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AN EXPERIMENTAL STUDY OF DIAMOND NANOLUBRICANT IN A WATER-COOLED CHILLER

David F. Marcucci Pico
Ítalo Franco Guilherme
Enio Pedone Bandarra
Federal University of Uberlandia, Mechanical School. Uberlandia (MG), Brazil. Av. Joao Naves de Avila, 2121.
dmarcucci@ufu.br
italoengmec95@gmail.com
bandarra@ufu.br

Abstract. *This work conducted an experimental study on nanolubricant based on synthetic lubricant polyol ester (POE) oil and diamond nanoparticles in a refrigeration system. The thermo-physical properties of the pure lubricant and the nanolubricants were evaluated. Moreover, an experimental refrigeration bench was developed in order to evaluate the refrigeration capacity, the power consumption by the compressor, the coefficient of performance (COP), the discharge temperature of the compressor and, finally, the performance of the nanolubricants at the mass fractions of 0.0%, 0.1% and 0.5% of diamond nanoparticles. Tests were performed with HFC-410A and HFC-32 refrigerants maintaining the condensation temperature at 41 °C and varying the evaporation temperature and the input power frequency of the compressor, from -7 to 7 °C and from 45 to 60 Hz, respectively. According to the results of HFC-410A, it was possible to conclude that, with the use of nanolubricant, there was an increase in both the refrigeration capacity and the coefficient of performance. The discharge temperature of the compressor decreased. In relation to HFC-32, the use of nanolubricants under the evaluated conditions show slightly improvements in the refrigeration system in terms of cooling capacity and discharge temperature.*

Keywords: COP, Nanolubricant, Nanoparticle, COP, HFC-32, HFC-410A.

1. INTRODUCTION

Among the several alternatives found in the literature to improve cooling systems, in search of better efficiency and lower energy consumption, the use of nanoparticles as lubricant additives has been studied with the objective of increasing the thermo-physical and tribological properties of conventional lubricants, used in the compressors of different refrigeration systems. The dispersion of nanoparticles within a base fluid is referred to as nanofluid (Choi and Eastman, 1995) and more specifically, when the base fluid is a lubricating oil, it is called nanolubricant (Rasheed et al., 2016).

With respect to refrigeration systems, the application of nanoparticles can lead to a reduction in energy consumption by the compressor, as well as increase heat transfer due to its thermo-physical properties such as dynamic viscosity and thermal conductivity. Bi et al. (2008) found reductions of up to 26% in the energy consumption of a domestic refrigerator operating with HFC-134a and nanolubricants composed of mineral oil (MO) and TiO_2 nanoparticles. Using the same nanoparticle and oil, Hussen (2014) found a COP increase of 12% and a reduction of up to 13% in the power consumption by the compressor. Xing et al. (2014) found a maximum reduction in the power consumption of 4.5% and an increase in the COP of 6% when adding fullerenes (C_{60}) in a system operating with R-600a. Similarly, with the same refrigerant and system type, Lou et al. (2015), using graphite nanoparticles, found increases in cooling speed and a reduction of up to 4.6% in energy consumption. Recently, Sharif et al. (2017) found gains of up to 3.3% in refrigeration capacity and reductions in compressor-specific work in an automotive air conditioning system using SiO_2 nanoparticles. Additionally, they reported that at high concentrations the specific work of the compressor tends to be increased, which was also reported by Ohunakin et al. (2018). On the other hand, Fedele et al. (2014) and Wang et al. (2017) did not find significant gains in terms of the cooling capacity and the energy consumption of the system, when using nanoparticles of different compositions.

This work presents an experimental evaluation of the use of nanolubricants (diamond nanoparticles and POE oil) in a refrigeration system. Presenting the values obtained for dynamic viscosity and thermal conductivity of nanolubricants, as well as the results of refrigeration capacity, COP and compressor discharge temperature of the refrigeration system operating with pure lubricant and two different concentrations of nanolubricant. The system was charged with two different refrigerants, HFC-410A and HFC-32.

2. METHODOLOGY

The two-step method was used to produce the studied nanolubricant samples. The initial step is to get the ultra-fine dry powder nanoparticles from a synthesizing process and the subsequent one compares to the dispersion of nanoparticles in the base fluid at the desired concentration. For this, the diamond nanoparticles were obtained from the company Nanostructured & Amorphous Material, Inc., in powder, without any superficial treatment, with spherical morphology, diameter between 3 - 6 nm and purity above 97%. The ultrasonic process was used for the dispersion of the nanoparticles in the base fluid, and the samples were dispersed for about an hour, waiting until homogeneous dispersion was reached. To evaluate the effect of the concentration, two samples were produced in addition to the pure lubricant, with mass concentrations of 0.1% and 0.5%.

In accord to the thermo-physical properties, the dynamic viscosity of the samples was measured using an Anton Paar SVM 3000/G2 Stabinger viscometer with an accuracy of the 0.1% for the dynamic viscosity and 0.02 °C for the temperature. The measure range of the equipment goes from 0.2 to 20.000 mPa s, and finally, the viscosity was measured varying the temperature from 10 to 100 °C by steps of 10 °C. On other hand, the measurement of the thermal conductivity of the nanolubricants at different concentrations was measured in a range of temperature from 5 to 65 °C with the increment of 10 °C Was used the transient hot bridge method with a LINSEIS model THB-1 thermal conductivity meter, able to measure until 1W m^{-1} K^{-1} with an uncertainty better than 2% of the measured value. In addition, to control the temperature of the sample for each measurement, a MQBMP-01 water bath was used. More details about the measured of the nanolubricants thermo-physical properties can be found in Marcucci et al. (2017).

An experimental bench was created for the analysis of the refrigeration system working with nanolubricants. Figure 1 shows the schematic diagram of the experimental facility used in the present work.

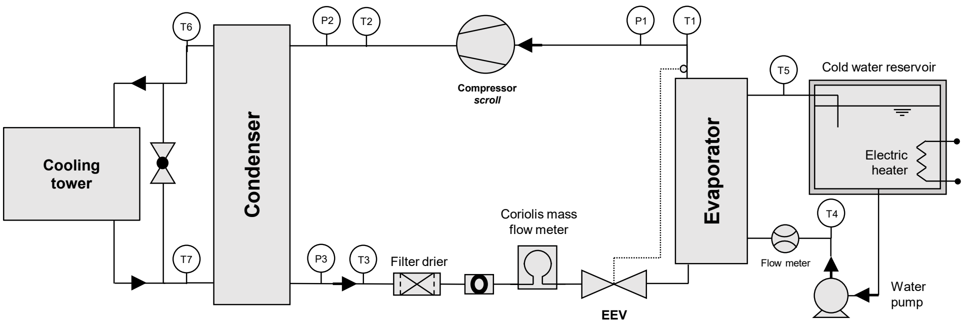

Figure 1. Schematic diagram of the experimental facility.

The experimental bench is composed by the refrigerant circuit, the cold water loop and the condensation water circuit. The refrigerant circuit is a basic refrigeration cycle that contains one compressor, two brazed plate heat exchangers (evaporator and condenser), one electronic expansion valve, one drying filter, one liquid sight glass and one Coriolis flow meter. While the cold water loop consists of a circulation pump, a turbine flow meter, a cold water reservoir and electrical heaters, which controls the temperature of the water at the evaporator inlet and is in charge of simulating the thermal load required for the operation of the refrigeration system. Lastly, the condensing water circuit consists of circulation pumps, a condenser and a cooling tower being responsible for rejecting the heat of the cooling system.

Some instruments were used to acquire pressure, temperature, power consumption by the compressor and refrigerant mass flow rate parameters, and the measuring points of the instruments used are shown in Fig. 1. System pressures were measured using piezoresistive pressure transducers, temperatures were measured using PT-100 type temperature sensors, power consumption was measured using a power analyzer, and the mass flow rate of the refrigeration system was measured using a Coriolis type mass flowmeter.

In addition to the nanoparticles' mass concentration variation, the rotation speed of the compressor ranged from 45 to 60 Hz and the evaporation temperature from -7 to 7 °C. All the tests were carried out in steady-state condition and the experimental data for HFC-410A can be found at Marcucci Pico et al. (2018).

3. RESULTS

Figure 2 shows the dynamic viscosity results of the base fluid and nanolubricants for the mass concentrations of 0.1% and 0.5%, evaluated over a temperature range of 10 to 100 °C. From this figure, it is possible to observe the reduction of dynamic viscosity with the increasing of the temperature. Increasing the temperature from 10 to 100 °C reduced the viscosity of the base fluid and nanolubricants by up to 96.5%.

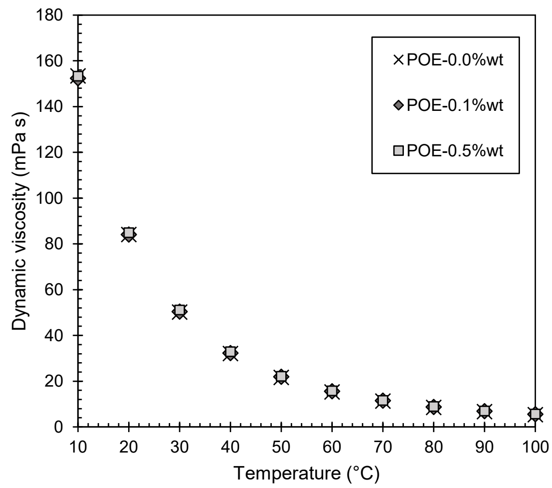

Figure 2. Dynamic viscosity as a function of temperature at different concentrations.

It can be observed that for both, the pure lubricant and the two diamond nanolubricant mass concentrations, the absolute values of dynamic viscosity were very similar. The results showed that for the lowest concentration evaluated and the temperature of 10 °C, the viscosity decreased by ~1%. This tendency of the dynamic viscosity of nanolubricants, to be lower than that of the base fluid at low concentrations and low temperatures, was reported by Almeida (2015) for refrigeration mineral oil nanolubricants and alumina nanoparticles.

Thermal conductivity of nanolubricants was measured over a temperature range of 5 to 65 °C, at concentrations of 0.0%, 0.1% and 0.5%, as can be seen in Fig. 3.

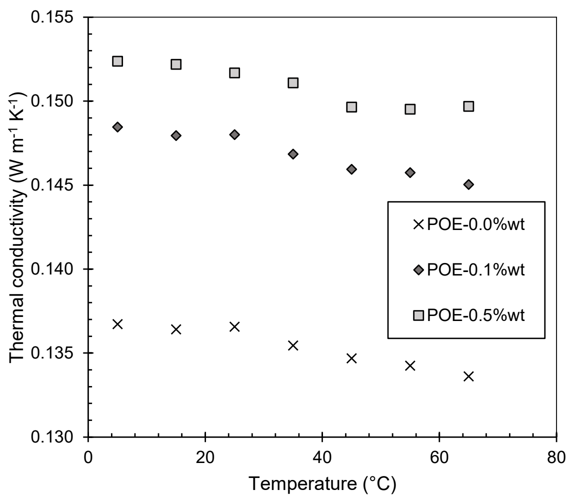

Figure 3. Thermal conductivity as a function of temperature at different concentrations.

It can be noted that as well as the pure lubricant, the nanolubricants presented reduction of the thermal conductivity with the increase of the temperature, this reduction is in accordance with the data reported by (Kedzierski et al., 2016), (Sousa, 2017) for POE oil and by (Sharif et al., 2016) for PAG refrigeration oil. It can also be observed that the thermal conductivity of nanolubricants tends to increase with increasing concentration, and that the relative gain due to concentration has been kept approximately constant with increasing temperature. Furthermore, it is possible to observe gains of 8% and 11% comparing to pure lubricant are observed for mass concentrations of 0.1% and 0.5%, respectively. Moreover, as the nanoparticles concentration increases relative gain tends to remain the same and the stability of the nanolubricant tends to worsen as the likelihood of the formation of nanoparticle agglomerates leading to decantation increases. Thus, the use of surfactants and improved production techniques is necessary to achieve more stable suspensions. In addition, as nanoparticle concentration increases, the viscosity of nanolubricant also increases, leading to higher energy consumption of the equipment. Therefore, there must be a compromise between nanoparticle concentration and the desired system gains.

Figure 4 shows the results obtained for the cooling capacity of the system operating with HFC-410A and HFC-32 and nanolubricants at different concentrations. Based on Fig. 4 (a) and Fig. 4 (b), the cooling capacity of the system operating with nanolubricants presented a tendency to increase in relation to the system operating with pure POE. In addition, when comparing both figures, it is noted that the increases in cooling capacity of the system, when compared to the system operating with pure lubricant under the same conditions, tended to be higher with increasing diamond concentration.

The maximum increase in this property found for HFC-410A at a concentration of 0.1% was 4.2%, evaporating at -7 °C and with a rotation of 45 Hz, whereas, at the concentration of 0.5%, the maximum increase was found to be ~7% under the same test conditions, -7 °C and 45 Hz. For HFC-32, at the concentration of 0.1%, a maximum increase of 4% in cooling capacity was found with the system evaporating at -7 °C and with the rotation frequency of 45 Hz. The mass concentration of 0.5% reached a maximum increase of 2% under the conditions of 1 °C and 45 Hz. Although some gains in this parameter of the system with HFC-32 were found for some conditions, mainly at low frequency and evaporation temperature, these were found in few operating conditions.

In relation to the power consumption by the compressor, it was possible to identify that there was no significant variation in this property, reaching maximum variations of 0.4% and 3.0% for HFC-410A and HFC-32, respectively. Similar results in which the compressor consumption was not sensitive by the addition of nanoparticles were found by Fedele et al. (2014) and Wang et al. (2017).

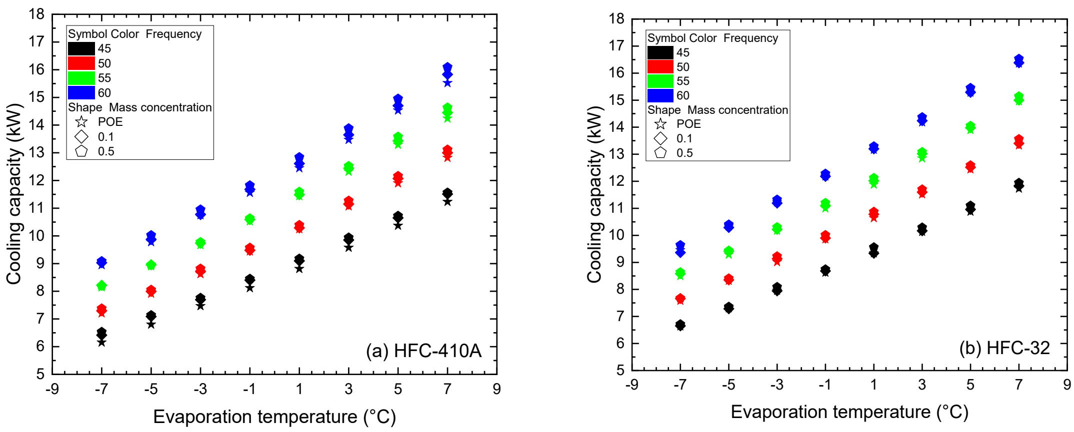

Figure 4. Cooling capacity of the system operating with (a) HFC-410A and (b) HFC-32.

Once the cooling capacity and the power consumption of the compressor were measured, for the system operating with the nanolubricants, it was possible the COP, which is presented by Fig. 5 (a) e Fig. 5 (b), for the HFC-410A and the HFC-32, respectively. For the system operating with HFC-410A and nanolubricants, it is possible to conclude that the addition of nanoparticles increased the performance of the system, with maximum increments in the range of 4% and 8% for lubricants containing 0.1% and 0.5% respectively. In this sense, it is possible to conclude that there is a tendency of performance gain with the accretion in the concentration of nanoparticles. For the HFC-32 refrigerant when operating with diamond nanolubricant, maximum increments of 2% and 5% were found for concentrations of 0.1% and 0.5%, respectively. In addition, in Figs. 5 (a) and (b) it can be seen that the system COP is reduced by decreasing the evaporation temperature and the rotation frequency of the compressor. This can be explained from the fact that when the compressor frequency is reduced, the leaks between the compression volutes are increased as a consequence of the increased compression time of each fluid volume (Cui and Sauls, 2008).

Figures 6 (a) and (b) show the compressor discharge temperature results for the system operating with fluids (a) HFC-410A and (b) HFC-32, respectively. In the figures, it is observed that the discharge temperature is decreased with the use of nanolubricants. For HFC-410A, a maximum reduction of 3 and 4°C in the compressor discharge temperature was found with the mass concentrations of 0.1% and 0.5% of diamond, respectively. Discharge temperature tends to decrease with increasing concentration of diamond nanoparticles. As for HFC-32, as can be seen in Fig. 6 (b), the discharge temperature can be reduced by up to 1 and 2°C with the use of diamond nanolubricants in the compressor at concentrations of 0.1% and 0.5%, respectively.

For both fluids, it is possible to observe in Figs. 6 (a) and (b) that the reduction was more pronounced at low frequency, since at the frequencies of 60 and 55 Hz the discharge temperature remained approximately constant.

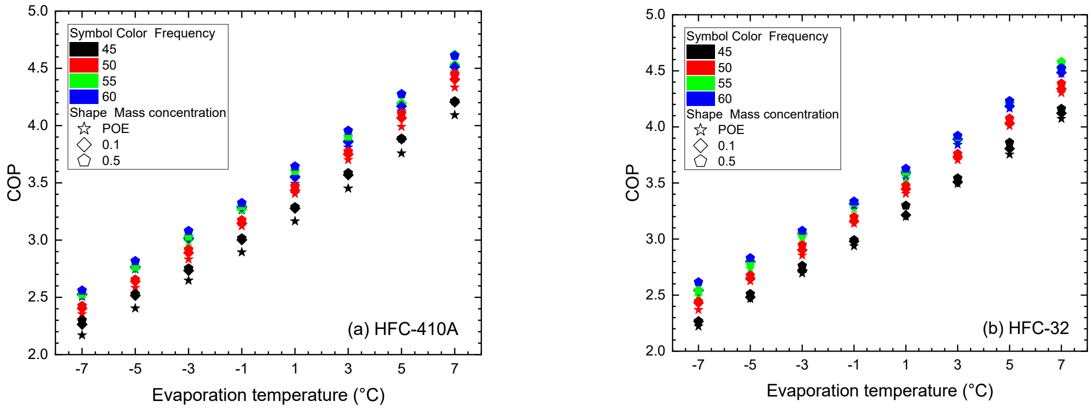

Figure 5. Coefficient of Performance of the system operating with (a) HFC-410A and (b) HFC-32.

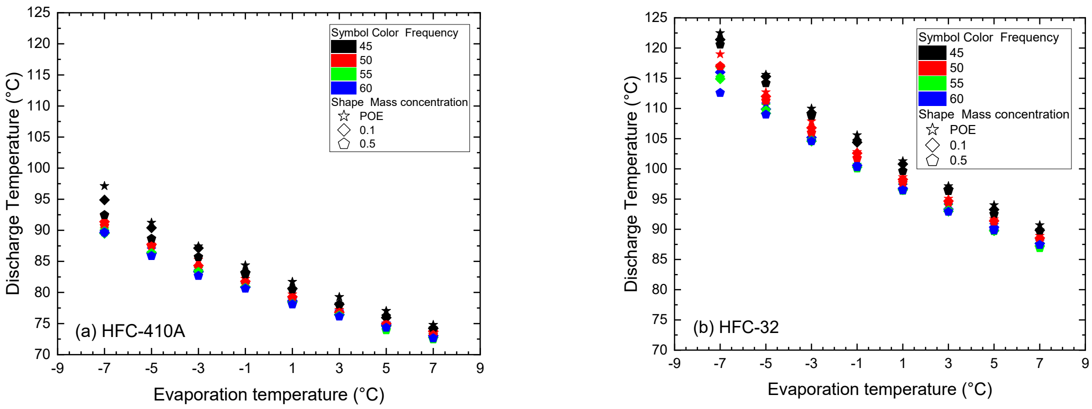

Figure 6. Compressor discharge temperature operating with (a) HFC-410A e (b) HFC-32.

4. CONCLUSIONS

In this work, the thermo-physical properties of the pure lubricant and the nanolubricants were evaluated. It was possible to observe that with the increasing of the temperature, either dynamic viscosity and thermal conductivity, for the base fluid and both concentrations of nanolubricants, suffered reductions. It was also observed that the thermal conductivity of nanolubricants tends to increase with the increasing of the nanoparticles concentration.

Furthermore, the effect of using Diamond/POE nanolubricants in a refrigeration system was evaluated, taking into account the HFC-410A and HFC-32 refrigerants. Maximum gains of 7% and 4% were found in the cooling capacity of the system operating with HFC-410A and HFC-32, respectively. It was found that the use of nanodiamond/POE lubricant does not significantly influence the power consumption of the compressor. Therefore, the enhancements obtained for the COP were attributed, mainly, to the increase in the cooling capacity.

As mentioned, it has been found that the discharge temperature of the compressor for HFC-410A can be diminished. On the other hand, for HFC-32, the decrease in the discharge temperature was less significant.

Focusing on the cooling capacity and efficiency caused by the addition of nanoparticles in relation to the pure oil, HFC-410A presented better increments than HFC-32.

HFC-32 works at high temperatures with respect to HFC-410A, which disturb the stability of nanolubricants. In this viewpoint, the use of diamond nanoparticles dispersed in the synthetic lubricant POE is a future perspective. In addition, more studies must be conducted using other nanoparticles to verify new potentialities.

5. ACKNOWLEDGEMENTS

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