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EXPERIMENTAL INVESTIGATION OF NANO COMPRESSOR OIL EFFECT ON THE COOLING PERFORMANCE OF A VAPOR-COMPRESSION REFRIGERATION SYSTEM

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ABSTRACT

In this study, cooling performance of a refrigeration system under the effects of nanoparticle (TiO_2) addition to the compressor oil (poly alkaline glycol (PAG)) was experimentally investigated. Thermodynamics analysis of the vapor-compression refrigeration system with various nanoparticle volume fractions of TiO_2 (between 0.5%, and 1%) added to the compressor oil was performed. R-134a was used as the refrigerant. Two-step method was used to prepare the nano-lubricant for different solid particle volume fractions. It was observed that COP of the refrigeration system enhances with the addition of nanoparticles and it is an increasing function of nanoparticle volume fraction.

Keywords: *Nanoparticle, Refrigeration System, Thermodynamic Analysis, Compressor Oil*

INTRODUCTION

The importance of nanotechnology in various engineering is growing. In thermal engineering applications and energy systems, nanofluids were shown to have great potential to provide enhanced heat transfer performance [1-6]. Recent advances in nanofluid preparation and application technologies make it possible to use nanoparticles in lubricants and in refrigerants. Thus, the application of nanofluid technology in refrigeration systems is a promising way to enhance their potential efficiency and performance.

The use of nanoparticles in lubricant and refrigerants results in remarkably improvement of the thermal conductivity which is due to the surface area effect, volume effect and other exceptional properties of nanoparticles. With the use of nano-refrigerants, enhancement in the heat transfer in the heat exchangers of refrigeration systems and improvement in the system performance will be obtained [7]. Nanoparticles can also be used as lubricant additives to enhance the lubrication properties of nano-oils for the compressor of vapor compression refrigeration systems [8]. Their ability to reduce the friction coefficient and wear of frictional surfaces in compressor results in efficiency and reliability enhancement of the compressors and energy consumption will be reduced [9].

The compressor which is an important part of the refrigeration system can consume over 80% of the total energy consumption [10]. An enhancement in the efficiency of the compressor will result in energy conservation and environmental protection. Lubricant properties and operating conditions are two important aspects in efficiency and reliability performance of compressors [11, 12]. With the latest improvement in the nanotechnology, the performance of various parts in the vapor-compression refrigeration systems can be improved. As a lubricant additive, nanoparticles can give better heat transfer performance and it is possible to obtain more environmentally friendly conditions. In the study in ref. [13], the use of TiO2 nanoparticles in the mineral oil as lubricant was tested for irreversibility of refrigeration process for various refrigerants in a vapor compression refrigeration system. It was observed that the irreversibility can be considerably reduced when using TiO_2 nanoparticles. R600a refrigerant was augmented with TiO_2 nanoparticles and performance of a domestic refrigerator using this refrigerant was tested in [14]. It was observed that 9.6% energy saving can be obtained and use of nanoparticles is feasible.

In this study, performance of a vapor-compression refrigeration system with the nanoparticle addition to the compressor oil was obtained with thermodynamic analysis of the system. COP of the system without nanoparticles and with the lubricant additives are compared. Results are obtained for various nanoparticle solid volume fractions.

PREPARATION OF THE NANO-OIL

Nano-oils were prepared in the R&D labs of Ege Nanotek Kimya Sanayi in İzmir. One set for each concentration containing various nanoparticle volume fractions of TiO2 (between 0.5% and 1%) was prepared.

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Compressor oil was mixed for about an hour to obtain a homogenous mixture. Then nanomaterial was fed and at room conditions it was mixed for about 8 hours at 1200 rpm. Mechanical mixing and two step method was utilized. To obtain an effective mixing, mixing blade that were used in paint industry was utilized which is shown in Figure 1. Agglomeration of the nanoparticles was not obtained. Studies were done at room temperature, including production. Properties of TiO_2 nanoparticle are shown in Table 1.

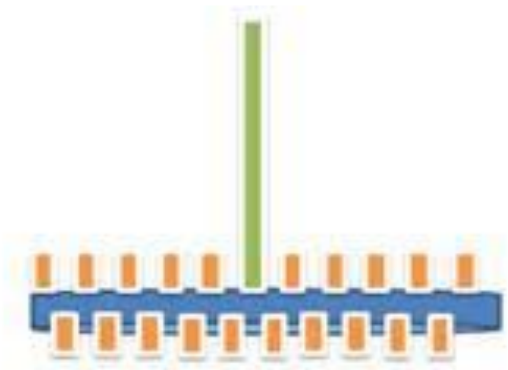

Figure 1. Mechanical blade used in two steps method for mixing of nanoparticles with base fluid

Table 1. TiO_2 properties

Average particle size	15 nm
Purity	%99.5
Surface area	60 m^2/g
Density	3.9 g/cm^3

DESCRIPTION OF THE SYSTEM AND THERMODYNAMIC ANALYSIS

Refrigeration is the process of heat removal from a region or transferring it to a place permanently. The experimental setup used for this study is a vapor-compression refrigeration system and it consists of four basic components such as a compressor, an evaporator, condenser, and an expansion device. The temperature and pressure are increased to higher values after the vapor at low temperature form the evaporator is sucked into the compressor. A polytrophic compression is assumed and vapors are condensed within an air cooled condenser. The evaporators and condensers are finned and their fan is driven by an electric motor. Fan speed of the evaporator and condenser were kept constant. R134a was used as the working fluid. A capillary tube was used as an expansion device. The compressor is a semi-hermetic type and it is 0.375 kW. Other devices such as filters and compressor protection devices also exist in the system. Temperatures were measured from 7 different points and the system consists of high and low pressure indicators. A schematic description of the vapor compression system and a photographic view of experimental system are shown in Figure 2 and Figure 3.

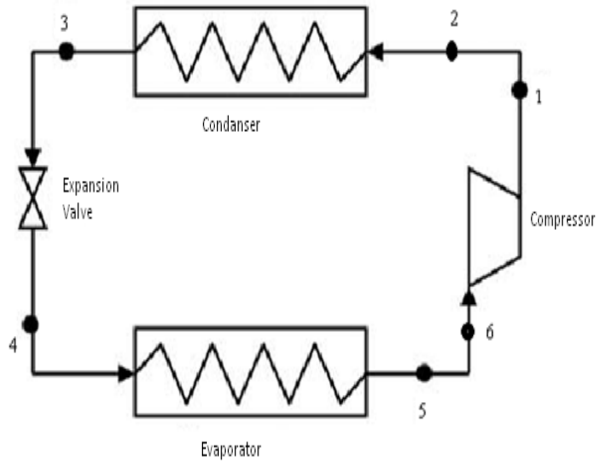

Figure 2. Schematic diagram of vapor-compression refrigeration system

Figure 3. Actual vapor-compression refrigeration system with temperature and pressure indicators

The aim of the first law of thermodynamic analysis is to determine the coefficient of performance (COP) for vapor-compression refrigeration system with respect to changes for various operating parameters such as evaporator temperature, condenser temperature etc. The first law analysis was applied to each system component. The compressor capacity can be obtained from:

$$\dot{W}_c = \dot{m}_r(h_1 - h_6) \tag{1}$$

Actual compressor efficiency:

$$\eta_{Komp} = \frac{h_{1s} - h_6}{h_1 - h_6} \tag{2}$$

where sub-index s denotes the case for isentropic process. Real compressor capacity is calculated as;

$$\dot{W}_c = \frac{\dot{m}_r(h_1 - h_6)}{\eta_{Komp}} \tag{3}$$

The heat transfer rate of the evaporator is calculated as follows:

$$\dot{Q}_e = \dot{m}_r(h_5 - h_4) \tag{4}$$

The heat transfer rate of the condenser is calculated as follows:

$$\dot{Q}_c = \dot{m}_r(h_2 - h_3) \tag{5}$$

The performance of refrigerators is determined in terms of the coefficient of performance (COP) which is defined as follows [15]:

$$COP = \frac{\dot{Q}_e}{\dot{W}_C} \tag{6}$$

RESULTS AND DISCUSSION

The reference system was the vapor-compression system without nanoparticle addition to the compressor oil. TiO_2 solid nanoparticles at volume fraction of 0.5%, 0.7%, 0.8% and 1% were added to the compressor oil. The results for temperature and pressure for inlet and outlet of different components were taken after about 30 min operation time when the system reaches steady state. For 6 different points, enthalpy and entropy values are obtained which will be used in thermodynamic analysis.

Effects of nanoparticle addition on the compressor input power were demonstrated in Figure 4. The input power (W_c) was normalized by using the value for the case without nanoparticles ($W_{c,ref}$). Adding nanoparticles results in input power reduction of the compressor. The rate of decrease is higher for higher particle volume fraction. Up to 15% reduction in the compressor work is achieved for the highest particle volume fraction for 1%.

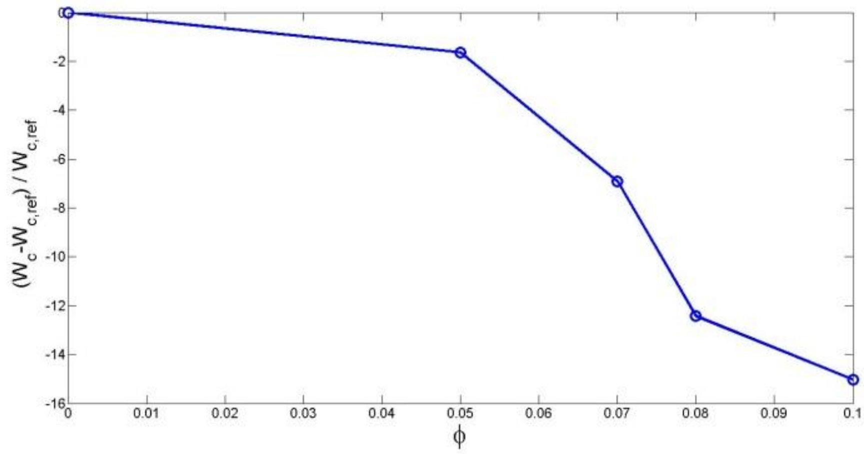

Figure 4. Normalized compressor power versus nanoparticle volume fraction

COP values calculated using Eq. (6) are shown in Figure 5. The COP of the system without nanoparticles is 2.10 which is the reference value. An enhancement of 1.43% is achieved for only 0.5% nanoparticle addition. 0.8% and 1% of nanoparticle addition to the compressor oil results in COP increment of 15.72% and 21.42%, respectively. COP is an increasing function of nanoparticle volume fraction.

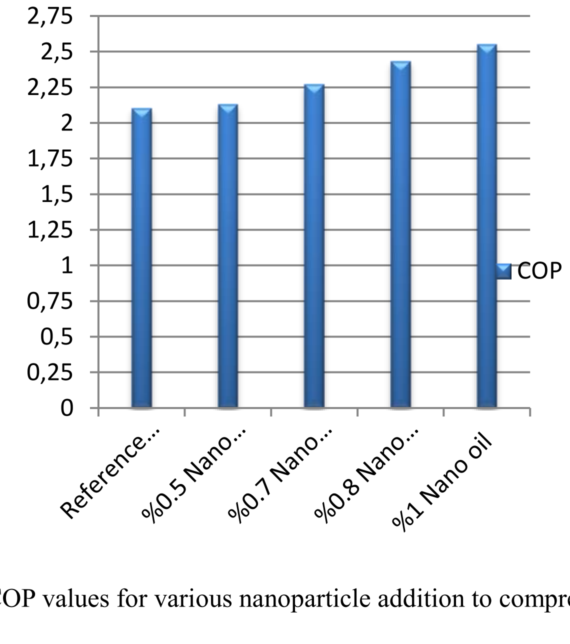

Figure 5. COP values for various nanoparticle addition to compressor oil

CONCLUDING REMARKS

In this study, four values of nanoparticle volume fraction of TiO_2 nano-additive was used in the compressor oil for a vapor-compression refrigeration system. Only 1% of nano-additive results in 21.42% enhancement in the coefficient of performance (COP) for the system. The COP is a non-monotonic increasing function of nanoparticle volume fraction. If the problems with the agglomeration of the nano-additive when used for longer times is encountered and the cost of nano-oil preparation is decreased, the use of this technology for refrigeration system in energy saving is tremendous.

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NOMECLATURE

COP	coefficient of performance
h	enthalpy [kJ/kg]
$\dot{m}_r$	flow rate of refrigerant [kg/s]
P	pressure [Pa]
$\dot{Q}_c$	condenser capacity [kW]
$\dot{Q}_e$	evaporator capacity [kW]
T	temperature [T]
TiO_2	titanium dioxide
$\dot{W}_c$	compressor capacity [kW]

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