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Analysis of the oil temperature in a scroll compressor with oil carter at discharge pressure using propane as refrigerant: Performance analysis for abnormally low oil volume

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Abstract: *Scroll compressors are widely utilized in refrigeration systems and heat pumps, operating through the interaction of two spiral-shaped elements, one stationary and the other orbital. These elements fit together and continuously oscillate, compressing the fluid into diminishing volumes. They offer significant advantages such as high volumetric and compressor efficiencies, low vibrations, and reduced leaks. In direct suction scroll compressors, the oil sump is at discharge pressure, resulting in a wide pressure difference between the housing and the backpressure chamber; also, the oil temperature is higher than in the most common suction-side oil crankcase design. Knowing the oil temperature is crucial in determining the properties of the oil/refrigerant mixture that affect the system's performance. It also allows us to estimate the amount of refrigerant dissolved in the oil. In the current study, a series of tests are conducted under various operating conditions to measure the oil sump temperature in a direct suction scroll compressor. This experimental campaign was conducted using a compressor with an unusually low oil level, and an analysis of the system's performance was performed until a failure occurred.*

Keywords: Scroll compressor, oil temperature, high-pressure shell scroll, low oil level.

1. INTRODUCTION

Research on oil characteristics and their influence on compressor reliability is of great importance for the design of better refrigeration and air conditioning systems. Scroll compressors are widely used thanks to their mechanical advantages and high performance. The correct lubrication of the compression system and thermo-physical properties of the refrigerant oil mixture are crucial to ensure proper operation. Oil viscosity is a critical parameter that influences compressor performance. Proper oil viscosity helps reduce friction between the moving parts of the compressor, which minimizes energy losses and also affects its ability to reduce internal leakage and improve overall system efficiency[1].

On the other hand, the solubility of the refrigerant in the oil also plays a crucial role in compressor performance and safety. The amount of refrigerant charge dissolved in the oil affects the total amount of refrigerant present in the system and its lubricating properties. Since R290 is highly flammable, the amount of refrigerant in the system has important implications for safety.

This study delves into comparing the performance of a compressor with a high-pressure shell and using propane as a refrigerant under very low and nominal oil levels. It also analyzes the oil temperature, which is vital to assess the oil/refrigerant properties while examining its overall performance.

2. METHODOLOGY

The compressor to be tested is a scroll compressor with the oil sump at discharge pressure; it is tested in a calorimeter located at the Instituto de Ingenería Energética (IIE) of Universitat Politècnica de València (UPV). The test rig consists of a refrigerant and water loop, allowing the compressor to be tested under different conditions by simulating a thermodynamic cycle. PID systems automatically control suction pressure, condensing pressure, superheat, and subcooling. Coriolis mass flow meter (Emerson Micro Motion CMF025) is used, having an accuracy of 0.05% of the measured value. The accuracy of the pressure sensors (Rosemount-3051) and the temperature sensors (RTD-PT100) are 0.02% and 0.05°C, respectively. Two thermocouples on the sides of the oil sump connected to an isothermal block with an error of 0.5 °C are used to measure the oil temperature. It is assumed that at a steady state, the thermocouples measurements on the shell surface are similar to the oil temperature in the sump.

The conditions to be tested are shown in Figure 1 for three compressor speeds: 30 RPS, 60 RPS, and 100 RPS. At 70 °C, no tests are performed at 100 RPS, considering that in this condition, the compressor failed, as explained below.

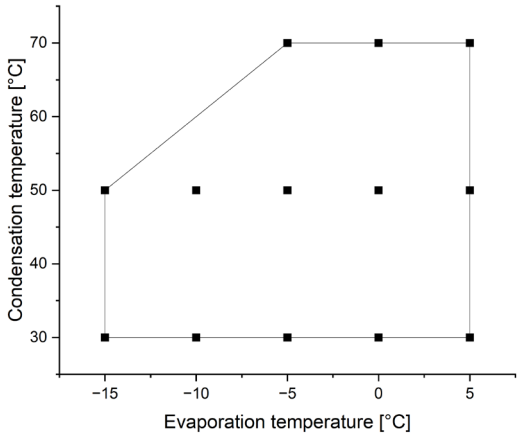

Figure 1. Test Matrix

2.1 Failure explanation

The tests proposed in the test matrix for 60 RPS and 30 RPS were performed successfully; the last test performed was the condition at 15°C evaporation temperature and condensation temperature of 50 °C at 60 RPS. At the end of the test point, the compressor speed is changed to 100 RPS with the same test conditions. Figure 2 shows the deterioration of the efficiencies at the time of failure of the tested compressor at a low oil level. In the 300s, the steady state of the last condition tested ended, and then the change of conditions started.

The increase to 100 RPS is done progressively, increasing by 15 RPS until the target speed is reached. From the 500s at the speed setpoint, the change in efficiencies is due to the progressive increase in condensing pressure. As the condensing pressure increases, the discharge temperature rises rapidly until the compressor failure occurs at around 800 seconds, at a discharge pressure of 23.14 bar, suction pressure of 2.95 bar, and discharge temperature of 121.4 °C

Further analysis of the compressor revealed that the oil level in the sump was at a minimum of about 10% of the total nominal oil level. There were signs of abrasion between the shaft receptacle on the orbiting scroll and the eccentric part of the shaft. It appears that the shaft had seized in the lower scroll, probably due to high temperature, poor lubrication, and high abrasion.

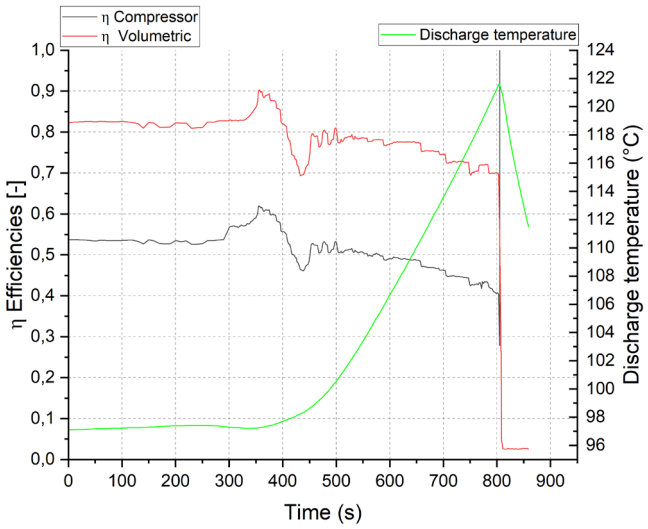

Figure 2. Efficiencies and discharge temperature at the time of compressor failure

3. RESULTS AND DISCUSSION

After the failure of the compressor due to a low oil level, the tests are performed again with the same compressor model but ensuring an oil level recommended by the manufacturer. Figure 3 shows the comparison in performance between the compressor with a low oil level and the compressor with a nominal oil level, which, for this compressor, is around 0.9L.

3.1. Performance comparison

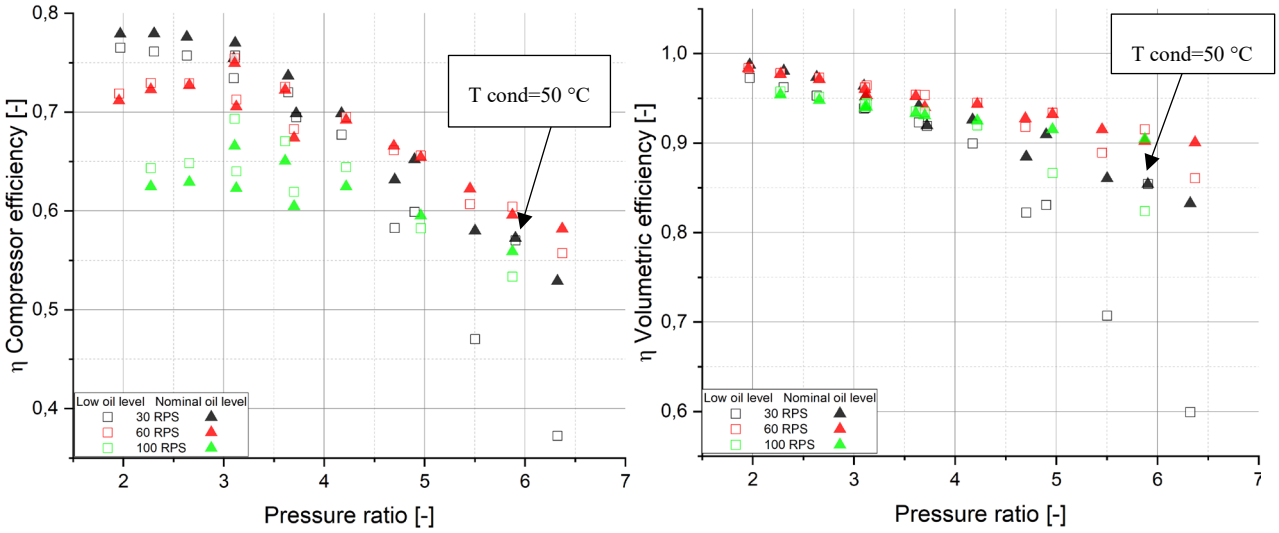

Figure 3. Compressor (left) and Volumetric (right) efficiencies.

Figure 3, left, shows the compressor efficiency for the compressor with the two oil levels tested; despite the difference in oil level, there does not appear to be a major impact on efficiency except for low-speed and high-pressure ratio conditions. There is even a slight increase in efficiency at medium and low-pressure ratios at high compressor speed, but at rated speed, there appears to be no difference between the compressors tested.

In Figure 3, right, the volumetric efficiency does not seem to be impacted by low oil levels in the 60 RPS and 100 RPS speed conditions at medium-low pressure ratios. On the other hand, as a general trend, the efficiency is lower at 30 RPS and low oil level conditions, and the efficiency drop seems to increase with the increase in pressure ratio. However, critical losses in efficiency only occur at high discharge temperature conditions, as in the three conditions evaluated at 70°C of condensation temperature. It should be mentioned that the condition of high-pressure ratio 5.8 with a condensing temperature of 50 ° C does not seem to have a difference in efficiency, although this seems to be an atypical result for the compressor with low oil level as the other points at this condensation temperature also have a lower efficiency with low oil level, without being so critical.

The drop in efficiency at high compressor ratios is due to the fact that a scroll compressor has an optimum pressure ratio determined by the built-in volume ratio. When the external conditions are outside these adapted conditions, efficiency losses occur; when the external pressure ratio is higher, under-compression occurs, leakage may occur, and extra work is needed to take the refrigerant to the necessary conditions [2]. On the other hand, the reduction of the compressor speed reduces the OCR, and the oil level also affects the amount of oil discharged and, therefore, the OCR [3]. Besides, a high discharge temperature reduces the viscosity of the oil, so together, a lower oil level and low compressor speed will greatly affect the amount of oil flowing in the system, increasing leakage and strongly impacting the volumetric efficiency, as shown above.

3.2. Oil temperature comparison

Figure 4, compares oil temperature (left) and discharge temperature (right) for the conditions evaluated and the two oil levels tested.

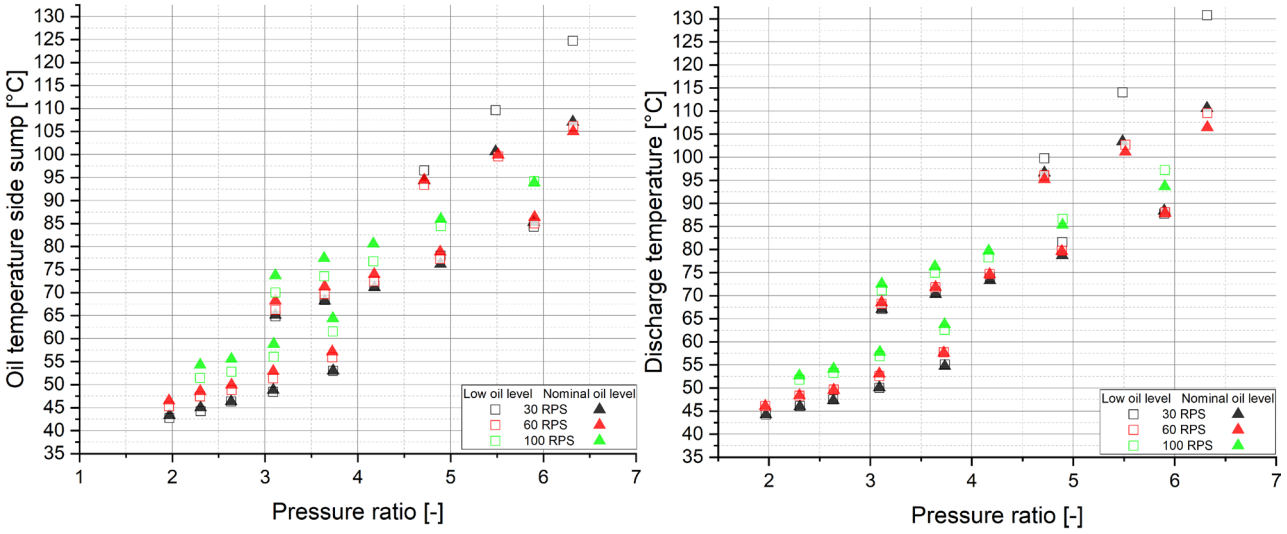

Figure 4. Oil temperature (left) and Discharge temperature (right) comparison

It can be seen that the three levels correspond to the three condensation temperatures evaluated, 30, 50, and 70 °C, to which the discharge temperature is mainly related. For each condensing temperature, an increase in the discharge temperature seems to be influenced by the increase in the pressure ratio and compressor speed. On the other hand, the oil temperature presents the same behavior and does not differ greatly from the discharge temperature, so they appear to be closely related, with the discharge temperature being the main parameter determining the oil temperature.

Regarding the low oil level cases, we see that in the conditions of 70 ° C condensing temperature, there is a significant increase in the discharge and oil temperature. This is probably because of the previous problems

discussed in the performance: low oil flow, increased leakage, and increased work of the compressor, which causes the heat losses to increase, increasing the discharge temperature and, thus, the oil temperature.

It should be mentioned that, at least for most of the conditions evaluated, it is not possible to detect that a low oil level exists until high condensing temperature and low compressor speed conditions are encountered since the discharge temperature does not seem to be affected by the oil level in conditions of high to medium rpm and low-pressure ratios

4. CONCLUSIONS

The present study evaluated two different oil levels for different conditions, and their performance and oil temperature were compared. The following conclusions were obtained:

- With a low oil level, the compressor can operate reliably without critical efficiency losses until demanding operating conditions are reached.
- Under high condensing temperature, high-pressure ratio, and low compressor speeds, the compressor and volumetric efficiency are drastically affected.
- The oil temperature is primarily related to the discharge temperature and is affected by the pressure ratio and compressor speed.

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