VIRTUAL SENSOR OF INSUFFICIENT LUBRICATION IN VARIABLE SPEED COMPRESSORS

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Abstract: The ability to modulate the compressor's speed and adapt the capacity to the load has permitted to decrease the annual energy consumption in many applications. However, in the compressor, having the correct lubrication at high speeds usually imply having insufficient lubrication at low speeds. This fact has to be considered by manufacturers as it limits the speed range of the compressor.

In this study, a methodology to establish the working limit of a compressor is proposed. It is based on the specific consumption surface of the compressor and no oil circulation measurements are required. A compressor working between 6600 and 900rpm with propane and POE oil has been used to test the proposed methodology. The results show that lubricating issues in this compressor start at 1800rpm and rise as speed decreases.

Keywords: Oil, lubrication, variable speed compressor, virtual sensor

1. INTRODUCTION

Oil is necessary for most heat pump systems to ensure the seal of the compression chamber and to lubricate the moving parts inside the compressor [1]. Consequently, the selection and management of the oil play an essential role in the design of a heat pump. In single-speed compressors, the main problem is finding the correct viscosity and solubility in the operating range [2]. However, in a variable speed compressor, the speed also has to be considered as it is the rotating shaft the responsible for pumping the oil to the critical spots [3].

Consequently, designers must ensure that oil is correctly pumped even when the compressor is running at minimum speeds [4]. This problem with insufficient lubrication typically limits the low speed limit of a variable speed compressor as a lack of lubrication wears the moving parts and significantly reduces the device's lifetime. However, detecting insufficient lubrication in a compressor can be difficult as no direct measurements can be carried out.

In previous publications [5], the effect of the rotation speed on the oil massflow scaping from the compressorwas studied. The results (which can be seen in Figure 1) suggested that the oil massflow scapping the compressor is reduced at low speeds. These results are indirect measurements but can give an idea of how much oil is being pumped into the key points of the compressor chamber.

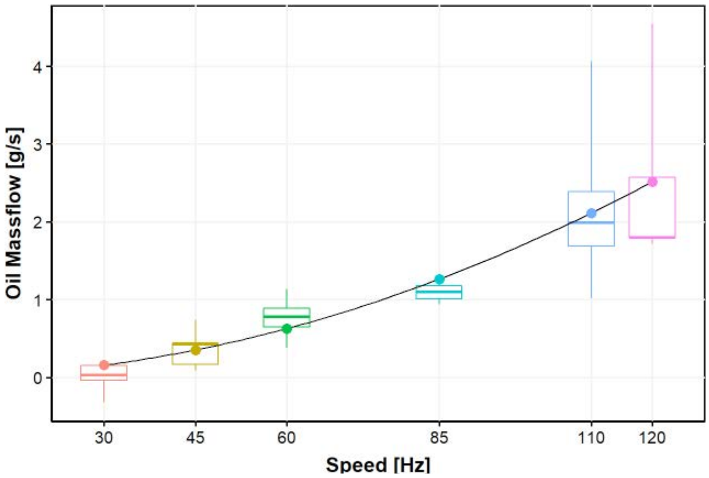

Figure 1. Evolution of oil massflow with the compressor speed

The purpose of this study is to propose a methodology to detect conditions with a lack of lubrication in a variable speed scroll compressor working with R290 and POE68 lubricant. In order to sense low lubrication conditions, an indirect measurement based on the specific power consumption has been used.

2. METHODOLOGY

A calorimetric test bench designed to satisfy the Standard EN13771 [6] has been used to obtain experimentaldata (a representation of it can be seen in Figure 2). The sensors used and their uncertainty are detailed in a previous publication [5].

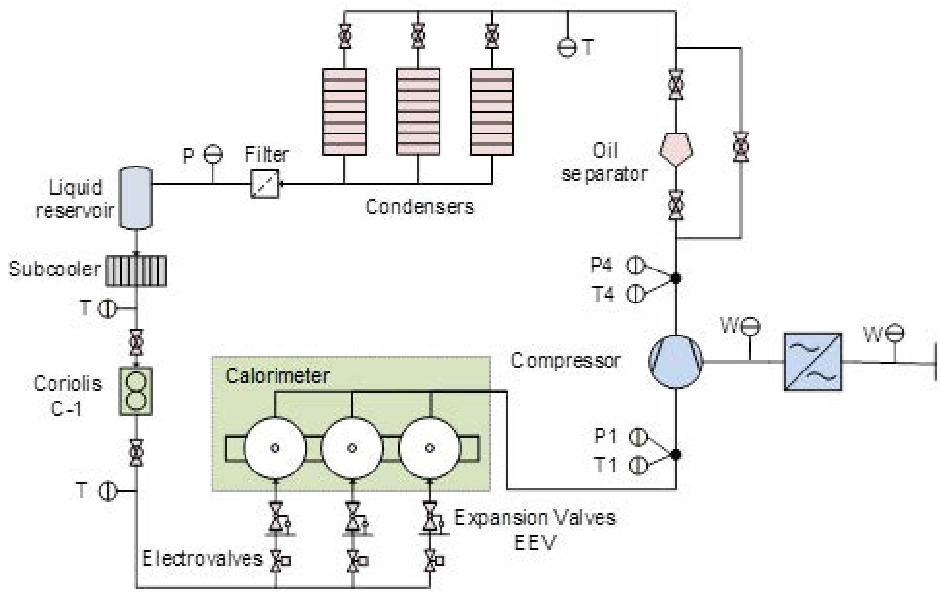

Figure 2. Calorimetric test bench

The compressor was tested in all its working range of speed (900 to 6600 rpm) and Condensing and Evaporating Temperature (20 to 70 ºC and -30 to 25 ºC respectively). In Figure 3 the envelope and the main tested conditions are displayed. This testing pattern was repeated at different speeds to have a complete performance map.

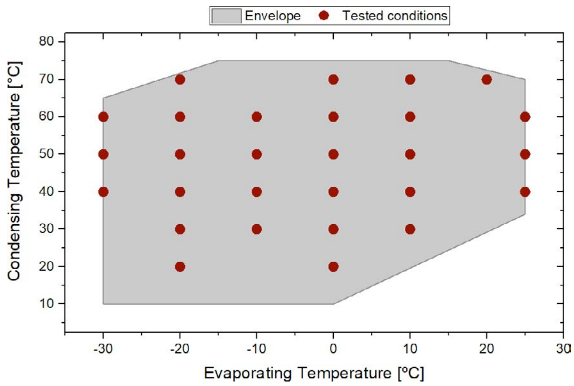

Figure 3. Compressor's envelope and main tested conditions

The compressor test bench can accurately control the test conditions through PID adjustments and records temperature and pressure conditions in the representative points of the cycle. Additionally, it measures the mass flow ($\dot{m}$) and the consumption of the compressor ($\dot{W}_c$). Remark that, in order to measure $\dot{W}_c$, a power meter was placed between the variable frequency drive and the compressor itself so the losses in the drive arenot included in the result.

In order to detect low lubrication conditions, the evolution of the specific consumption $\dot{W}_{esp}$ was studied (Eq.1). This magnitude was chosen as it considers both consequences of a lack of lubrication; an increase of consumption due to friction and a decrease of mass flow due to leakages in the compression chamber. Additionally, analysing $\dot{W}_{esp}$ is preferred as it reduces the influence of the speed in the analysis, consequentlyan increase of the specific consumption at low speeds would imply a problem with lubrication.

$$\dot{W}_{esp} = \dot{W}_c / \dot{m} \tag{1}$$

At first, speeds up to 1800rpm were tested to know the compressor's performance without lubricating problems. However, even at 1800 rpm, a decrease in $\dot{W}_{esp}$ was observed at low evaporating pressures and high condensing pressures. Once the nominal performance was studied, additional tests at 1500 rpm and 900 rpm were carried out at 50°C condensing temperature and different evaporating temperatures to check if the $\dot{W}_{esp}$was further increased.

3. RESULTS

In Figure 4, a 3D representation of the consumption and the mass flow as a function of Tevap, Tcond andspeed is shown.

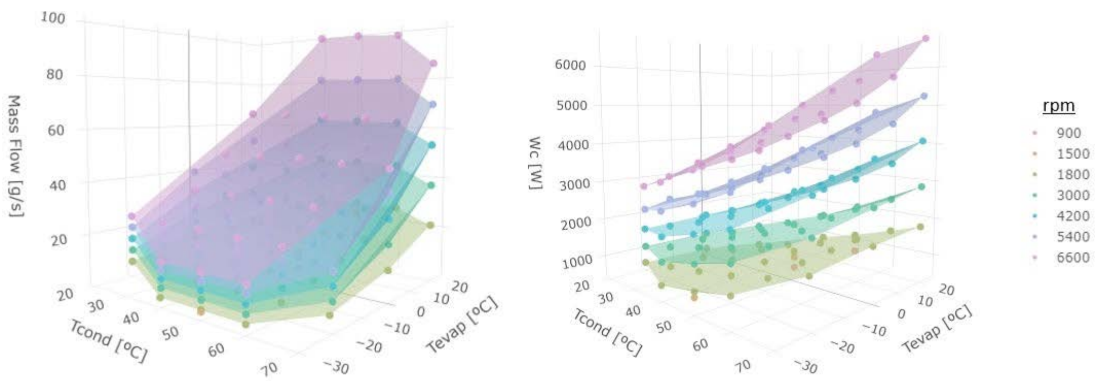

Figure 4. Experimental Mass flow(left) and Consumption (right) as a function of Tcond, Tevap and Speed

As it can be seen $\dot{W}_c$ and $\dot{m}$ depends strongly on speed so the effect of lubrication can not be checked. In Figure 5, the same plot is provided but with the specific consumption ($\dot{W}_{esp}$) instead.

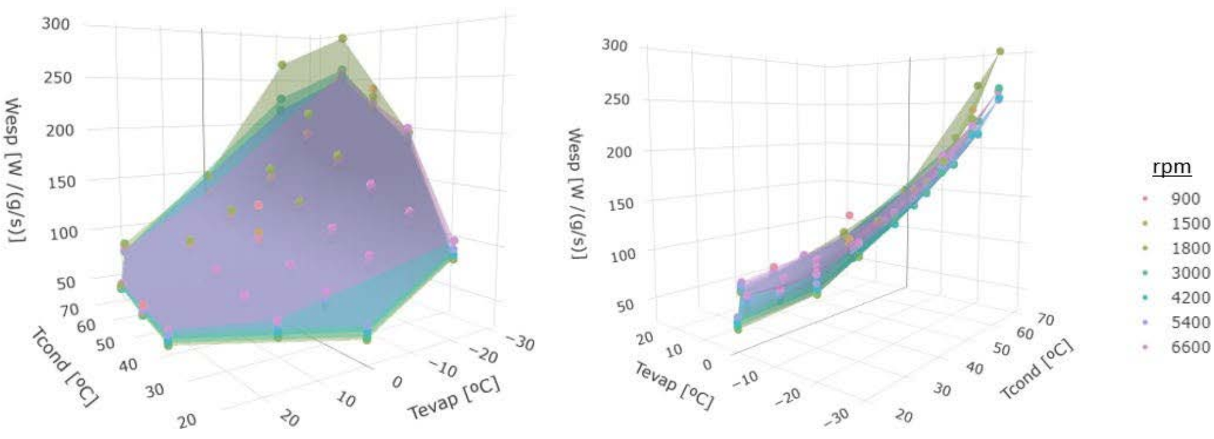

Figure 5. 3D plot of Wesp as a function of Tcond, Tevap and speed. From two different perspectives

In this case the results, as previously mentioned, show a low dependence on speed and converge into a 3D surface. However, it can be noticed that, when the speed reaches 1800rpm, the surface starts detaching at low evaporating and high condensing temperatures (high-pressure ratios).

To check if this behaviour was consistent even at lower speeds additional test were carried out at 50ºC condensing temperature and low speeds of 1500 and 900 Hz. The results are shown in Figure 6. It represents the evolution of $\dot{W}_{esp}$ with Tevap and speed (keeping the condensing temperature at 50ºC). It consists of a 2Dslice of the 3D graph in Figure 4.

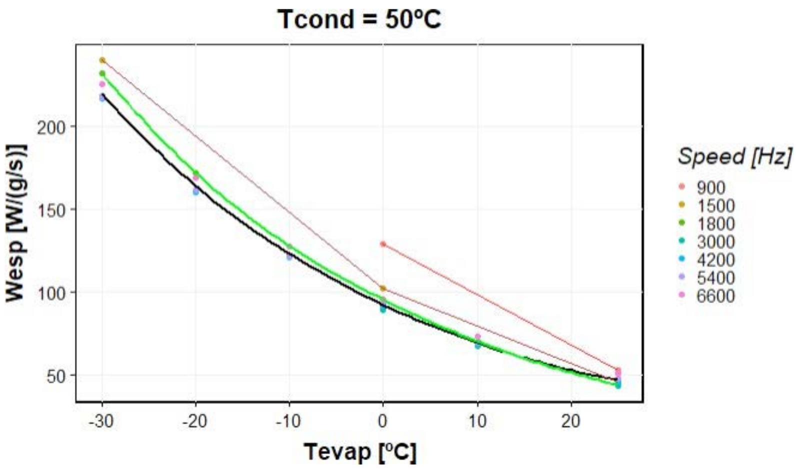

Figure 6. Evolution of Wesp with Tevap and speed at fixed Tcond

It is confirmed that the experimental results with speeds higher than 1800rpm converge. A solid black line represents this convergence. In this graph, it can be checked more clearly how $\dot{W}_{esp}$ detaches at low Tevap at 1800 rpm. If the speed is further decreased, it can be seen that the detachment is more significant and starts at higher Tevap.

It is also noticeable an increase of $\dot{W}_{esp}$ at 6600 rpm (high speeds), the magnitude of the increase is less significant than the increase at very low speeds but clearly detaches out of the nominal values.

The highest increase in specific consumption was a 40 % increase and was found at Tevap = 0 ºC and 900 rpm.

4. CONCLUSION

The study results show that for variable speed scroll compressor $\dot{W}_{esp}$ increased at low speeds. The main hypothesis is that this increase is due to a lack of lubrication. It is known that insufficient lubrication can lead to a diminution in the compressor's lifetime. Consequently, this approach could be used to define the speed range of a variable speed compressor not allowing the compressor to work at low speeds and avoid low lubricating conditions.

Additionally, an increase in $\dot{W}_{esp}$ at high speeds was observed. This behaviour will be analysed in future studies but could be produced by a increase of friction losses at high speeds.

5. ACKNOWLEDGMENT

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