ANÁLISIS DE UNA METODOLOGÍA ALTERNATIVA PARA REALIZAR MEDIDAS EN TIEMPO REAL DE LA TASA DE CIRCULACIÓN DE ACEITE EN UNA INSTALACIÓN DE REFRIGERACIÓN

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RESUMEN

En un sistema de refrigeración, los compresores toman el refrigerante a baja presión y lo bombean hacia el condensador a una presión más elevada. Sin embargo en su proceso de operación no sólo bombea el refrigerante, parte del aceite utilizado en la lubricación del compresor también se bombea al resto del sistema. La magnitud básica utilizada para caracterizar la cantidad de aceite bombeado se conoce como tasa de circulación de aceite (TCA) y representan la fracción de aceite sobre el flujo de masa total de aceite más refrigerante.

TCA es una variable importante a determinar en la caracterización de un compresor. Puede dar información acerca de problemas de lubricación del compresor y también desde el punto de vista de la operación de la instalación, valores demasiado altos de esta magnitud deben ser evitados. Sin embargo, hasta ahora no existe una metodología precisa para medir TCA que no incluya desventajas importantes como necesitar una gran cantidad de tiempo, no ser en tiempo real, costosa, o requiera una calibración muy precisa in situ de los dispositivos de medida.

En este trabajo, se analiza una metodología para medir TCA indicando las principales fuentes de error implicadas. La metodología consiste en instalar un medidor de flujo másico tipo Coriolis en la línea de retorno de aceite entre el separador de aceite de la instalación y el compresor. Este sensor mide el flujo de aceite desde el separador de aceite al compresor y posteriormente se relaciona esta medida con la TCA a través del sistema.

Los resultados se han comparado sistemáticamente con la metodología propuesta en ASHRAE Standard ANSI 1994 [1] en varias condiciones y con varios diseños de compresores y el grado de precisión de esta metodología se ha determinado.

Palabras clave: Lubricación, Compresor, Aceite.

1.- Introduction

One of the most important elements in refrigeration and air-conditioning vapour compression systems is the oil, since it influences the performance and reliability of the compressor as well as the operation of the cycle. The main functions of the oil are lubricating the mechanical moving elements, sealing the compression chambers, and removing the heat from the hottest parts of compressor. As is pointed out by [2], a consequence of performing these functions is that a certain amount of oil is discharged with refrigerant from the compressor, by forming an equilibrium mixture, some other is simply dragged as a result of very high refrigerant vapour velocity at the compressor discharge.

This secondary effect is undesired as it increases the pressure drops in heat exchangers, modifies the thermodynamic equilibrium and thermodynamic properties of the refrigerant [3]. It also penalizes the heat transfer and in some cases with a bad oil return it could result in lubrication problems and the failure of the compressor [4].

The evaluation of the OCR, therefore is very important to improve cycle performance and to ensure the reliability of the system. Up to now there is no good method to determine OCRwith enough simplicity and accuracy needed. Most of the techniques are very time consuming, expensive and require a very refined calibration process, or even the knowledge of mixture property data, not always available in the open literature, as mentioned by [5]. Therefore the development of a new methodology which allows the performance of this measurements being cost effective, no time consuming (even being able to have an OCR value in real time) and easy to implement will imply a significant advance on the field.

In the literature there are two general points of view to classify the methods for assessing the OCR: sample-removal methods, and in-situ measurement methods. In the last classification there are two additional sub-categories: methods based in the measurement of single phase liquid mixtures, and methods based in the gas-oil separation.

The most general technique used to evaluate the OCR is by the direct weight measurement method ASHRAE [1], which consists in the measurement of the weight percentage of oil in an oil/refrigerant mixture sample. As noted [6] and [7], there are other sampling methods like liquid chromatography, infrared spectrometry, or methods based on flame ionisation. Nevertheless, these methods as well as the weighting technique, are time-consuming and reduce the amount of refrigerant in the cycle and oil in the compressor, since they requires relatively large samples, with the additional inconvenience of not be a real time measurement techniques. In addition, a representative sample of the mixture can only be withdrawn when conditions in liquid line are steady. As a result, these methods are useless for the investigation of transient oil circulation.

Alternative methods for the extraction of samples were studied in depth by [8], showing a complete report of oil-refrigerant mixtures properties that could be measured in real time to infer the oil concentration in the liquid line of a refrigeration system. [9] shown also, a good review of the sensors and principles used to evaluate the OCR by means of real-time measurement techniques. Among the properties and sensors of major interest at present are found: viscosity sensors, acoustic velocity, density variation, absorption of light or dielectric constant and refractive index.

The techniques commented above are mainly implemented in the liquid line of refrigeration systems, and their success largely depends on two principal factors: Firstly, the property must vary significantly with changes in oil concentration, and secondly the method must have an accurate means of measuring the property in a flow stream.

The aim of this study has been evaluate the viability of the use of an alternative online method for the OCR evaluation. The technique proposed in this paper consists in the use of a technique classified as gas-oil separating method, it requires an oil separator mounted in the compressor discharge line.The advantages of this methodology are: it is a real time measurement; it can be used in systems with low refrigerant charge, or even without liquid line (gas cycle test stand for reliability studies).

In order to validate the results obtained from the oil separating method, results were analysed and also compared with the results obtained using the standard sampling weight method ASHRAE, and a shortcut industrial method based in the density variation of the mixture.

2.- Experimental setup and evaluation procedures

The experimental work was conducted using the calorimeter test rig shown in figure 1 (left). The test rig has been provided with several PID control loops (compressor inlet and outlet pressures, and superheat control), which allow a precise adjustment of the refrigerant conditions at compressor inlet (evaporating temperature and superheat) and outlet (condensing temperature). The rig is fully automated, and designed to work in steady state conditions for long time periods. Table 1 summarizes the most relevant features of the transducers used in the test rig.

Table 1. Specifications of the measuring sensors

Sensor	***Type***	***Range***	**Uncertainty**
Refrigerant discharge pressure	Rosemount 2088	*0 to30 bar*	±0.10%
Refrigerant suction pressure	Rosemount 3051	*0 to 10 bar*	±0.065%
Refrigerant inlet/outlet Temperatures	PT100 DIN 1/10	*-220 to 800ºC*	± 0.1K
Refrigerant Mass flow rate	ELITE CMF 025	*0 to 250 g/s*	±0.10%
Oil mass flow rate	ELITE CMF 025	*0 to 10 g/s*	±0.10%
Oil temperature	Type T thermocouples	*-270 to 400 ºC*	±0.5 K
Oil pressure	Rosemount 3051	*0 to 25 bar*	±0.065%

Three methods were used and systematically compared in order to evaluate the OCR in test facility shown in figure 1. The first method used was the standard ASHRAE procedure (1996), for the measurement of proportion of lubricant in liquid refrigerant. The second one was the method based on the variation of the density of the oil/refrigerant mixture, by means of the use of a Coriolis density-mass flow meter placed in the liquid line of the system. The last one was an alternative gas-oil separating method, in which the oil mass flow rate discharged from the compressor was directly measured and correlated with the total refrigerant mass flow rate circulating through the system.

The gas-oil separating methodology here proposed is similar to that used by [10], based on the use of an oil separator mounted in the compressor discharge line. However, in the present study the oil separator was equipped with a mass flow meter and a set of valves capable of regulating the flow rate of oil through the oil return line. The purpose of regulate the oil flow is to get an homogenous and uniform flow of oil through the mass flow meter, avoiding the presence of a two-phase oil/ refrigerant mixture flow.

A variable speed scroll compressor with a displacement of 88.4 cm^3/rev was tested in order to evaluate the OCR at different working frequencies. Tests were performed using propane as refrigerant, and an ISO VG 68 POE oil as lubricant, which has a density of 984.97 kg/m^3 at 15.6ºC and a viscosity of 10.9 cSt at 100ºC.

The tests were carried out for steady state conditions with a constant evaporating temperature of 15ºC, a constant condensing temperature of 50ºC and a superheat of 10K. In the compressor, three different frequencies were adjusted in order to evaluate and compare the oil circulation rate under different refrigerant velocities (30Hz, 60Hz and 90Hz).

Data reduction was performed considering that fluid circulating in the system is pure refrigerant (oil separating method): tests with oil separator; and by taking into account the oil presence in the circuit (ASHRAE method and density variation method): tests without oil separator.

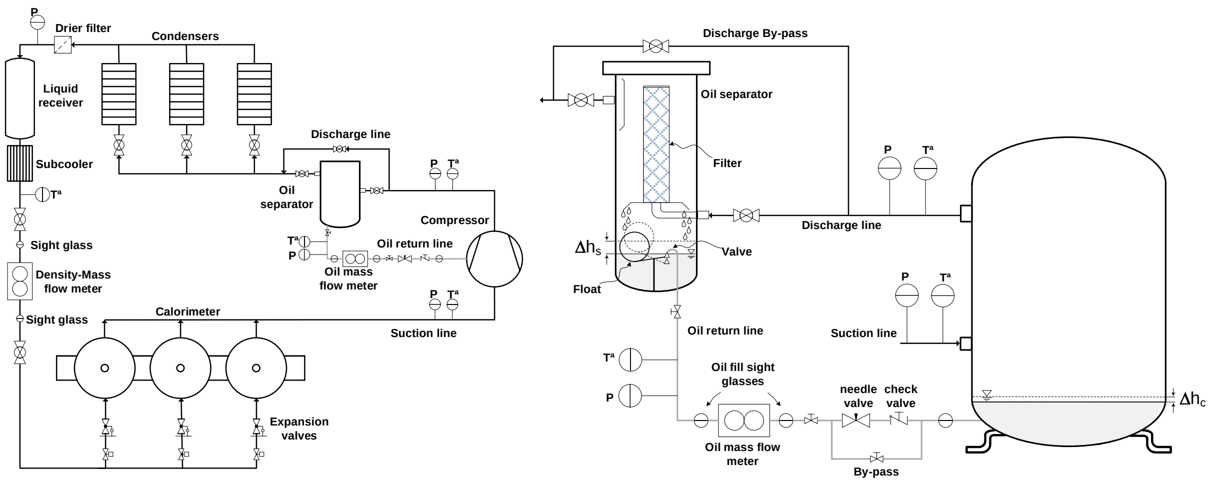

Figure 1. Schematic diagram of the tests facility (left), and the oil retention loop used in the method proposed (right).

In order to study the feasibility of the oil separating method, a Coriolis mass flow meter was installed on the oil return line, just after the oil separator device, see figure 1(right). Additionally, this system was equipped with a needle valve that allowed the regulation of the oil mass flow back to the compressor crankcase and a check valve which prevents oil flow back to the mass flow meter, avoiding negative flows. The oil return line was also equipped with a pressure transducer and a set of temperature transducers in order to determine the thermodynamic properties of the oil/refrigerant mixture. The oil separator was properly insulated in order to minimize heat conduction and temperature change effects that could allow the increase of the solubility of refrigerant in oil by the condensation of refrigerant.

3.- Methods description

Oil separating method

The operation principle of the method proposed is to allow an extra filling of oil into the oil separator over a fixed period of time, by decreasing the drained oil velocity through the valves system placed in the oil return line. This additional quantity of oil retained in the oil separator corresponds to the amount of oil expelled by the compressor in this period of time.

An important characteristic of this method is that the system of valves does not interfere with the natural oil circulation rate of the compressor, because the oil separator simply stores the expelled quantities of oil temporarily, slowing its flow back to the compressor crankcase. This is done by means of a manual synchronization between the internal float valve of the oil separator and an external needle valve in the oil return line, allowing a cyclical process.

Figure 2 (left) shows a typical oil mass flow profile, measured with a Coriolis mass flow meter without using the needle valve. As can be seen, the values of mass flow of oil show a significant dispersion due to the action of the float valve, what makes it very difficult to evaluate the amount of oil passing through the separator.

In contrast, figure 2 (right) depicts the cycles expected from the method suggested, using a needle valve in the oil return line. From the figure 2 (right) it can be related both, the refrigerant and the oil mass flow rate along different intervals of the cycle. In the figure, $\dot{m}_{ref}$ represents the refrigerant mass flow rate pumped from the compressor to the system, $\dot{m}_{oil}$ represents the oil mass flow of oil that leaves the oil separator when the internal floating valve opens, it is related to the measurement intervalΔt_{v_open}.

Finally, the parameter $\overline{\dot{m}_{oil}}$ is the average of the mass flow of oil that has been expelled by the compressor in a cycle, and is defined as the oil mass flow rate $\dot{m}_{oil}$ multiplied by the ratio between the opening time of the floating valve$\Delta t_{v_open}$and the total time of the cycle $\Delta t_{filling}$.

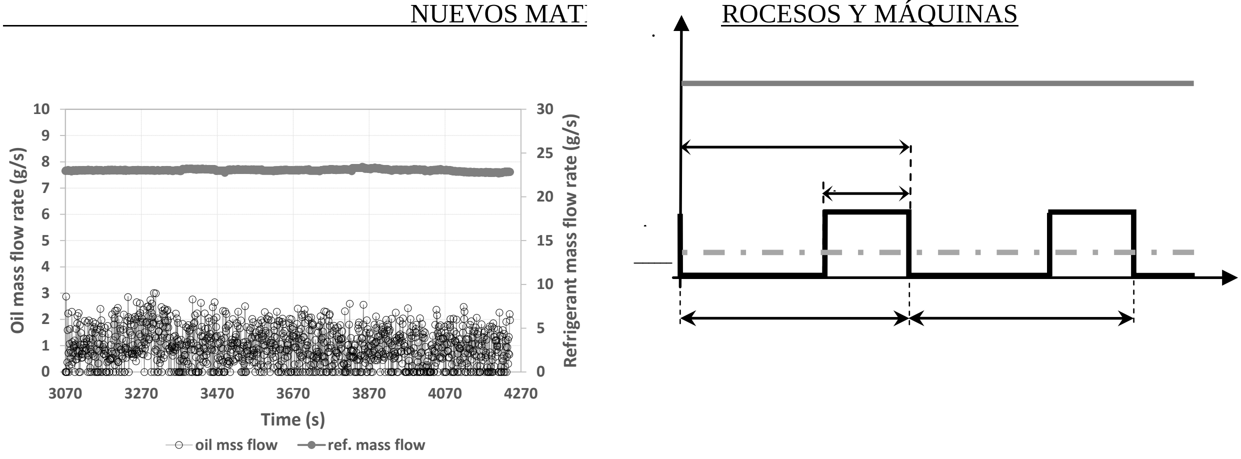

Figure 2. Oil mass flow profile without the needle valve in the oil return line (left), and the oil mass flow profile expected by the use of a needle valve (right).

The oil circulation rate can then be calculated as the ratio between the average of the oil mass flow rate and the total mass flow (refrigerant + oil) according the following expression:

$$OCR = \frac{m_{oil}}{m_{mix}} = \frac{\overline{\dot{m}_{oil}}}{\overline{\dot{m}_{oil}} + \dot{m}_{ref}} \qquad (1)$$

Standard ASHRAE method.

In this case a sample of mixture of refrigerant/oil of approximately 600g is taken in a cylinder from the liquid line of the calorimeter. Then the refrigerant is slowly evacuated from the cylinder and the remaining oil is weighted. The OCR is calculated as the ratio of the oil mass remaining in the cylinder and the total mass of the mixture.

The evaluation of the OCR was performed taking as a guide the ASHRAE (1996), for measurement of proportion of lubricant in liquid refrigerant. This method was adjusted to the particular conditions of the compressor characterization tests, and the features of the calorimeter test rig.

Among other things, the ASHRAE method establishes that the lubricant concentration shall be the arithmetic mean of at least three independent determinations differing less than 5%. The weight of lubricant in the sample is the difference between the weight of the cylinder with the remaining lubricant minus the weight of the cylinder.

Density-flow meter technique.

In order to have an additional reference to compare the results obtained from the oil separating method and the standard weight measurement method, it was applied a density based method following the guidelines proposed by [11] and [12]. This method is based on the evaluation of the OCR by means of the density of the mixture and an ideal mixing law for an ideal density, according (ASHRAE, 1994).

As is pointed out by [7], the law of the mixture most commonly used to calculate density assumes that the total volume is strictly equal to the sum of the volumes of each of the two components:

$$\frac{1}{\rho_{mix}} = \frac{OCR}{\rho_{oil}} + \frac{1-OCR}{\rho_{ref}} \qquad (2)$$

Solving this expression, the OCR is calculated as follows:

$$OCR = \frac{(\rho_{oil}/\rho_{mix})(\rho_{ref}-\rho_{mix})}{(\rho_{ref}-\rho_{oil})} \qquad (3)$$

The refrigerant density is calculated by REFPROP 9. The lubricating oil density is calculated using a method adapted from [13], it can be estimated from the following equation for lubricating oils:

$$\rho_{oil} = \rho_{man}\left[\frac{T_{crit}-T}{T_{crit}-(T_{man}+273.15)}\right]^{0.29} \quad (4)$$

where ρ_{man} is the oil density at the temperature provided by the manufacturer T_{man}, T_{crit} is the critical temperature of the oil (assume equal to 760K for all oils as an approximation), T is the measured temperature (K).

Results

As a result of the tests performed at different working frequencies, the compressor showed different values of oil circulation rate. Figures 3 to 5 illustrate the cycles observed at 30Hz, 60Hz and 85Hz.

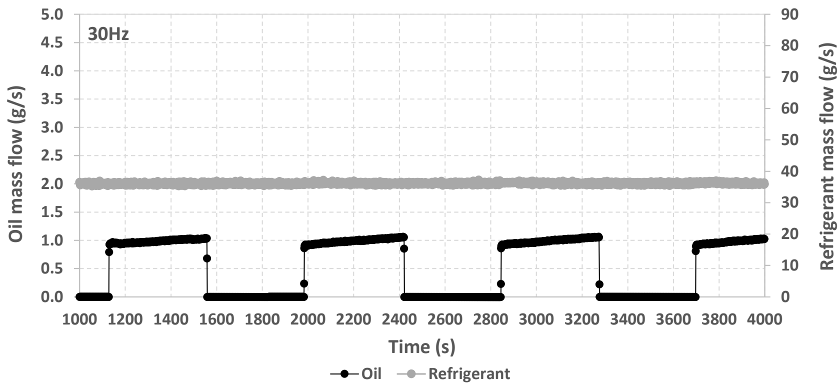

Figure 3. Oil mass flow profile measure at 30 Hz.

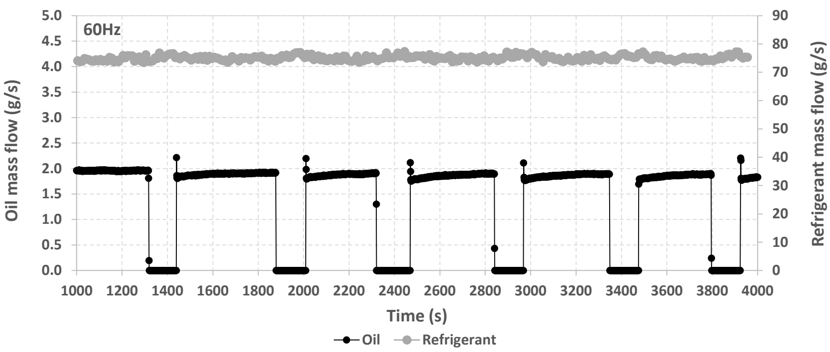

Figure 4. Oil mass flow profile measured at 60Hz

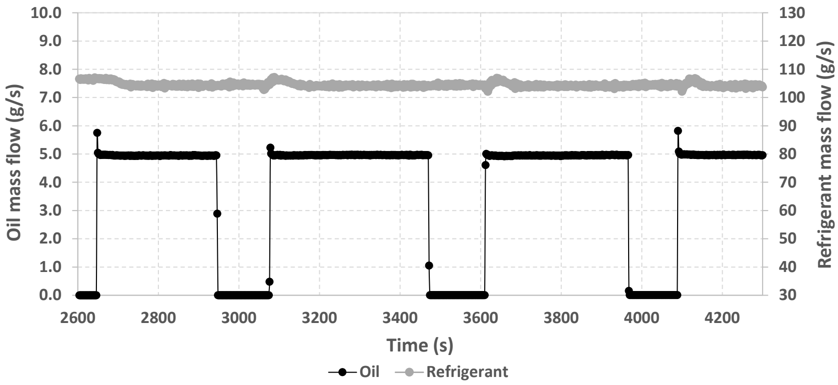

Figure 5. Oil mass flow profile measured at 85Hz

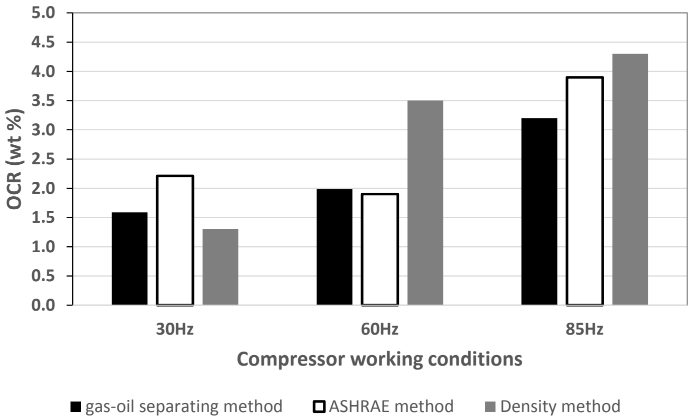

Figure 6. Oil circulation rate obtained from the three different methods compared

Table 2Experimental results comparing three different methods

Test	Freq. (Hz)	$\dot{m}_{ref}$ (g/s)	$\overline{\dot{m}_{oil}}$ (g/s)	OCR ASHRAE (wt %)	OCR Oil separation (wt %)	OCR density (wt %)
4 with oil separator	30	36.15	0.50	-	1.6	-
3 without oil separator	30	36.33	-	2.2	-	1.3
1 with oil separator	60	74.91	1.37	-	2.0	-
2 without oil separator	60	76.49	-	1.9	-	3.5
5 with oil separator	85	107.11	0.47	-	0.4	-
6 without oil separator	85	107.39	-	4.1	-	4.3

Table 3 Experimental results comparing three different methods

Test	Freq. (Hz)	P_{dis} (bar)	P_{suc} (bar)	T_{dis} (ºC)	T_{suc} (ºC)	P_{oil} (bar)	T_{oil} (ºC)	ρ_{oil} (kg/m^3)	SC (K)	SH (K)
4 with oil separator	30	17.13	7.32	70.9	24.9	17.08	56.2	875.5	22.6	10.0
3 without oil separator	30	17.13	7.32	71.3	24.8	-	-	-	22.5	9.9
1 with oil separator	60	17.13	7.31	70.8	24.8	16.78	61.2	865.0	17.3	10.0
2 without oil separator	60	17.12	7.32	70.2	24.7	-	-	-	17.2	9.9
5 with oil separator	85	17.64	7.31	76.7	24.9	17.11	63.0	877.7	16.34	10.5
6 without oil separator	85	17.13	7.32	71.9	24.9	-	-	-	20.6	10

4.- Conclusions

In this study were compared three measurement methods of evaluating the oil circulating rate. From the results obtained it can be concluded that among the three methodologies, the density methods has shown the highest deviation as compared with the other two. The methodology proposed by ASHRAE and the gas-oil separating methods show quite similar values considering the intrinsically deviations of the process. More tests are required to validate the gas-oil separating method, but from the results obtained, it seems to be a promising methodology with the advantage of not requiring the extraction of refrigerants and allowing a continuous tracking of the oil circulation process.

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