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Principles of Using Nanorefrigerant in A VCRS: An Experimental Application

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***Abstract* –** In this study, the basic principles of using nanorefrigerant in a mechanical vapor compression refrigeration system were presented. The aim of this study was to introduce the concept of nanorefrigerant. In addition, it was to explain the usage of nanorefrigerant practically. Within the scope of this study, alumina nanoparticles were added to the system using R134a as the working fluid. Alumina nanoparticles were added to the system by means of compressor lubricant, a polyolester oil. Two-step method was used the preparation of nanoparticles and lubricant mixture. Preparation and stability control of nanorefrigerants were detailly explained. In conclusion, it was observed that the system worked safely and efficiently with the addition of alumina nanoparticles to the system with R134a.

Keywords – Nanorefrigerant, Nanolubricant, POE Oil, Alumina, R134a, VCRS.

I. Introduction

The Vapor Compression Refrigeration System (VCRS) is commonly used to refrigeration applications such as household refrigerators, split and automobile air conditioners. The VCRS performance parameters are directly associated with thermophysical properties of the working fluid called refrigerant. It is stated that the addition of nanoparticles impacts on refrigerant thermophysical properties such as density, specific heat capacity, thermal conductivity, thermal diffusivity, and dynamic viscosity [1-2]. Accordingly, it is considered that addition of the nanoparticles to the working fluid can enhance its thermophysical properties. However, it is quite difficult to add nanoparticles to the working fluid in VCRSs. The refrigerants used as working fluids in VCRSs are generally in the gas phase under standard atmospheric conditions. Since the refrigerants are in the gas phase under standard atmospheric conditions, it is difficult to add nanoparticles to the refrigerant and to ensure the stability of the mixture. However, nanoparticles can be added to the VCRS by means of compressor lubricant. It is known that the compressor comes into contact with the refrigerant at working VCRSs. Thus, it can be stated that nanoparticles also come into contact with the working fluid in case of the addition to the compressor lubricant. It is considered that nanoparticles affect on the refrigerant due to this contact. It is called as the nanorefrigerant to the working fluid of the systems in which the interactions of the refrigerant and nanoparticles are indirectly provided.

The nanorefrigerant application has been often preferred by researchers [3-5]. Therefore, it is noted that nanorefrigerant application can be improved the system performance in VCRSs. In the literature, it was stated that the addition of nanoparticle enhanced system performance parameters of the VCRS [6-10]. Nanoparticles are usually added to the system by means of compressor lubricant [11]. A wide variety of refrigerants and nanoparticle types are used in nanorefrigerant applications [12-14]. Currently, it is seen that the most widely used nanoparticles are metal oxides and carbon-based nanoparticles. On the other hand, it is noted that R134a is the most frequently used refrigerant in nanorefrigerant applications in the literature [15]. Thus, in this study, it was used R134a as refrigerant and alumina as nanoparticle in nanorefrigerant application. In nanorefrigerant applications in VCRSs, blending of the nanoparticles and compressor lubricant and adding them to the system is a very difficult process. This study has been prepared as a guide in order to minimize the mistakes about preparation and addition of nanoparticles to the system. Also, it is considered that this study will contribute to researchers in nanorefrigerant applications in terms of principles of practice.

II. Materials and Method

In this study, nanoparticle addition to a VCRS is presented in detail. In the study, R134a as refrigerant and alumina as nanoparticle were considered.

A. *Experimental setup*

The setup includes the refrigeration and auxiliary water circuits. Refrigeration circuit consist of the compression, condensation, throttling, and evaporation processes. Condensation and evaporation processes provide with the help of the auxiliary water circuits, which are composed of water and brine water lines. The compression occurs in a semi-hermetic reciprocating compressor, condensation occurs in a water-cooled plate heat exchanger, throttling occurs in an electronic expansion valve, and evaporation occurs in a brine water-heated plate heat exchanger. Schematic representation of the experimental setup is given in Fig. 1.

Pressures and temperatures are measured at each state for the control of the operating conditions in the system. In pressure and temperature measurements are used the Piezoresistive Pressure Transmitters (PPT) and Resistance Temperature Detector (RTD), respectively. All devices are calibrated, and technical specifications of measurement devices used in the experiments are given in Table 1.

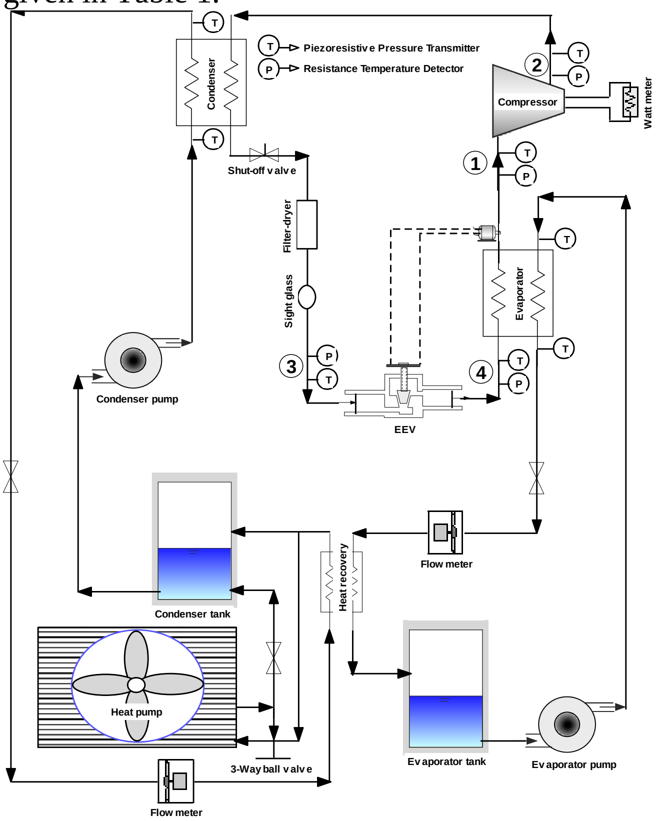


Fig. 1 Schematic representation of the VCRS test installation.

Table 1. Technical information of measurement devices

Measurement device	**Measurement range**	**Accuracy**
PPT sensor	0 ~ 25 bar	±0.25%
RTD sensor	–70 ~ 200 °C	±0.5 °C

B. *Addition of nanoparticles to the system*

Nanoparticles are added to the refrigeration system by means of compressor lubricant, a polyolester (POE) oil in this study. It is used two-step method to obtain the nanorefrigerant in scope of this study. Firstly, POE oil and nanoparticles are stirred in a mechanical stirrer, then mixture is stirred with an ultrasonic stirrer. The sonication time is applied as 90 minutes for the dispersion stability of POE oil and nanoparticles mixtures prepared with the two-step method [16]. Devices used in the application of two-step method are shown in Fig. 2. In this study, alumina nanoparticles are added to the VCRS by means of POE oil. Technical information of the alumina nanoparticles and POE oil are given in Table 2 and Table 3, respectively.

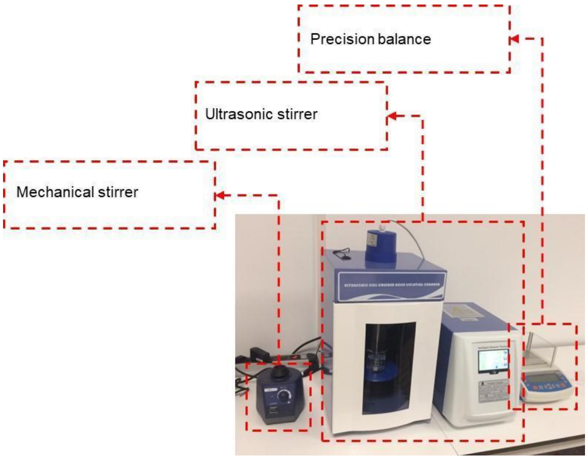


Fig. 2 Devices used in two-step method.

Table 2. Technical properties of alumina nanoparticles

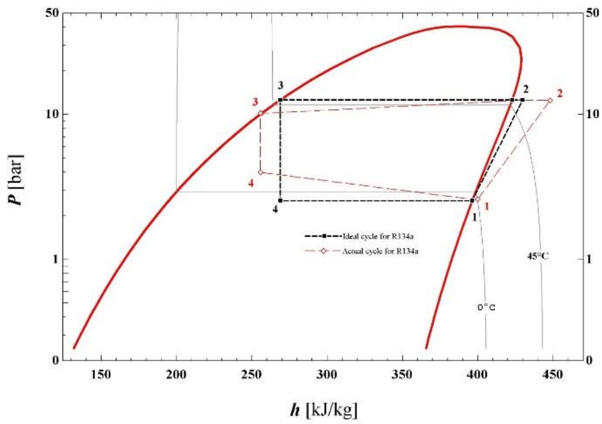
Properties	Typical value
Purity	99.5
Colour	White
Average particle size	18 nm
Specific surface area	140 m^2/g
Morphology	Spherical

Table 3. Technical properties of POE oil [17]

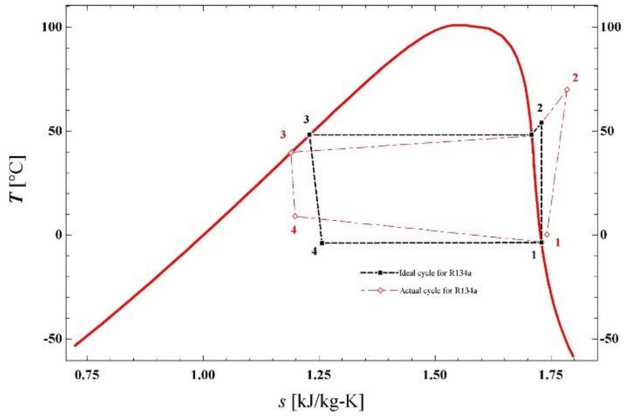
Properties	Standard	Typical value
Viscosity	ASTM D445	32.5 cSt (at 40 °C)
Viscosity	ASTM D445	5.8 cSt (at 100 °C)
Viscosity index	ASTM D2270	121
Pour point	ASTM D97	-55 °C
Density	ASTM D1298	0.98 g/mL (at 20 °C)
Flash point	ASTM D92	264 °C

III. RESULTS

First of all, results about the validation of test installation are given. Then, results about critical parameters of the nanorefrigerant application are presented. Validation of test installation is provided by comparing the actual and ideal *P-h* and *T-s* diagrams obtained from the validation tests given in Fig. 3a and Fig. 3b, respectively. Accordingly, Pressure-Specific enthalpy (*P-h*) and Temperature and Specific entropy (*T-s*) diagrams overlapped with similar studies in the literature [18]. Consequently, it can be said that the experimental setup is reliable.



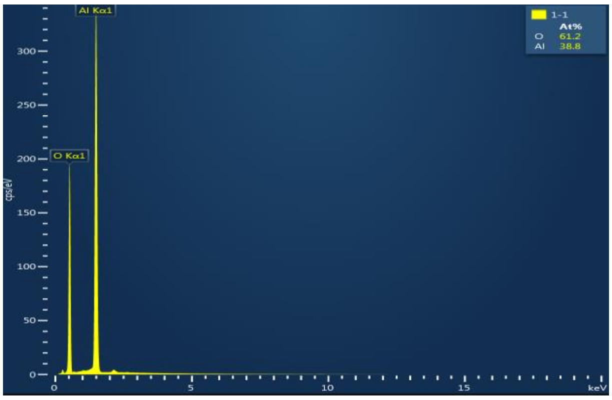
a) *P-h* diagram



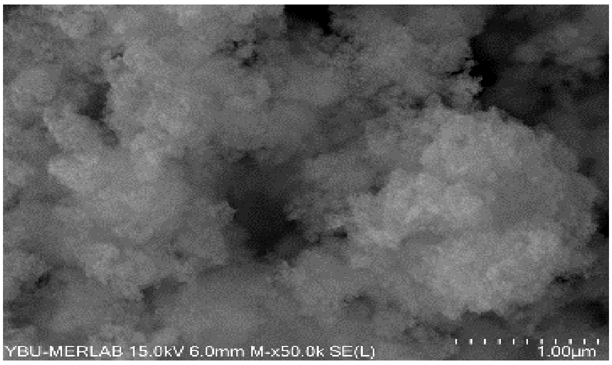
b) *T-s* diagram

Fig. 3 Result of EDS analysis.

Nanoparticles used in nanorefrigerant application can be produced by researchers or purchased from various manufacturers. However, it is vital that nanoparticles are suitable for nanorefrigerant application in terms of purity, size, and morphology. The purity of nanoparticles can be checked by Energy Dispersive X-ray Spectroscopy (EDS) analysis. The diagram obtained as a result of the EDS analysis of the alumina nanoparticle used in this study is shown in Fig. 4a. Accordingly, it is understood that the purity of alumina nanoparticles is suitable for nanorefrigerant application. It is very important to check the purity of nanoparticles in order to achieve the expected system performance improvement in nanorefrigerant applications. Other critical features in refrigerant application are nanoparticle size and morphology. The size and morphological properties of nanoparticles can also be checked by Field Emission Scanning Electron Microscopy (FE-SEM) analysis. The diagram obtained from the FE-SEM analysis of the alumina nanoparticle is also given in Fig. 4b. The control of the nanoparticles various properties prevents the problems such as sedimentation or aggregation of nanoparticles into the POE oil with the methods like EDS or FE-SEM analyses. Problems such as sedimentation and aggregation are among the most common problems in refrigerant applications. Nanoparticle selection is very important in solving these problems. One of the most reliable methods for the control of nanoparticles is the X-ray Diffraction (XRD) analysis method. The characteristic curve of nanoparticles is obtained by XRD analysis. This curve can be compared with the reference curve in previous studies in the literature and it can be evaluated the suitability of the nanoparticles. The characteristic curve obtained as a result of XRD analysis for the alumina nanoparticles used in this study is given in Fig. 5. According to XRD analysis, it is seen that alumina nanoparticles agreed with the literature [19].



a) EDS analysis



b) FE-SEM analysis

Fig. 4 Result of EDS and FE-SEM analysis.

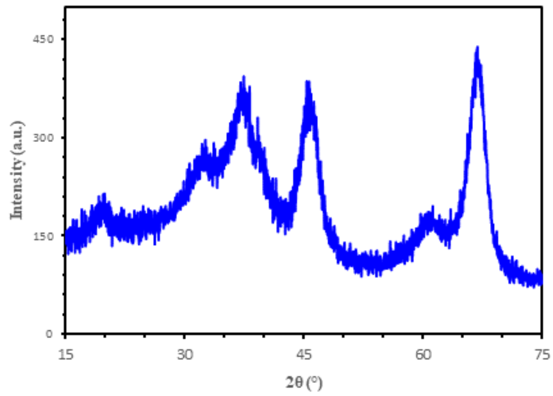


Fig. 5 Result of XRD analysis.

After selecting the appropriate nanoparticle, the nanoparticles are mixed into the lubricant. The mixing process is done to obtain a stable mixture. Sonication time is essential to obtain a stable mixture. The recommended sonication time in the literature for a stable mixture is 90 minutes [16]. Zeta potential values can be used for stability control of samples prepared for nanorefrigerant application [20-21]. Within the scope of this study, two different samples containing alumina in mass fraction of 0.25% and 1.00% were prepared by considering previously studies [15]. The zeta potential values obtained from these samples are shown in Fig. 6. Accordingly, it is seen that the prepared samples are stable.

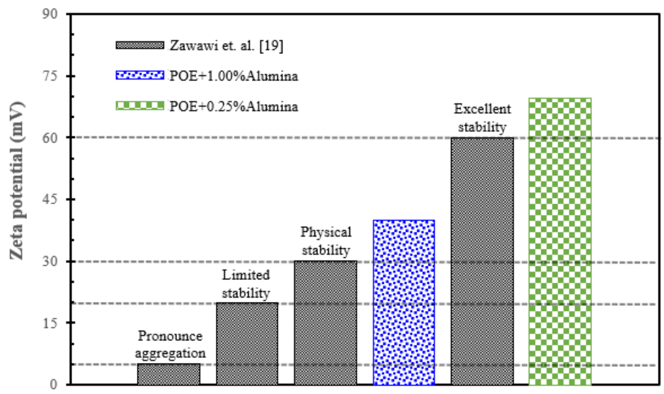


Fig. 6 Stability of samples.

IV. DISCUSSION

In this study, it was discussed the basic principles of nanorefrigerant application in a VCRS. There were some points to be considered in order to get the expected efficiency in the nanorefrigerant application. Particle purity, size and morphology are key characteristics for nanoparticles. Examination of these characteristics with EDS, FE-SEM and XRD analyses is critical for the success of nanorefrigerant application. The methodology is also vital for the stability of the nanoparticle and lubricant mixture. A two-stage method is recommended to prepare stable mixtures in nanorefrigerant applications. Optimum sonication time should be applied for stability in the samples prepared with the help of the two-step method. The sonication time applied in this study was 90 minutes. Excellent stability was achieved thanks to this sonication time. Accordingly, the prepared samples were tested in the test setup, and it was determined that the system worked safely and efficiently.

V. CONCLUSION

In this study, it is presented an application guide for research about nanorefrigerant applications. Determination of the purity, size and morphology of the nanoparticle is required in nanorefrigerant applications, and these properties can be determined with methods such as EDS, FE-SEM and XRD analysis. The use of the two-step method in the preparation of samples gives successful results. The stability of the prepared samples can be checked by measuring the zeta potential. It is recommended that these findings should be considered in future studies about nanorefrigerants.

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