Review on The Energy and Exergy Analysis of Vapour Compression Refrigeration System Using Nanolubricant

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Abstract-
The vapour compression refrigeration system (VCRS) is an energy system used for preservation and cooling of household, agricultural and industrial products but the energy consumption of the system is high globally. With this challenge, the need to reduce the energy consumed and enhance its performance becomes eminent. The thermal conductivity of heat transfer fluids plays a significant role in the heat transfer characteristics of the fluid and the overall performance of an energy system. The low thermal conductivity of refrigerant can be enhanced by dispersing nanoparticles into the refrigerant. The use of nano refrigerant or nano lubricant has been found to be useful in the reduction of energy consumption and enhancement of the VCRS performance. This review discusses the energy and exergy performance of the VCRS with the aim of identifying some critical factors that affects the performance optimization and exergy destruction within the system.

Key words: Nano refrigerant; Nano lubricant; Optimization; Energy; Exergy; VCRS

1. Introduction

The utilization and conservation of energy is essential in the development of any nation. The vapour compression refrigeration system is an energy system that is widely utilized in the preservation and cooling of household, agricultural and industrial products. The energy consumed by this system is high globally. Owing to the depletion of fossil fuel reservoir, increase in demand of energy, deterioration of the environment, effect of fossil fuel emission on human, global warming and depletion of the ozone layer the need to develop energy system that possess efficient energy utilization and excellent waste heat recovery becomes eminent [1 - 3]. To achieve this, several methods such as increasing the surface area of the heater surface through the introduction of fins and the alteration of the type and properties of refrigerant used have been deployed [4 – 6]. After the Kyoto and Montreal protocols [2], there was an urgent need to source for refrigerants that are environmentally friendly and also possess excellent heat transfer characteristics. The thermal conductivity of fluids is a major determinate in heat transfer characteristics of the fluid. Table 1.1 shows the thermal conductivity of solids, heat transfer fluid and refrigerants.
Table 1.1: Thermal conductivities of different convectional heat transfer fluids and solid [7-8]

| MATERIAL       | FORM            | THERMAL CONDUCTIVITY (Wm\(^{-1}\)K\(^{-1}\)) |
|----------------|-----------------|---------------------------------------------|
| Carbon         | Nanotube        | 1800 – 6600                                 |
|                | Diamond         | 2300                                        |
|                | Graphite        | 110-190                                     |
|                | Fullerenes Film | 0.4                                         |
| Metallic Solid | Silver          | 429                                         |
|                | Copper          | 401                                         |
|                | Nickle          | 237                                         |
| Non-metallic solid | Silicon    | 148                                         |
| Metallic Liquid | Aluminum       | 40                                          |
|                | Sodium at 644K | 72.3                                        |
| Others         | Ethylene Glycol | 0.253                                       |
|                | Engine oil      | 0.145                                       |
|                | water           | 0.614                                       |
| Refrigerants   | R-11            | 0.1022                                      |
|                | R-12            | 0.0814                                      |
|                | R-22            | 0.0970                                      |
|                | R-30            | 0.1664                                      |
|                | R-40            | 0.1612                                      |
|                | R-134a          | 0.080                                       |
|                | R-113           | 0.0971                                      |
|                | R-744           | 0.5026                                      |
|                | R-410A          | 0.0130                                      |
|                | R-764           | 0.3466                                      |
|                | R-245fa         | 0.0810                                      |
|                | R-600a          | 0.107                                       |
Comparing the thermal conductivity of refrigerant with metals and other fluids used for heat transfer purpose, it is observed that refrigerants used in the VCRS possesses the poorest thermal conductivity. This observation led to the discovery of nanofluid. Nanofluids are distinct kind of heat transfer fluid formed by properly dispersed nanoparticles into base fluid. The nanoparticles are synthesized mostly from metals and its oxides into smaller size of 1-100 nm [5]. Nanoparticles can be introduced into the vapour compression refrigeration system by dispersing them into the refrigerant or compressor lubricants. The dispersion of nanoparticles into the refrigerants alters the properties of the refrigerants, thereby increasing the viscosity and thermal conductivity of the refrigerant [9–10]. Hence, the alteration in the thermophysical properties of nanorefrigerants has the potential to improve the rate of heat transfer when compared to the refrigerant [11]. Therefore, the use of nanorefrigerant in the refrigeration system will enhance the heat transfer rate and overall performance of the VCRS; thereby reducing energy consumption of the system [12].

The preparation of nanorefrigerant can be done using the one step or the two-step methods [13–14]. The two-step method involves the dispersion of nanoparticles into the refrigerants or lubricants while the one step method involves the direct synthesizing of nanoparticles into the base fluid during its production. The two-step method is frequently used because it is less expensive and nanorefrigerant can be produced in large quantity. Due to the fact that most refrigerant do not occur as liquid at atmospheric conditions, nanoparticles are mostly dispersed in the compressor lubricating oil.

For effective use of nanorefrigerant in the VCRS, a detailed understanding of its energy and exergy analysis through thermodynamics is essential for design and process optimization. The energy analysis is carried out using the first law of thermodynamics and this does not present the irreversibility that occurs within the system or process. Meanwhile the second law of thermodynamics gives full details of the irreversibility that occurs within the system and the process in order to obtain exergy and its destruction within the system. The exergy analysis of a complex system can be analyzed by investigating the component separately. Identification of the component with the highest exergy destruction (irreversibility) shows the need for improvement of such component.

Several factors such as nanoparticle source, size and concentration, refrigerant type influences the rate of heat transfer and performance of VCRS. This review paper discusses the effect of nanoparticles concentration, refrigeration type and the concentration of nanoparticle on the energy performance in relation to energy consumption and coefficient of performance (COP) and irreversibility within each component of the system. The discoveries from this review will assist in understanding the effect of nanorefrigerant on the performance of VCRS and provide addition information on the design parameter and optimal operating condition necessary for the optimum performance of the VCRS.

2. Theoretical formulation for vapour compression refrigeration system

The major components of VCRS are the compressor, condenser, evaporator and throttle valve. The compressor compresses the refrigerant to a high temperature and pressure state through the supply of electrical power. The high temperature and pressure vapour refrigerant is transfer to the condenser where heat is removed at constant pressure. Expansion of the refrigerant occurs in the throttle valve through an adiabatic process where $h_3 = h_4$, thereafter the refrigerant moves
to the evaporator where heat is absorbed from the cooling compartment. The performance of each component determines the overall performance of the VCRS. The schematic diagram and T – S diagram of VCRS is shown in Figure 1 and Figure 2 respectively. For simple analysis of thermodynamics process, a process can be assumed to be reversible if the process can be returned to its original state without leaving any trace on the surrounding. In this case, the system and surrounding returns to its original state. Actually, reversible process does not exist because of factors that causes irreversibility. Some of the factors are friction in the compressor due to some moving part, heat transfer across a finite temperature gradient in the condenser, evaporator and compressor, superheating of the refrigerant to guarantee that pure vapour enters the inlet of the compressor and subcooling to ensure pure liquid at the inlet of the throttling valve [15].

Energy and exergy analysis of the VCRS requires some mathematical formulation and some of the assumptions made for the formulations are:

1. All the component in the system are analyzed at steady state condition.
2. Pressure loss in the pipelines of the condenser and evaporator are negligible.
3. Potential energy and kinetic energy losses are negligible.
4. The heat losses or gained from the system or to the system are negligible.

The energy analysis of the VCRS gives information on the efficiency of energy utilization in the system. First law of thermodynamics is used in the analysis of the energy performance of the VCRS. In the energy analysis, the parameter necessary for the evaluation of the VCRS performance is COP. COP deals with the relationship between the heat removed from the evaporator to the mechanical work input into the compressor given as.

$$COP = \frac{Q_e}{W_c}$$  \hspace{1cm} (1)

where $W_c$ is the compressor work done and $Q_e$ is refrigeration effect which is

$$Q_e = h_1 - h_4$$  \hspace{1cm} (2)

The COP of the VCRS can be enhanced by improving the rate of heat removal from the evaporator or decreasing mechanical work input into the compressor. The use of nanoparticles in the lubricant oil used in VCRS has the ability to reduce friction and wear within the compressor, thereby improving on the efficiency of the and lower the energy consumed in the compressor.
The combination of first law and second law of thermodynamics is used in the exergy analysis of VCRS and this analysis is essential for the design, optimization and performance assessment of the systems. The exergy of the VCRS is the maximum work obtained if the system is permitted to reach equilibrium with the environment. The exergy analysis of the VCRS predicts inefficiencies in the system and the amount of exergy destroyed within each component of the VCRS. The second law of thermodynamics is employed to carry out the exergy analysis of the different components in the system. This analysis defines all loses in the components of the system and also the overall system and determines the maximum performance of the system,
recognize the core location with highest irreversibility and display the direction for potential improvement.

General exergy balance with respect to time is expressed in Equation (2)

\[ \dot{E}_{in} - \dot{E}_{out} = \dot{E}_{dest} \]  

Equation (3) can also be written as:

\[ \dot{E}_Q - \dot{E}_W + \dot{E}_{mass,in} - \dot{E}_{mass,out} = \dot{E}_{dest} \]  

Equation 5 - 7 gives the exergy of heat, work and mass

\[ \dot{E}_Q = \dot{Q} \left( 1 - \frac{T_0}{T} \right) \]  

\[ \dot{E} = \dot{W} \]  

\[ \dot{E}_{mass} = \dot{m}_{of} \varepsilon \]  

where \( \dot{Q}, T_0 \) and \( \varepsilon \) are the rate of heat transfer at T, reference temperature and specific flow exergy respectively.

The specific flow exergy neglecting the chemical exergy is given in Equation (8)

\[ \varepsilon = (h - T_o s) + \frac{1}{2} V^2 + g z - (h_0 - T_0 s_0) \]  

where \( g, V \) and \( z \) are the gravitational acceleration, velocity and elevation of the reference level respectively. The kinetic and potential energies are neglected.

Therefore, Equation (7) becomes

\[ \varepsilon = (h - T_o s) - (h_0 - T_0 s_0) \]  

where \( h_0 \) and \( s_0 \) are the enthalpy values of the dead state of the refrigerant at pressure \( P_0 \) and temperature \( T_0 \).

Combining Equation (5 – 9), Equation (4) becomes

\[ \dot{E}_{dest} = \sum \dot{Q} \left( 1 - \frac{T_0}{T} \right) - \dot{W} + \sum \dot{m}_{of} \varepsilon - \sum \dot{m}_{of} \varepsilon \]  

The exergy destruction term \( \dot{E}_{dest} \) can also be identified as the irreversibility rate.
Applying the exergy analysis equation on the different components of the VCRS, the irreversibility rate for each of the component is defined as;

Compressor exergy balance

$$\dot{I}_c = \dot{E}_{dest}$$  \hspace{1cm} (11)

$$\dot{E}_1 + W_{e,m} = \dot{E}_2 + \dot{I}_w$$  \hspace{1cm} (12)

$$\dot{I}_w = \dot{E}_1 - \dot{E}_2 + W_{e,m}$$  \hspace{1cm} (13)

$$\dot{I}_w = m_{ngf} (h_1 - T_0s_1) - m_{ngf} (h_2 - T_0s_2) + W_{e,m}$$  \hspace{1cm} (14)

The Condenser exergy balance is given as

$$\dot{E}_2 = \dot{E}_3 + \dot{E}_{Qc} + \dot{I}_c$$  \hspace{1cm} (15)

The thermal exergy association with $Q_c$ is zero, Equation (15) becomes

$$\dot{I}_c = \dot{E}_2 - \dot{E}_3$$  \hspace{1cm} (16)

$$\dot{I}_c = m_{ngf} (h_2 - T_0s_2) - m_{ngf} (h_3 - T_0s_3)$$  \hspace{1cm} (17)

Evaporator exergy balance

$$\dot{E}_4 = \dot{E}_1 - \dot{E}_{Qe} + \dot{I}_E$$  \hspace{1cm} (18)

The thermal exergy related with $Q_e$ is given in Equation (19)

$$\dot{E}_{Qe} = Q_e \left(1 - \frac{T_0}{T_E}\right)$$  \hspace{1cm} (19)

Substituting Equation (17) into (16), the evaporator exergy balance becomes

$$\dot{I}_E = \dot{E}_4 - \dot{E}_1 + \dot{E}_{Qe} \left(1 - \frac{T_0}{T_E}\right)$$  \hspace{1cm} (20)

$$\dot{I}_E = m_{ngf} (h_4 - T_0s_4) - m_{ngf} (h_1 - T_0s_1) + Q_e \left(1 - \frac{T_0}{T_E}\right)$$  \hspace{1cm} (21)

Expansion valve exergy balance
\[ \dot{E}_3 = \dot{E}_4 + \dot{I}_{Exp} \quad (22) \]

\[ \dot{I}_{Exp} = \dot{E}_3 - \dot{E}_4 \quad (23) \]

\[ \dot{I}_{Exp} = m_{nf} (h_3 - T_0 s_3) - m_{nf} (h_4 - T_0 s_4) \quad (24) \]

Since the expansion of the refrigerant in the throttling valve is an isentropic process, the enthalpy across the capillary tube remains constant \((h_3 = h_4)\). Therefore, Equation (24) becomes

\[ \dot{I}_{Exp} = m_{nf} T_0 (s_4 - s_3) \quad (25) \]

The total exergy of the VCRS is given as

\[ I_{total} = \sum I_i \quad (26) \]

Therefore

\[ I_{total} = I_W + I_C + I_E + I_{Exp} \quad (27) \]

The ratio the exergy output and the exergy input is known as the exergy efficiency given as

\[ \eta_{exe} = \left( \frac{\dot{E}_{out}}{\dot{E}_{in}} \right) \times 100 \quad (28) \]

\[ \dot{E}_{out} = \dot{E}_{in} - I_{total} \quad (29) \]

The electric power into the compressor \((\dot{W}_{comp})\) is the main source of exergy input into the VCRS.

\[ (\dot{W}_{comp}) = \dot{E}_{in} \quad (30) \]

and

\[ \eta_{exe} = \left( \frac{\dot{W}_{comp} - I_{total}}{\dot{W}_{comp}} \right) \times 100 \quad (31) \]

Simplifying Equation (31)

\[ \eta_{exe} = \left( 1 - \frac{I_{total}}{\dot{W}_{comp}} \right) \times 100 \quad (32) \]
3. Energy and Exergy analysis of a VCRS system

Understanding the influence of nanoparticles on the performance of the VCRS is essential in advancing the design of VCRS components and process. [18] found out that the addition of TiO$_2$ into R134a refrigerant reduced the energy consumption of the system by 21.2% when compared with R134a and POE oil system. [19] investigated the heat transfer of Ni/R134a nanorefrigerant in a mobile hybrid powered VCRS. The result showed that Ni/R134a nanorefrigerant had a COP of 12.8% better than conventional R134a refrigerant and the system consumed less energy for Ni/R134a when compared with pure R134a refrigerant. [20] stated that the substantial decrease in power consumption and remarkable enhancement in the performance of the system was due to the improvement of the thermophysical properties of the lubricant oil due to the addition of nanoparticles.

3.1 Effect of nanoparticle concentration on energy and exergy analysis

Concentration of nanoparticles in the lubricating oil or refrigerant affects the rate of heat transfer in the VCRS. The nanoparticle concentration has the tendency to enhance or deteriorate the heat transfer within the VCRS thereby affecting its performance, energy consumption and exergy destruction. [21] dispersed Al$_2$O$_3$ nanoparticles of varying concentration of 0.05, 0.1 and 0.2 wt.% in mineral oil to improve its lubricity and also to enhance the heat transfer rate. From the result, power consumption was lowest at 0.1 wt.% by 2.4% and the coefficient of performance was improved by 4.4% at the same concentration. [22] conducted an experimental analysis on the energy performance of VCRS using Al$_2$O$_3$ of varying mass concentration of 0.04%, 0.06% and 0.08% with R134a/polyester oil. The freezing capacity of the system was greater for 0.06% mass concentration of Al$_2$O$_3$ when compared with 0.04%, 0.08% and pure refrigerant. The power consumption of the compressor reduced by 14.71%, 7.94% and 5.37% for 0.06%, 0.04 and 0.08% mass concentration respectively. For the COP, 0.06% had the highest increase in COP of 28.03% when compared with pure refrigerant. [23] used R12/TiO$_2$/mineral oil nanorefrigerant at varying volumetric concentrations of 0.050%, 0.010%, and 0.015% to analysis the performance of the VCRS. The optimum performance was obtained at 0.010% volume concentration where the compressor work reduced by 11% and the COP improved by 17%. The average rate of heat transfer enhanced by 3.6% when compared with R12/mineral oil. In the energy analysis carried out by [24], the increased in COP of the system using 0.05 and 0.01 vol.% of Al$_2$O$_3$ nanoparticles and R134a/POE oil was gotten as 19% and 22% respectively. [25] used dispersed ZnO in R152a refrigerant to study the performance of VCRS. The concentration of ZnO was varied in the range of 0.1% vol., 0.3%vol. and 0.5% vol. with nanoparticle size of 50 nm and 150g of R152a. From the analysis, the power input into the compressor was the least in 0.5%vol and the highest was 0.1%vol and a reduction of 21% was obtained. The COP increased with an increase in nanoparticle concentration for the refrigerant with 0.5%vol. having a COP of 3.56 and pure R152a having a COP of 3.12.

For the exergy analysis, [26] varied the exergy destruction with evaporation temperature using LPG and TiO$_2$ nanoparticles of varying weight concentration of 0.1wt%, 0.2wt% and 0.4wt%, and found out that the exergy efficiency of the refrigerator was best at 0.2%wt for LPG/TiO$_2$ when compared with other concentration and pure refrigerants.
It is observed from the literatures reviewed that the COP increased with the dispersion of nanoparticles into the refrigerant. This is attributed to the enhancement of the thermal conductivity of the base fluid by the addition of nanoparticles. The influence of nanoparticles concentration increment on the energy and exergy analysis of the VCRS does not following a consistent trend. Further research will need to be conducted to establish the optimum nanoparticle concentration that will give the optimum system performance. More research work needs to be conducted on the effect of nanoparticles concentration on exergy analysis.

3.2 Effect of nanoparticles source on energy and exergy analysis

To study the influence of nanoparticle source on heat transfer performance [27] used (DI) water, CuO nanofluid and TiO\(_2\) nanofluid in a heat pipe. The result showed that CuO nanofluid exhibited higher results when compared to TiO\(_2\) nanofluid and DI water at 1.0% wt. Considering vapour compression refrigeration system, the influence of nanoparticle type on the performance of VCRS was conducted by [28] using TiO\(_2\), Al\(_2\)O\(_3\) and CuO nanoparticles with SUNISO 3GS oil as base fluid. The power consumption of the system decreased by 15.4%, 11.9% and 8.4% with TiO\(_2\), Al\(_2\)O\(_3\) and CuO nanoparticles respectively. The increase in COP of TiO\(_2\) was the highest with the value of 20% while Al\(_2\)O\(_3\) and CuO nanolubricant had a value of 16% and 11% respectively. The freezing capacity of TiO\(_2\) was also the highest. [29] also carried out a similar research using TiO\(_2\) and Al\(_2\)O\(_3\) nanoparticles of 0.06% and 0.01 mass concentration using HFC134a and mineral oil as the base fluid. Energy saving of 26.13% was obtained for TiO\(_2\) at 0.01% mass concentration while 23.24% was obtained for Al\(_2\)O\(_3\) at 0.06% mass concentration. Contrary to these findings, [24] found out that the COP of Al\(_2\)O\(_3\) with an increase of 22% was higher than that of TiO\(_2\) with an increase of 5.62% at 0.01% volume concentration. The energy consumption was reduced by 27.73% for 0.1% Al\(_2\)O\(_3\) nanoparticles dispersed in POE oil while it reduced by 14.19% for the same volume concentration of TiO\(_2\). The influence of SiO\(_2\) and CuO nanoparticles dispersed in R134a and R134a/polyester mixture on flow boiling was investigated by [30]. The analysis showed that a direct dispersion of SiO\(_2\) into R134a caused a decrease in the coefficient of heat transfer by 55% when compared with R134a but an enhancement of heat transfer of over 100% was achieved for CuO nanoparticles dispersed in R134a/polyester mixture. This was attributed to the stable dispersion of CuO in the mixture.
[31] experimentally investigated the performance of HFC-134a refrigerant using TiO$_2$ and Al$_2$O$_3$ nanoparticles to enhance the thermophysical properties of the pure refrigerant. It was observed that the nanolubricant containing TiO$_2$ was more efficient in heat removal from the system and higher COP than nanolubricant containing Al$_2$O$_3$. The energy consumption for TiO$_2$ based nanolubricant was lower than that of Al$_2$O$_3$ and pure POE oil.

The exergy analysis of the VCRS using different nanoparticles was investigated by [32]. The study involved the use of aluminum composite nanolubricant in a refrigerator compressor system. The aluminum based nanolubricants used were Al$_2$O$_3$, AlNi, AlCo and AgAl and the results were compared with the conventional base oil (i.e. Capella D). From Figure (5), all the nanolubricant/R134a systems performed better than the conventional base oil system with the exception of AgAl-composite. AlNi-composite nanolubricant/R134a system AlNi exhibited the highest exergy seconded by aluminum oxide.

The reduction in energy consumption from the literatures reviewed can be attributed to the introduction of nanoparticles into the lubricating oil. The tribology of the lubricating oil is
enhanced thereby reducing the rate of wear and coefficient of friction among the moving parts in the compressor. This in return reduced the energy consumed by the compressor. The solubility of nanoparticles in based fluid and the properties of the nanoparticles such as thermal conductivity plays a significant function in the performance and energy consumption of VCRS. Therefore, further studies need to be conducted to obtain a detailed information on the solubility of nanoparticles in refrigerants and its effect on the performance and heat transfer of vapour compression refrigeration system.

3.3 Effect of refrigerant type on energy and exergy analysis

After the ban of some refrigerant, several refrigerants have been introduced that possesses low global warming potential (GWP) along with zero ozone depletion potential (ODP) but the solubility of the refrigerant in the compression oil coupled with the introduction of nanoparticles on the performance of VCRS needs to be properly understood. [33] investigated the performance of VCRS using various eco-friendly refrigerants of HFC152a, HFC32, HC290, HC600a, HC1270 and RE170 and the result obtained was compared with R134a in order to determine a possible replacement for it. From analysis, R152a showed a COP of 4.65% higher than R134a. Using nanorefrigerant, [34] investigated the compressor work and the performance of VCRS by introducing Al2O3 nanoparticles into R134a, R12, R430a, R436a and R600a refrigerants. The results presented that the compressor work decreased and the heat transfer in the condenser increased with the addition of nanoparticles into the refrigerants. The result also showed that COP of the system enhanced by the introduction of nanoparticles to the pure refrigerant and the highest value of COP was obtained for Al2O3/R600a. [21] compared the performance or R12 and R134a with nanoparticles dispersed in them. From the findings, it was reported that R12 has a lower compression ratio when compared with R134a refrigerant and the 0.1 wt.% of AL2O3 added into the mineral oil caused 2.4 % decrease in power consumption and 4.4% enhancement in COP when compared with pure R13a and mineral oil. Further comparing the effect of refrigerant type on the performance of VCRS, [35] investigated the performance of VCRS using ZrO2 nanoparticles with R134a and R152a. The concentration of ZrO2 nanoparticles ranged from 0.01% and 0.06% volume concentration and particle size of 20 nm. The compressor work of the system for ZrO2/R152a nanorefrigerant was lower than that of R152a and higher than that of R134a. The COP was varied with evaporation temperature and the COP increased as evaporation temperature increased. The performance of the system with ZrO2/R152a nanorefrigerant was higher than that of R134a and R152a refrigerant.

For the exergy analysis, [36] analysed the exergy performance using HFC152a and RE170 refrigerants as a substitute to R134A. The result showed that the refrigerant R152a has a higher exergy efficiency of 5.02% at -10°C when compared with R134a while the average exergy destruction for R152a was 8.2% lower than that of R134a. [37] carried out a numerical study on performance of VCRS using R134a, R152a, R407c, R143a, R410a, R502 and R507a. From the result obtained, it was observed that the condenser and evaporator temperature have significant influence on the exergy efficiency. R134a had better performance when compared to other refrigerant while R407C performance was the poorest. [38] carried out an exergy analysis of VCRS using R11 and R12 refrigerant. The result obtained is presented in Table 1. From the result most of the exergy is destroyed in the compressor and it is higher for R11 refrigerant. [39] compared R134a refrigerant and R290/R600a mixture on the performance of vapour compression refrigeration system. R290/R600a mixture showed better exergy efficiency
than R134a and the highest irreversibility occurred in the compressor when compared to other
components of the VCRS. A similar analysis conducted by [40] using isobutene and butane
mixture confirmed that the highest irreversibility occurred in the compressor and comparing the
result obtained with R134a refrigerant, it was found that the isobutene and butane mixture had
exergy efficiency higher than R134a. Considering the exergy performance of VCRS with
nanorefrigerants, [41] experimentally studied the exergy analysis of a domestic refrigeration
refrigerator using R600a and LPG refrigerant at 0.05, 0.15 and 0.3%wt using 15nm particle
sized TiO$_2$ nanolubricant. The exergy efficiency decreased with increase in evaporation
temperature. The average exergy efficiencies for LPG/TiO$_2$ (0.15%wt), R600a/TiO$_2$ (0.15%wt)
and R134a were 13.8% and 17.53% higher when compared with R134a. The R600a/TiO$_2$
(0.15%wt) and LPG/TiO$_2$ (0.15%wt) performed better than other 0.05 and 0.3% weight
concentration of nanoparticles dispersed in the lubricant.

From the above review, the exergy efficiency of the VCRS is strongly dependent on the
refrigerants used. Therefore, further analysis needs to be carried out using nanoparticles
dispersed in various refrigerants.

Table 1: Exergy losses for refrigeration cycle [38]

| Components  | R11 (KJkg$^{-1}$) | R12 (KJkg$^{-1}$) | % Total losses |
|-------------|-------------------|-------------------|---------------|
| Throttle    | 4                 | 5                 | 16.7          |
| Evaporator  | 5                 | 2                 | 20.8          |
| Compressor  | 10                | 7                 | 41.7          |
| Condenser   | 5                 | 4                 | 20.8          |

4. Conclusion

The use of nanorefrigerant has shown to reduce the energy consumption in the vapour
compression refrigeration system, thereby reducing emission of greenhouse gases. The
performance of VCRS improved with the addition of nanoparticles in the refrigerant but at a
much higher concentration the performance of the VCRS tends to deteriorate. On the average
the energy consumption was the lowest for TiO$_2$ and CuO nanorefrigerant and the performance
was better than other nanorefrigerant considered in this review. The highest irreversibility
occurred in the compressor.

5. Recommendation

For further understanding on the effect of nanoparticles on the VCRS, these following
recommendations are proposed:
1. More research needs to be done to study the effect on nanoparticles size on the performance and exergy destruction in the VCRS. This is to enable designers of VCRS to determine the optimum size of nanoparticles that is suitable for each concentration in order to avoid the deposition of nanoparticles on the heat transfer surface and compressor surface. This will also aid in determining the pressure drop for each concentration in relation to nanoparticle size in the VCRS.

2. The solubility and stability of different nanoparticle source in different refrigerant and lubricant needs to be further investigated. This is to further help researches to determine the best combination of nanoparticles source and its concentration for each refrigerant in order to optimize the performance of the VCRS.

3. More research work needs to be conducted on the effect of nanoparticles type on exergy destruction in the various components of the VCRS.

Reference

[1] Hoel M and Kverndokk S. (1996). Depletion of fossil fuel and the impact of global warming. Resources and Energy Economics, 18(20), 115 – 136.

[2] World Meteorological Organization Global Ozone Research and Monitoring Project (2007). Scientific Assessment of Ozone Depletion: 2006 (World Meteorological Organization, Geneva), Report 50.

[3] United Nations Framework Convention on Climate Change (1997) Kyoto Protocol to the United Nations Framework Convention on Climate Change.

[4] Choi, S.U.S. (1995). Enhancing thermal conductivity of fluids with nanoparticles. ASME FED. 231, 99-103.

[5] Chou F.C., Lukes J. R and Tien C.L (1999). Heat Transfer Enhancement by Fins in the Microscale Regime. J. Heat Transfer, 121(4), 972-977.

[6] Gerken I., Brandner J. J., Dittmeyer R. (2014). Heat transfer enhancement with gas-to-gas micro heat exchangers. 4th Micro and Nano Flows Conference UCL, London, UK, 7-10 September 2014.

[7] ASHRAE Fundamentals Handbook, 2001.

[8] Cheng, L., Bandarra Filho, E.P., Thome, J.R. (2008). Nanofluid Two Phase Flow and Thermal Physics; A New Research Frontier of Nanotechnology and its Challenges. J. Nanosci. Nanotechnology, 8, 3315-3332.

[9] Alawi, O.A., Sidik, N.A.C., (2015). The effect of temperature and particles concentration on the determination of thermo and physical properties of SWCNT nanorefrigerant. Int. Commun. Heat Mass Transf., 67, 8–13.

[10] Mahbubul I.M., Saidura R., Amalina M.A (2013) Influence of particle concentration and temperature on thermal conductivity and viscosity of Al2O3/R141b nanorefrigerant. Int. Commun. Heat Mass Transfer, 43, 100-104.

[11] Ding G., Peng H. Jiang W., Gao Y. (2009). The migration characteristics of nanoparticles in the pool boiling process of nanorefrigerant and nanorefrigerant–oil mixture. Int. J. Refrig., 32, (1), 114–123.

[12] Nair V, Tailor P.R. and Parekh A.D. (2016). Nanorefrigerants: A comprehensive review on its past, present and future. International Journal of Refrigeration, 67, 290–307.

[13] Kumar S. D., Elansezhian R. (2012). Experimental Study on Al2O3-R134a Nano Refrigerant in Refrigeration System. International Journal of Modern Engineering Research (IJMER), 2(5), 3927-3929
[14] Eastman J.A, Choi S.U.S, Li S., Yu W., Thompson L.J. (2001). Anomalously Increased Effective Thermal Conductivities of Ethylene Glycol-Based Nanofluids Containing Copper Nanoparticles. *Appl Phys Lett.*, 78 (6), 718-720.

[15] Yumrutas R., Kunduz M. and Kano’glu M. (2002). Exergy analysis of vapor compression refrigeration systems. *Exergy, an International Journal*, 2, 266–272.

[16] www.themopedia.com

[17] Cengel Y. A. and Boles M. A. (2006). Thermodynamics: An Engineering Approach. McGraw-Hill College, Boston, MA.

[18] Bi S., Shi L. and Zhang L., (2007). Performance study of a domestic refrigerator using R134a/mineral oil/nano-TiO2 as working fluid. ICR07-B2-346.

[19] Ajayi O. O., Useh O. O., Banjo S. O., Oweoye F. T., Attabo A., Ogbonnaya M., Okokpujie I. P., Salawu E. Y. (2018). Investigation of the heat transfer effect of Ni/R134a nanorefrigerant in a mobile hybrid powered vapour compression refrigerator. The 1st International Conference on Engineering for Sustainable World (ICESW). *IOP Publishing IOP Conf. Series: Materials Science and Engineering* 391 doi:10.1088/1757-899X/391/1/012001.

[20] Bi S., Shi L. and Zhang L. (2008). Application of nanoparticles in domestic refrigerators. *Applied Thermal Engineering*, 28, 1834-1843.

[21] Jwo C-S, Jeng L-Y, Teng T-P, Chang H. (2009). Effects of nanolubricant on performance of hydrocarbon refrigerant system. *Journal of Vacuum Science and Technology B: Microelectronics and Nanometer Structures*, 27, 1473-1477.

[22] Mohod V. P., Kale N. W. (2017). Experimental analysis of vapour compression refrigeration system using nanorefrigerant. *International Journal of Mechanical and Production Engineering*, ISSN: 2320-2092, 5(3).

[23] Sabareesh, R.K., Gobinath, N., Sajith, V., Das, S., Sobhan C.B. (2012). Application of TiO2 nanoparticles as a lubricant-additive for vapor compression refrigeration systems - An experimental investigation. *International Journal of Refrigeration*, 35, 1989-1996.

[24] Haque M.E, Bakar R.A., Kadirgama K., Noor M.M., and Shakaib M. (2016). Performance of a domestic refrigerator using nanoparticles-based polyolester oil lubricant. *Journal of Mechanical Engineering and Sciences*, 10(1), 1778-1791.

[25] Kumar D. S, R. Elansezhian R. (2014). ZnO nanorefrigerant in R152a refrigeration system for energy conservation and green environment. *Front. Mech. Eng*. DOI 10.1007/s11465-014-0285-y.

[26] Ajuka L. O. and Odunfa K. M. (2017). Experimental Evaluation on Exergy Analysis of Vapour Compression Refrigeration System Using LPG with TiO2-Nanoparticle. *International Journal of Energy Policy and Management*, 2(1), 1-8.

[27] Manimaran R., Palaniradja K., Nataranjan A. and Hussain J. (2014). Experimental comparative study of heat pipe performance using CuO and TiO2 nanofluids. *International Journal of Energy Research*, 38(5).

[28] Subramani N., Ashwin M. and Prakash M. J. (2013). Performance Studies on A Vapour Compression Refrigeration System Using Nano-Lubricant. *International Journal of Innovative Research in Science, Engineering and Technology*, 2, 522-530.

[29] Bi S., Guo K and Liu Z. (2011). Performance of domestic refrigerator using TiO2/R600a nanorefrigerant as working fluid. *Energy Conservation and Management*, 52(1), 733-737.
[30] Henderson K, Park Y-G, Liu L and Jacobi A. M. (2010). Flow-boiling heat transfer of R-134a-based nanofluids in a horizontal tube. *International Journal of Heat and Mass Transfer*, 53, 944-951.

[31] Babu A. M, Nallusamy S., Rajan K. (2016). Experimental analysis on vapour compression refrigeration system using nanolubricant with HFC-134a refrigerant. *Nano Hybrids*, 9, 33-43.

[32] Ajayi O. O., Ukasoanya D. E., Salawu E. Y., Ojiijeagbon I. O., Oyawale F. A. and Agarana M.C. (2018). Experimental Investigation into the Effects of Al-composite Nanolubricants on the Energy and Exergy Performance of Vapour Compression Refrigerator Compressor. Proceedings of the World Congress on Engineering 2018 Vol II WCE 2018, July 4-6, 2018, London, U.K.

[33] Baskaran A. and Matthews K. (2017). Exergetic analysis of a vapour compression refrigeration system with R134A, RE170, R429A, R435A. *International Journal of Current Advanced Research*, 6(6), 4029-4036.

[34] Aktas M., Dalkilic A. S., Celen A., Cebi A., Mahian O., and Wongwises S. (2014). A Theoretical Comparative Study on Nanorefrigerant Performance in a Single-Stage Vapor-Compression Refrigeration Cycle. *Hindawi Publishing Corporation. Advances in Mechanical Engineering*.

[35] Sureshkumar V. P., Baskaran A. and Subaramanian K.M. (2016). A performance study of Vapour compression refrigeration system using ZrO2 Nano particle with R134a and R152a. *International Journal of Scientific and Research Publications*, 6 (12), 410 – 421.

[36] Baskaran A. (2013) energy and exergy analysis of a vapour compression refrigeration system with R134a, R152a and RE170. *Archives Des Sciences*, 66 (3), 1-15.

[37] Reddy V. S., Panwar N. L. and Kaushik S. C. (2012). Exergy analysis of a vapour compression refrigeration system with R134a, R143a, R152a, R404A, R407C, R410A, R502 and R507A. *Clean Techn Environ Policy*, 14, 47-53.

[38] Kumar S., Prevost M. and Bugarel R. (1989). Exergy analysis of a compression refrigeration system. *Heat Recovery Systems*, 9 (2), 151-157.

[39] Saravanakumar R. and Selladurai V. (2013). Exergy analysis of a domestic refrigerator using eco-friendly R290/R600a refrigerant mixture as an alternative to R134a. *Int. J. Therm Anal Calorim*.

[40] Ahamed J. U., Saidur R., Masjuki H. H, and Sattar M.A. (2012). An analysis of energy, exergy and sustainable development of a vapour compression refrigeration system using hydrocarbon. *International Journal of Green energy*, 9, 707-717.

[41] Ajuka L. O., Odunfa M. K., Ohunakin O. S. and Oyewola M. O. (2017). Energy and exergy analysis of vapour compression refrigeration system using selected eco-friendly hydrocarbon refrigerants enhanced with TiO2-nanoparticle. *International Journal of Engineering & Technology*, 6 (4), 91-97.