in low temperature.

Conclusion

Proper compressor selection for cooling requirements established, generate an efficient performance of equipment and adequate energy consumption. For this reason, this article shows a comparison of the system capacity with net refrigeration effect for low and medium temperature applications, varying return gas temperature. Some of the conclusions that can be drawn are:

- For the same type of compressor, differences in system capacity are approximately constant regardless of the type of refrigerant used in low temperature applications.
- Compressor capacity for medium temperature systems is independent of return gas temperature using R-22.
- The estimation of the total superheating in the suction line will allow a more accurately determination of the return gas temperature, reflected in a better compressor selection.
- By adjusting the suction temperature, compressor capacity can be accurately estimated, responding to established cooling loads.

The error between the simulation results and the monitored data was less than 1% in medium and low temperature applications.

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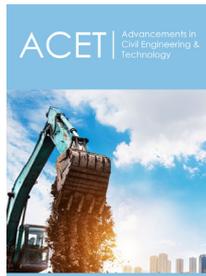
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