Performance Enhancement of Vapour-Compression Refrigeration Systems Using Nanoparticles: An Experimental Study

V. La Rocca, M. Morale, A. Ferrante, and A. La Rocca

1 Introduction

In recent years, the development and characterization of new refrigerants with higher energetic efficiency have gained considerable interest [1], with a particular emphasis on the energetic performance of suitable replacements. Nanofluids have been proposed as possible alternative due to their role in enhancing the thermo-physical proprieties of traditional refrigerants [2]. The comprehensive review in [2] suggests that thermal conductivity of nanofluid increases with temperature and volume concentration, but it is dependent on nanoparticle size distribution; specific heat is also increased if nanoparticles are added to the refrigerant. As consequence, the improved heat transfer coefficients lead to COP improvements for the same cooling capacity. Recently, the addition of nanoparticles to the compressor oil from a refrigerator has been found to reduce the friction coefficient up to 90% [3]; this suggests that nanoparticles migrating to the lubricant oil can also contribute to improve efficiency and reliability of the system. Findings from the literature are however contradictory at times [2]; it is therefore necessary to further explore the benefits of using nanoparticles dispersed in refrigerants. The present work focuses on a quantitative analysis of the performance enhancement for a vapour-compression refrigeration system due to addition of aluminium oxide (Al_2O_3) nanoparticle to a commercially available refrigerant, tetrafluoroethane (R134a).

V. La Rocca (✉) · M. Morale
Dipartimento di Ingegneria, Università degli Studi di Palermo, Palermo, Italy
e-mail: vincenzo.larocca@unipa.it

A. Ferrante · A. La Rocca
Department of Mechanical Materials and Manufacturing Engineering, The University of Nottingham, Nottingham, UK

C. Wen and Y. Yan (eds.), *Advances in Heat Transfer and Thermal Engineering* ,
https://doi.org/10.1007/978-981-33-4765-6_49

2 Methodology

The experimental apparatus was assembled and instrumented to experimentally measure the heat transfer coefficients at the evaporator and the coefficient of performance (COP) of the system. The components are: a hermetic compressor, an evaporator consisting of a shell with a straight copper pipe centrally mounted, a thermal expansion valve with adjustable throttle, a commercial condenser and a subcooler.

R134a was used as the refrigerant working fluid, the evaporator exchanged heat with water flowing over the copper tube and through the shell, while condenser was cooled by forced convection with air. Flow metres, pressure transducers and type T copper–constantan thermocouples were used to monitor performance at different points of the refrigeration systems. The evaporator has a length of 1800 mm and an external diameter of 9 mm; it is instrumented with 14 thermocouples located axially, seven on the top and seven at the bottom, to monitor phase change across its length as shown in Fig. 1. Preparation of nanofluid R134a + Al_2O_3 was carried out with a bespoke sealed vessel. Nanoparticles were firstly introduced, and vacuum was produced; refrigerant in liquid state was then added. The results obtained for the R134a were used as baseline to compare the refrigeration performance when aluminium oxide (Al_2O_3) nanoparticles were added to the working fluid. Four different mass concentrations were investigated: 0.005, 0.01, 0.015 and 0.02%. Transmission electron microscopy (TEM) was used to characterize morphology of the Al_2O_3 nanoparticles and samples were dispersed onto TEM support films, while dynamic light scattering (DLS) was used to check size of nanoparticles deposited into the lubrication oil during operation of the refrigeration system.

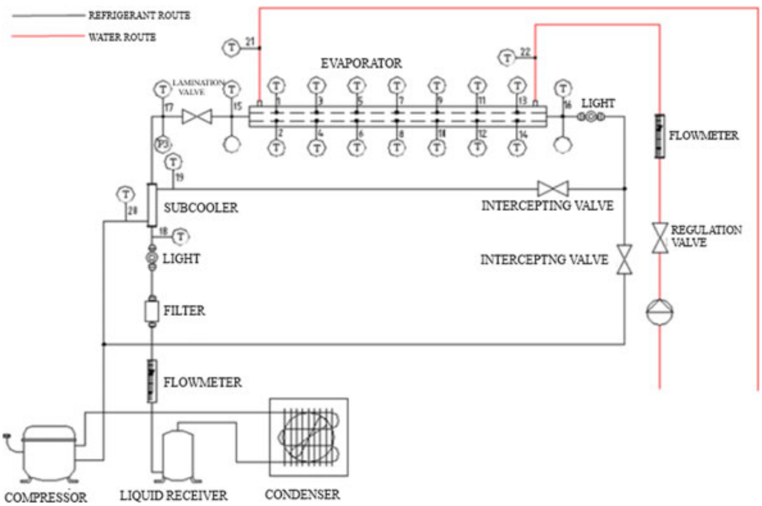

Fig. 1 Schematic representation of the test rig setup

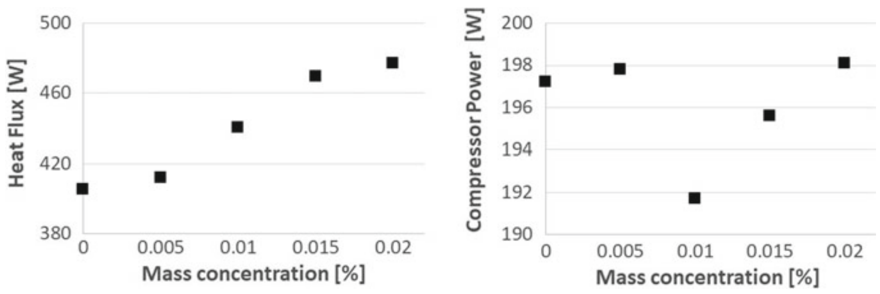

Fig. 2 Heat flux exchanged at the evaporator (left) and power measured at the compressor (right) as function of nanoparticle mass concentration in the refrigerant. Zero mass concentration refers to R134a with no nanoparticles

3 Results

The total heat transfer to the wall all along the pipe was calculated from the measurements of mass flow rate and inlet/outlet temperatures of the counterflow exchanger. For each of the mass concentrations investigated, the heat flux value is given in Fig. 2. Increasing the concentration of Al_2O_3 in the refrigerant results in a higher heat flux. A 0.01% concentration leads to a 8.7% increase; the heat flux doubles when the concentration of nanoparticles is doubled to 0.02%. This increase is mainly related to the increased heat transfer coefficient, which increases from 2985 to 4495 W/m^2 K increasing the mass concentration of aluminium oxide from 0% (R134a only) to 0.01%.

TEM analysis of the Al_2O_3 sample shows fractal agglomerates of 1000 nm in size were composed by spherical-like particles of 50–100 nm in diameter. The DLS analysis of oil sampled from the compressor at the end of the experimental campaign shows the presence of particles with an average size of 800 nm. Figure 2 shows a 3% reduction in power to the compressor when a 0.01% concentration is added to the refrigerant. In agreement with [3], nanoparticles transferred to the compressor oil might be responsible for a decrease in friction. This is corroborated by the DLS results.

4 Conclusions

Aluminium oxide nanoparticles were successfully added to R134a in mass concentration up to 0.02%. The nanofluid was used as the refrigerant in a vapour-compression system. The experimental results show an increase in the heat flux exchanged at the evaporator; in particular, there is a monotonic increase in heat flux which is linked to the increase in nanoparticle concentration, reaching a plateau at around 0.015%. A maximum increase of 18% in heat flux was measured for a concentration of 0.02%. The heat transfer coefficient from the refrigerant side almost doubles when a 0.01% Al_2O_3 is added to the tetrafluoroethane. DLS analysis of lubricant shows that nanoparticles migrate to the lubricant oil; a 0.01% mass concentration of Al_2O_3 in the refrigerant was found to reduce the power consumption of the compressor by 3% compared to the R134a case. However, increasing the concentration of particles in the oil does not necessarily lead to a further reduction in friction.

References

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