International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

2004

Oil Content Measurement in the Liquid Line of Refrigeration Equipments with the Three Transducers Array Method

Yvon Goth
CETIM

Goth, Yvon, "Oil Content Measurement in the Liquid Line of Refrigeration Equipments with the Three Transducers Array Method" (2004). *International Refrigeration and Air Conditioning Conference.* Paper 635.
http://docs.lib.purdue.edu/iracc/635

OIL CONTENT MEASUREMENT IN THE LIQUID LINE OF REFRIGERATION EQUIPMENTS WITH THE THREE TRANSDUCERS ARRAY METHOD

Yvon GOTH

CETIM, 52 av. Felix Louat, BP 80067 – 60304 Senlis FRANCE
tel (33)3 44 67 34 54 fax (33)3 44 67 36 17
email : yvon.goth@cetim.fr

ABSTRACT

We present here an application of the in line measurement of the speed of sound in the refrigerant liquid, based on the three transducers array method.

This method consists in measuring the pressure fluctuations at three equidistant locations in the refrigeration line and deduce the speed of sound in the fluid. This measuring method, set at first to measure the pressure fluctuations in the gas flow at the exit of compressors, can be applied successfully to the measurement of the speed of sound in the liquid line.

The paper describes the experimental set-up, the signal processing method, and the results that have been obtained. Preliminary measurements show a high sensitivity to small variations of the oil fraction in the oil-refrigerant mixture. More test are requiered to estimated the overall precision of the method.

1. INTRODUCTION

In refrigeration equipments, a small amount of the compressor lubricating oil is carried out in the refrigeration loop by the refrigerant fluid. This oil can have a noticeable influence on the efficiency of the system and must be brought back to the compressor to avoid failure.

The knowledge of the oil content in the refrigerant fluid in line and in real time is then an important issue for manufacturers of refrigeration equipments.
Among the available methods, the ones that rely on the measurement of the speed of sound in the refrigerant-oil liquid mixture seems promising.

The speed of sound in the liquid refrigerants, in the conditions of pressure and temperature that can be met at the exit of the condensor or sub-cooler, varies in the range of 350m/s to 650 m/s, while the speed of sound in the lubricants for refrigeration varies in the range from 1100 to 1500 m/s. This difference is large enough to allow to detect small amount of oil in the liquid refrigerant by measuring the overall speed of sound in the mixture.

The speed of sound and the oil content in liquid refrigerant-lubricant mixture has been measured with success using the time transit of ultrasound waves (Navarro de Andrade & al, 1998). In a R22-Alkhyl Benzene mixture, they found that an oil content of 10% would increase the speed of sound by roughly 50 m/s.

We present here an application of the in line measurement of the speed of sound in the refrigerant liquid, based on the three transducers array method.
This method consists in measuring the pressure fluctuations at three equidistant locations in the refrigeration line and, by appropriate signal processing, deduce, among other parameters, the speed of sound in the fluid. This measuring method has been set at first to measure the acoustic properties of fluid flow in ducts (Seung-Ho, Jeong-Guon, 1998), and has been used in refrigeration to measure the pressure fluctuations in gas at the exit of the compressors.
It is shown here that it can be applied successfully to the measurement of the speed of sound in the liquid lines of refrigeration systems.

2. COMPUTATION OF THE SPEED OF SOUND

In the tubes of refrigeration systems, up to a frequency up to hundreds Hertz, the acoustic waves that are generated by the compressor travels as one dimensional plane waves.

In that conditions, the pressure pulsations field has the following form (in complex notation) :

$$P = ae^{-j\frac{2\pi fx}{c}} + be^{j\frac{2\pi fx}{c}} \tag{1}$$

where f is the frequency (Hz), c is the speed of sound (m/s), and x the axial distance along the tube (m).
The first term can be regarded as a wave travelling along the increasing x, and the second term as a wave travelling in the other direction.
In that formulation, we neglect the influence of the speed of the liquid, that is always small compared to the speed of sound. In gas pipes, we would have to take this parameter into account.

When measuring these pressure fluctuations with 3 equidistant pressure gauges, with the distance d between each gauge, we obtain, for each gauge numbered 1,2,3 :

$$\begin{aligned} P_1 &= ae^{j\frac{2\pi fd}{c}} + be^{-j\frac{2\pi fd}{c}} \\ P_2 &= a + b \\ P_3 &= ae^{-j\frac{2\pi fd}{c}} + be^{+j\frac{2\pi fd}{c}} \end{aligned} \tag{2}$$

that gives:

$$\frac{P_1 + P_3}{2P_2} = \cos(\frac{2\pi fd}{c}) \tag{3}$$

The unknown in equation (3) is the speed of sound, c, that is taken as the value that minimize the difference function E :

$$E = \sum_{i=1}^{n} \left(\frac{P_1 + P_3}{2P_2} - \cos(\frac{2\pi f_i d}{c}) \right)^2 \tag{5}$$

3. EXPERIMENTAL SETTINGS

The measurements of the speed of sound in a R410-POE oil mixture have been driven in the 45 kW refrigeration compressors test loop facility of CETIM(Figure 1).

A 3 pressure transducers array has been settled at the exit of the liquid subcooler, and a system of manifold allows to use or not the oil separator (Figure 2).

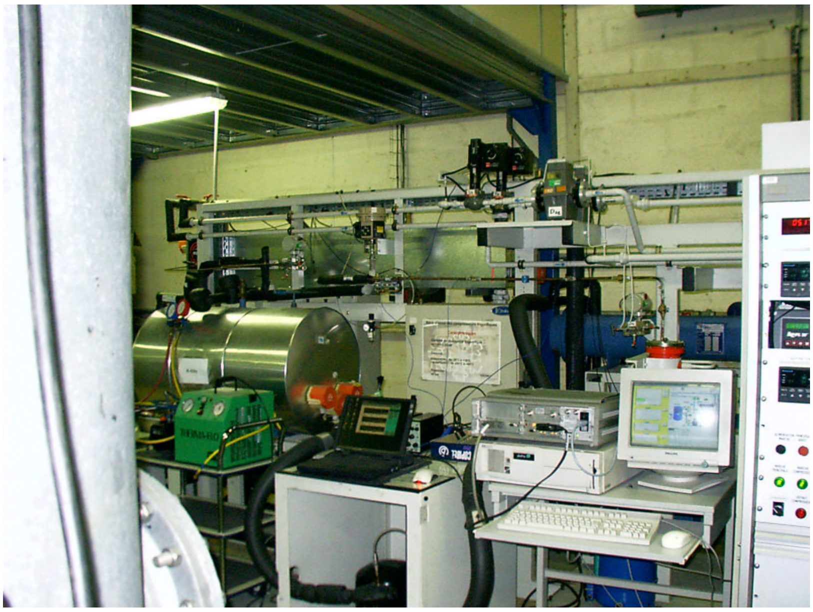

Figure 1- General view of the test loop and of the data acquisition system.

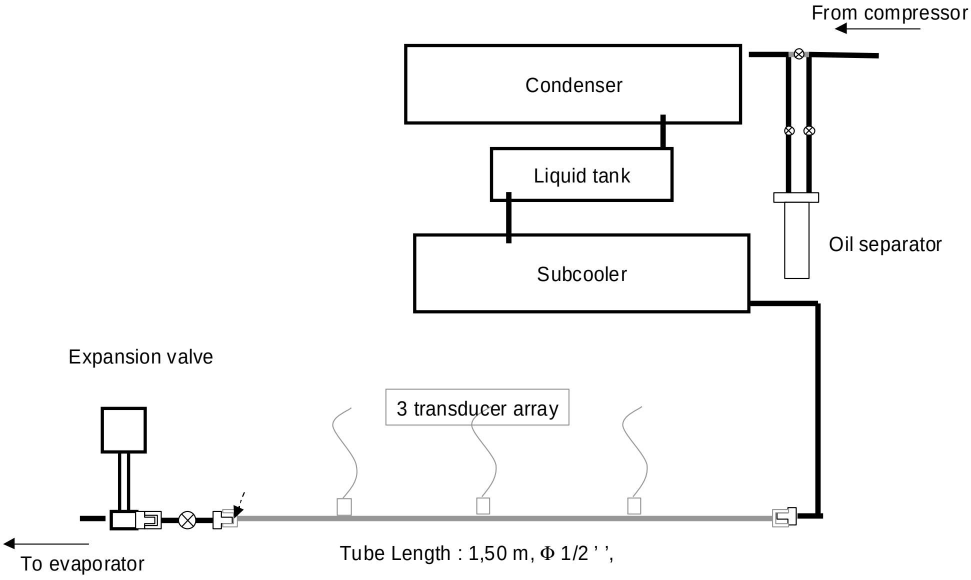

Figure 2- Disposition of the 3 transducer array.

The distance between the transducers is 510 mm.

The recorded data are :
- The flow, pressure and temperature of the liquid,
- The 3 power-spectrums and the2 cross-spectrums of pressure gauge 1 and 3 relative to the central gauge.

We used three Kistler 6031 piezo pressure gauges, connected to a HP 35650b Paragon system.
The power-spectrums and cross-spectrums of pressure fluctuations have been obtained by averaging of 64 data acquisitions, in the frequency range 40 Hz to 840 Hz.

4. RESULTS AND DISCUSSION

4.1 Data processing.

According to equation (3) the function fs given by

$$fs = \frac{P_{12} + P_{32}}{2P_{22}}$$

, where P12, P22, P32 are the cross-spectrums of the transducers 1,2,3, relative to the transducer 2, should varies as a cosine function of the frequency.

A typical example of the results that have been obtained is given in Figure 3. One can see that the theoretical cosine shape is only roughly approached.

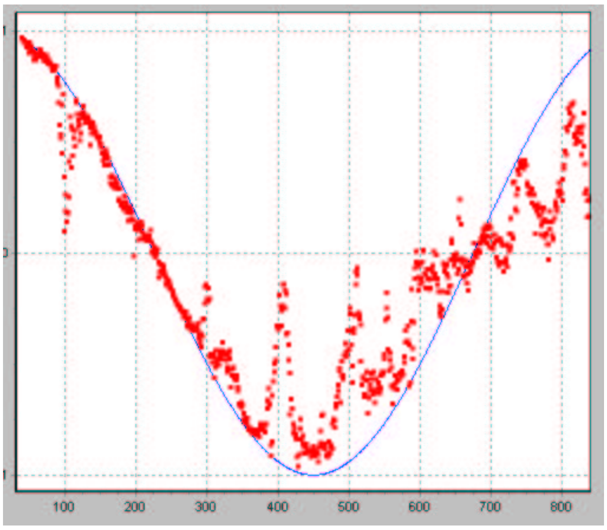

Figure 3– Example of fs in function of frequency for raw data's.

The analysis of the difference between the measured and theoretical function has shown that the ripples are due to a small offset of the zero of the reference transducer. With the appropriate correction, the ripple disappear. The dispersion of the distance between the experimental points and the theoretical curve was then checked against the coherence, and show that a minimal coherence of 0.5 was needed to get a small dispersion (Figure 4).

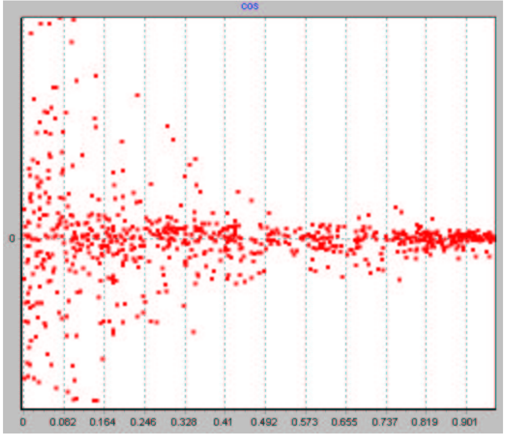

Figure 4- Dispersion against coherence.

Finally, with the offset correction, and taking into account only the data where the coherence was larger than 0.5, the curve obtained with the experimental points was "clean" enough to allow the computation of sound by minimization of the least square function given by equation (5) ,as shown in Figure 5.

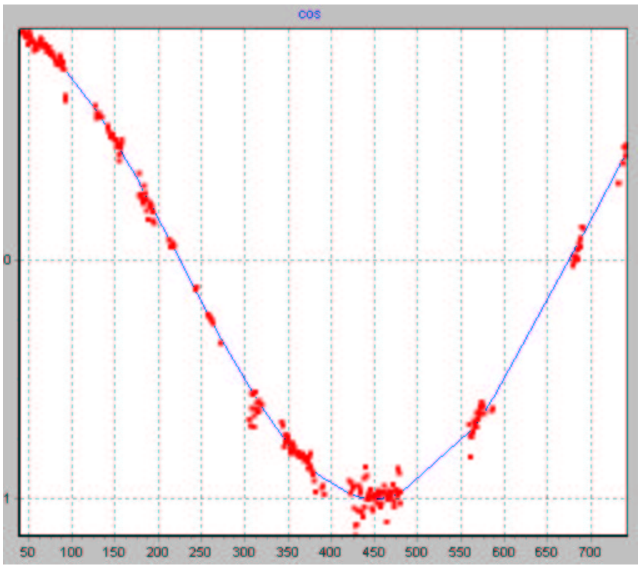

Figure 5 – Experimental and theoretical fs function, after cleaning of the datas.

4.1 Results and discussion.

Table 1 give the detail of the results that have been obtained.

This table gives also, for reference, the apparent speed of sound for the pure refrigerant in the tube. This value has been computed by using Refprop 6.0 for the refrigerant, and take into account the lowering effect of the tube wall, following equation (6)

$$c = \frac{1}{\sqrt{\frac{\rho D}{Ee} + \frac{1}{c_f^2}}} \qquad (6)$$

where cf is the speed of sound in the fluid alone, c the speed of sound of the fluid in the tube, ρ is the density of the refrigerant, D and e are the diameter and thickness of the tube wall, and E is the Young modulus of the wall. The difference between c and cf is here of the order of 1.5%.

The difference between the values coming from the measurements and the values for the pure fluid varies between -0.7% et +1.1%. (Figure 6).

One can see that the influence of the temperature on the speed of sound of the pure fluid is very important, so that any trial to measure the oil content by the way of the speed of sound in the mixture must rely on accurate measurement of the fluid temperature.

Figure 7 show the evolution of the difference between the experimental values of the speed of sound in the mixture and the value for the pure fluid, in function of the status of the oil separator during the test.

- The oil separator is switched on at 11h05, and the difference decreases at this moment.
- The oil separator is switched on at 11h34, and the difference increases a few minutes later.

Despite of the large data uncertainty linked to the low level of the phenomenon, one can see that there is a good correlation between the variations of the speed of sound computed in the mixture and the operations of the oil separator. It can be then deduced that, for a large part, the difference between the speed of sound in the mixture and in the pure fluid are due to the variations of the oil content in the mixture.

The amount of oil that the compressor used here put in the refrigerant is smaller than expected, and, even with no oil separator, is not enough to be able to make accurate calibration of the oil content by another way.
More experiments, based on a calibrated oil source that would allow to put a larger amount of oil in the circuit, are required to ascertain the relation between the speed of sound and the oil content.

Table 1 – Results

reference	Oil separator	T, °C	P, kPa	Adjusted speed of sound of the mixture, m/s	Computed speed of sound of the pure refrigerant, m/s(*)
h1	no	20,0	1670	476	464,2
h2	no	19,7	1760	472,5	470,3
h3	no	23,0	1800	451,5	451,3
h4	no	21,4	1780	460	460,5
h5	no	20,8	1780	466	464,1
h6	no	20,9	1810	465	464,0
sh1	yes	20,9	1790	464	463,7
sh2	yes	21,4	1825	461,5	461,2
sh3	yes	22,2	1880	461	457,3
sh4	yes	22,4	1850	455	455,7
hh1	no	21,5	1870	459,5	461,3
hh2	no	21,3	1870	461	462,4
hh3	no	21,2	1870	460	463,1
hh4	no	19,8	1710	470,5	468,9
hh5	no	19,3	1740	473	472,2
hh6	no	20,1	1830	472,5	468,9
hh7	no	21,7	1890	463,5	460,5
hh8	no	22,9	1900	458,5	453,5

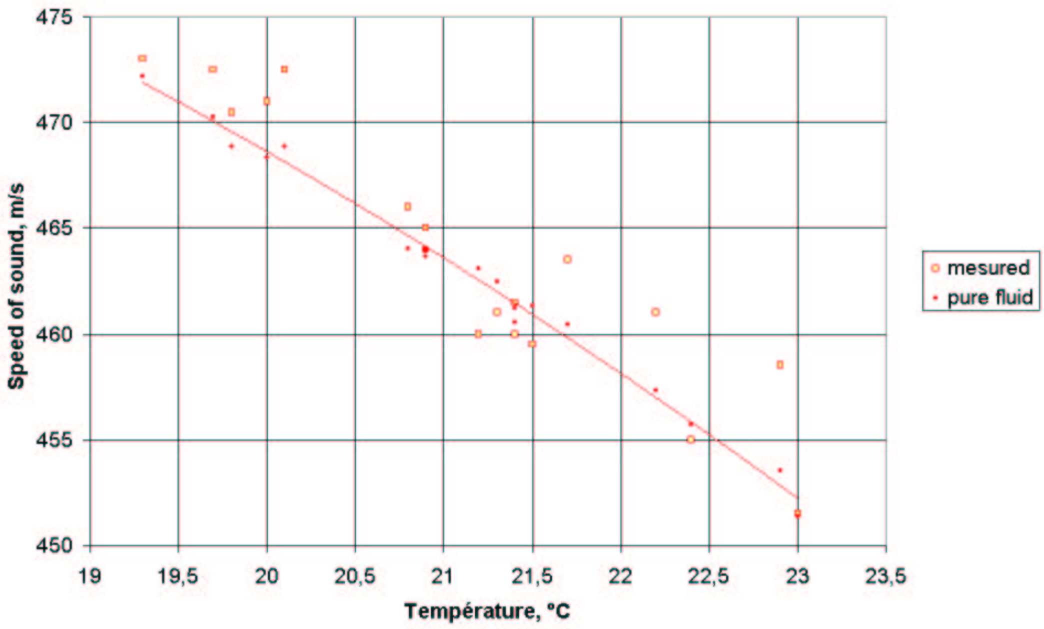

Figure 6- Speed of sound against temperature.

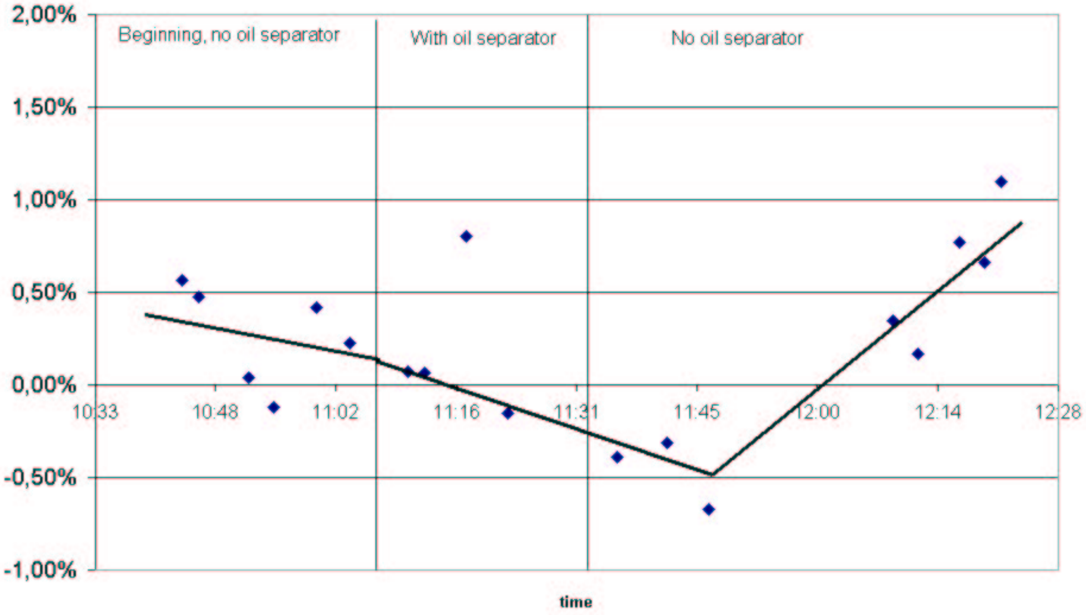

Figure 7 – Relative difference between the speed of sound in the mixture and the speed of sound of the pure fluid.

6. CONCLUSIONS

A new method for in line measurement of the oil content in refrigerants in the liquid part of refrigeration circuits is proposed.
This method relies on the use of the 3 transducer array technique to determine the speed of sound in the liquid.

The preliminary experiments have shown that, with adequate data processing, this method has a good sensitivity, as it allows to detect small variations (0.5%) of the oil content.

More test are required to evaluate the global precision of the method. As any method based on the measurement of the speed of sound in the liquid mixture, it will, anyway, be very sensitive to the temperature.

REFERENCES

Navarro de Andrade E., Skowron E., Goldschmidt V., Groll E., 1999, Oil Concentration in liquid refrigerants: in situ measurement, *Int. J. Refrig.*, vol. 22, p. 499-508.

Seung-Ho J., Jeong-Guon I., 1998, On the multiple microphone method for measuring in-duct acoustic properties in the presence of mean flow, *J. Acoust. Soc Am.*, vol. 103, march 1998, p. 1520-1526.