A COMPREHENSIVE REVIEW ON SCOPE OF HYDROCARBONS AND NANOREFRIGERANTS IN REFRIGERATION SYSTEM

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Abstract: The most commonly used refrigeration system operates on vapor compression system which consumes high amount of high-grade energy. Also its refrigerants cause environmental problems. Hydrocarbon refrigerants provides best alternative to the conventional halogenated refrigerants in terms of environmental impacts, efficiency and energy consumption. They also have zero ODP and very low GWP. Another way to improve system efficiency and to decrease energy consumption is introduction of nanoparticles in refrigerants (nanorefrigerants) and lubricants (nanolubricants).The aim of this paper is to present a comprehensive review about previous studies regarding application of hydrocarbon refrigerants, nanorefrigerants and nanolubricants in refrigeration systems. Previous results showed that hydrocarbon refrigerants and their mixture can be used as an alternative to halogenated refrigerants for the improvement of various factors such as environmental impacts, efficiency, and COP. Also addition of nanoparticles improves compressor performance, cooling speed and energy consumption.

Index Terms– Hydrocarbon, Refrigerator, VCR, Nano refrigerants.

1. INTRODUCTION

Refrigeration plays a fundamental role in sustainable development since it has many applications in different number of fields in our daily lives. It has been used in many applications including domestic purpose, commercial purpose, industrial purpose etc. The most widely used refrigerators and air conditioning systems works on the traditional vapor compression refrigeration system (VCRs).The high-grade energy consumption of the system is very high and they consume more than 30% of the total world energy consumption. Traditionally used refrigerants are also responsible for high energy consumption and environmental impacts. The use of VCRs will continue to expand worldwide especially in developing countries, due to its high COP. [7]

A large number of chemical substances had been used as a refrigerant. Chloro fluorocarbon (CFCs), hydro chlorofluorocarbons (HCFCs) and hydro fluorocarbons (HFCs) are commonly used as working fluids because of their excellent thermodynamic and chemical properties. CFCs and HCFCs contain chlorine and are responsible for ozone layer depletion. HFCs does not have any chlorine content but their carbon content is responsible for global warming. They have a global warming potential (GWP) higher than that of CO_2 (thousands of times). So all of these refrigerants are needed to be phased out and should be replaced by others with zero ozone depletion potential (ODP) and GWP. But Replacement should not affect the performance of heat exchangers and overall system. In addition, the performance of heat exchangers should be improved to minimize the indirect GWP caused by the electricity generated by the combustion of fossil fuels. [7]

The best possible alternative to replace halogenated refrigerants is hydrocarbons. Hydrocarbons (HCs) are naturally occurring inexpensive refrigerants. Ozone depletion potential is zero and global warming potential is very low for hydrocarbons. More than that, hydrocarbons are not only just good for the environment but also, can be more efficient conductors of heat than halogenated refrigerants. Hydrocarbons can be as pure refrigerants. Their blends also have a good potential in refrigeration system. Moreover Mixture of Hydrocarbon and halogenated refrigerants (halocarbon mixture) can be used as a refrigerant in refrigeration system.

Table 1: Different refrigerants and their environmental impacts [7]

Refrigerant group	**Refrigerants**	**ODP**	**GWP (100 year)**	**Flammability**
CFCs	R11, R12, R115	0.6–1	4750–14,400	Non-flammable
HFCs	R22, R141b, R124	0.02–0.11	400–1800	Non-flammable
HCFCs	R407C, R32, R134a	0	140–11,700	Non-flammable
HFOs	R1234yf, R123ze, R1234yz	0	140–11,700	Flammable
Natural refrigerants	R744, R717, HCs	0	0	Flammable

1.1. Potential of hydrocarbon refrigerants

Hydrocarbons have excellent thermodynamic properties together with suitable physical and chemical properties which are particularly energy-efficient. They provide good energy savings with good system performances and can be used as long term alternatives for refrigerators and air-conditioning refrigerants. [7]

There are two key performance parameters which can largely affect system performance: critical boiling point and normal boiling point. All refrigerants are having different values of normal and critical boiling point. Refrigerants having higher values of critical and normal boiling point give higher system performance. Also vapor density of refrigerant depends on its critical boiling temperature. At higher critical temperature, vapor density will be low. And this affects system performance by reducing volumetric refrigerating capacity. So increasing the critical temperature of a refrigerant decreases the volumetric refrigerating capacity. Hydrocarbons cannot only be used in a system designed specifically for their use but can also be used as a drop-in replacement in system which specifically designed for other refrigerants. For replacement, there are certain factors which should be considered. This factor includes compatibility of oil with hydrocarbon and miscibility of oil with hydrocarbon refrigerants. For better system performance this factors must be considered. In general, HCs are technically useful for small and medium-sized residential and commercial applications, low capacity air-conditioners for vehicles, heat pump, as well as fluid chiller. Recently, the use of HC refrigerants has increased in domestic and industrial application. [7]

Table 2: Physical and environmental properties of hydrocarbons [7]

Refrigerant	**No.**	**Chemical formula**	**Molecular mass (kg/kmol)**	**Critical pressure (bar)**	**ODP**	**GWP (100 year)**
Propane	R290	C_3H_8	44.1	42.5	0	3.3
Butane	R600	C_4H_{10}	58.12	38	0	4
Isobutane	R600a	C_4H_{10}	58.12	36.4	0	3
Ethane	R170	C_2H_6	30.07	48.7	0	5.5
Propylene	R1270	C_3H_6	42.08	46.1	0	1.8
Cyclopropane	RC270	C_3H_6	42.08	54.9	0	1.8
Dimethyl ether	RE170	C_2H_6O	46.07	53.7	0	1

1.2. Nano refrigerants and nano lubricants

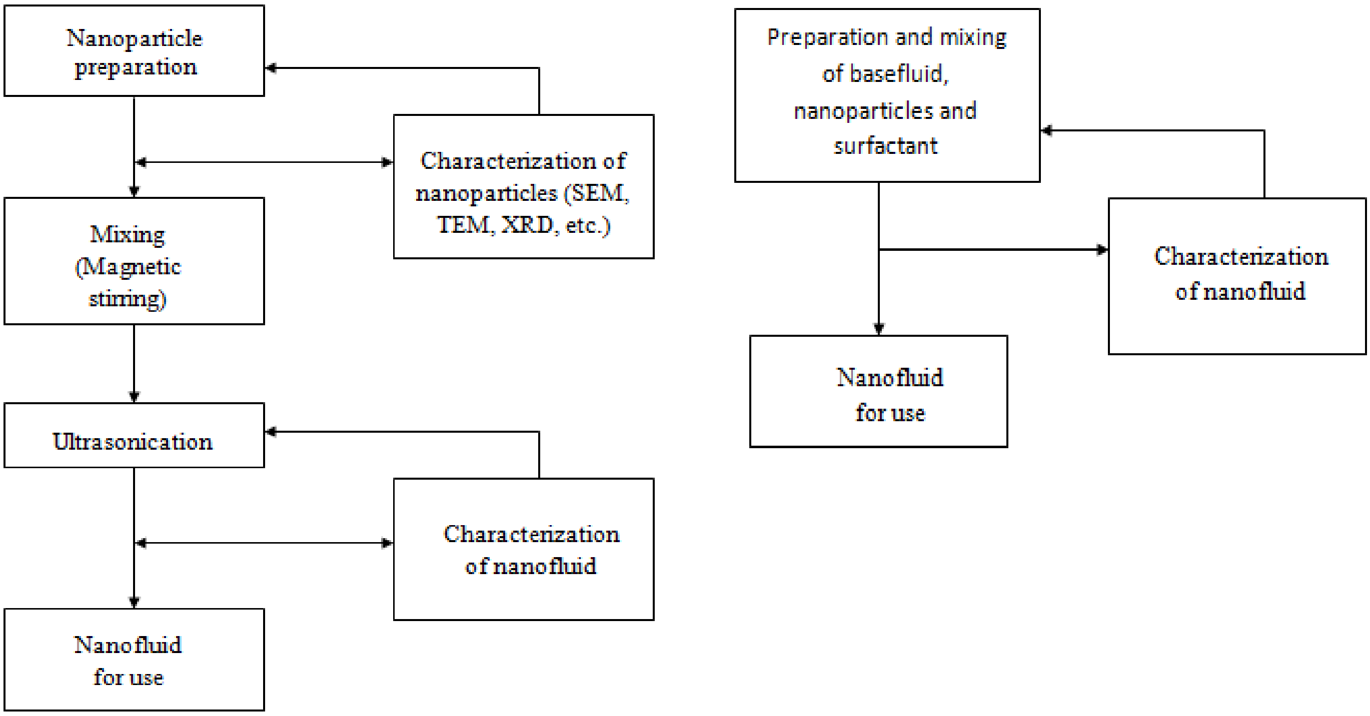
Nano fluids are made of a base fluid and nanoparticles (1–100 nm). Common base fluids include water, organic liquids (e.g. ethylene, tri-ethylene-glycols, refrigerants, etc.), oils and lubricants, bio-fluids, polymer solutions and other common liquids. Materials commonly used as nanoparticles include chemically stable metals (e.g. gold, copper), metal oxides (e.g., alumina, silica, zirconia, titania), oxide ceramics (e.g. Al_2O_3, CuO), metal carbides (e.g. SiC), metal nitrides (e.g. AIN, SiN), carbon in various forms (e.g., diamond, graphite, carbon nano tubes, fullerene) and functionalized nanoparticles. According to the application, nano fluids are classified as heat transfer nano fluids, tribological nano fluids, surfactant and coating nano fluids, chemical nano fluids, process/extraction nano fluids, environmental (pollution cleaning) nano fluids, bio- and pharmaceutical nano fluids and medical nano fluids (drug delivery, functional and tissue–cell interaction). [2]

Many researchers have studied the thermal behavior of nano fluids. Many studies have been conducted to estimate the thermodynamic properties of nano fluids including thermal conductivity, Kinematic viscosity and density. Also there have benn numbers of studies regarding heat transfer characteristics of nano fluid. It has been found that nano fluids can have significantly better heat transfer characteristics than the base fluids. From the available research of nano fluids, the following conclusions has been made [2]:

i) Larger thermal conductivities compared to conventional fluids
ii) A strongly non-linear temperature dependency on the effective thermal conductivity
iii) Enhance or diminish heat transfer in single-phase flow
iv) Enhance or reduce nucleate pool boiling heat transfer which is due either to the systematic scatter in experiments or to the large scenarios which may be encountered
v) Yield higher critical heat fluxes under pool boiling conditions.

Nanorefrigerant was proposed on the basis of the concept of the nano fluids, which was prepared by mixing the nanoparticles and traditional refrigerant. Nanolubricants are also proposed on the basis of nanorefrigerants which is the mixing for compatible oil and various nano particles.

Two methods (one-step method and two-step method) are used for synthesis of nano- refrigerants. Two-step method is commonly used to prepare nanorefrigerants. In this method, the nanomaterials are synthesized as dry powders by thermal decomposition and photochemical methods, transition metal salt reduction, ligand reduction and displacement from organometallics, metal vapor synthesis and electrochemical synthesis methods. After production, the nanosized powder is put into the oil to form nanoparticle/oil mixture. Then, this mixture is dispersed by using different type of dispersion techniques such as ultrasonic agitation, magnetic force agitation, homogenizing, high-shear mixing. In one-step method, vapor phase nanophase powders are condensed into a liquid having low vapor pressure and dissolved in liquid at the same time. The nanoparticles are produced by applying a physical vapor deposition method or liquid chemical method. [2]



For two step method

For single step method

Figure 1: Preparation method for nano fluids [2]

1.3. Potential of nanorefrigerants/nanolubricants

Nanoparticles are basically in solid particle form. For solids, thermo-physical properties are better than that of gases and liquids. They are also good conductor of heat. Nanoparticles are used in refrigeration because of their good thermo-physical properties and heat transfer capabilities. Nanoparticles can be used in refrigeration system which are dispersed in refrigerant or lubricant to check various performance parameters of the systems. They also can be used to improve solubility between oils and refrigerants or can be dispersed in oils improve lubrication properties of oils. For example, TiO_2 nanoparticles can be used as additives to enhance the solubility of the mineral oil with the hydro fluorocarbon (HFC) refrigerant. Refrigeration systems using a mixture of R134a and mineral oil with TiO_2 nanoparticles appear to give better performance by returning more lubricant oil to the compressor with similar performance to systems using R134a and POE oil [21].

In the refrigeration system, the nanorefrigerant can be effectively used as a heat absorber in evaporator. Addition of nanoparticles results in extraction of more heat from the cooled space. Nanorefrigerant works effectively as a coolant in condenser side. Nanolubricant just lubricate the compressor so they work in a separate system. Nanorefrigerants improves the heat transfer; while nanolubricants work more by lubricating the moving piston by having better tribology characteristics. By adding nanoparticles on both refrigerant and lubricant oil, system efficiency can be improved. It can also improve energy consumption of a refrigeration system. Nanorefrigerant and nanolubricant are a great alternative to enhance the performance of refrigeration system due to better heat transfer characteristic, better tri-bological performance, and the properties enhancement of refrigerant-lubricant mixture. The suspended nanoparticles enhance the thermal conductivity of the base lubricant and refrigerant-lubricant mixture, and . The increase in thermal conductivity property can benefit to the heat exchanger of the system. [1]

In condenser, more heat will be removed from the system due to better convective heat transfer. This will result with higher heat transfer coefficient however with minimum penalty in pumping power. The nanofluid also can probably enhance the evaporator performance. This is due to better heat transfer coefficient and critical heat flux in flow boiling and pool boiling. The use of nanolubricant can also benefit to the compressor performance by giving better tribological properties of friction coefficient and wear of the compressor. Thus resulting to low pumping power requirement and better wear characteristic consequently more life cycle of the moving components. However, the increase in concentration of nanoparticles will affect significantly to the viscosity of the nanofluid. Therefore, a stable solution of nanorefrigerant and nanolubricant mixture need to be identified in order to have better performance in vapour compression of refrigeration system for specific application. [1]

2. Previous studies related to application of hydrocarbon refrigerants and nano refrigerants

2.1. Studies related to hydrocarbons and their mixtures

Lee and Su [12] studied experimentally the performance of a domestic refrigeration system with R600a as an alternative to R12 and R22. The experimental unit is shown in Figure 2. Results showed that the cooling capacity of R600a found to be higher than that of R12 and R22. Power consumption for refrigerant R600a was between 230 W and 300 W and the refrigerant mass was 150 g and the COP was between 1.2 and 4.5.

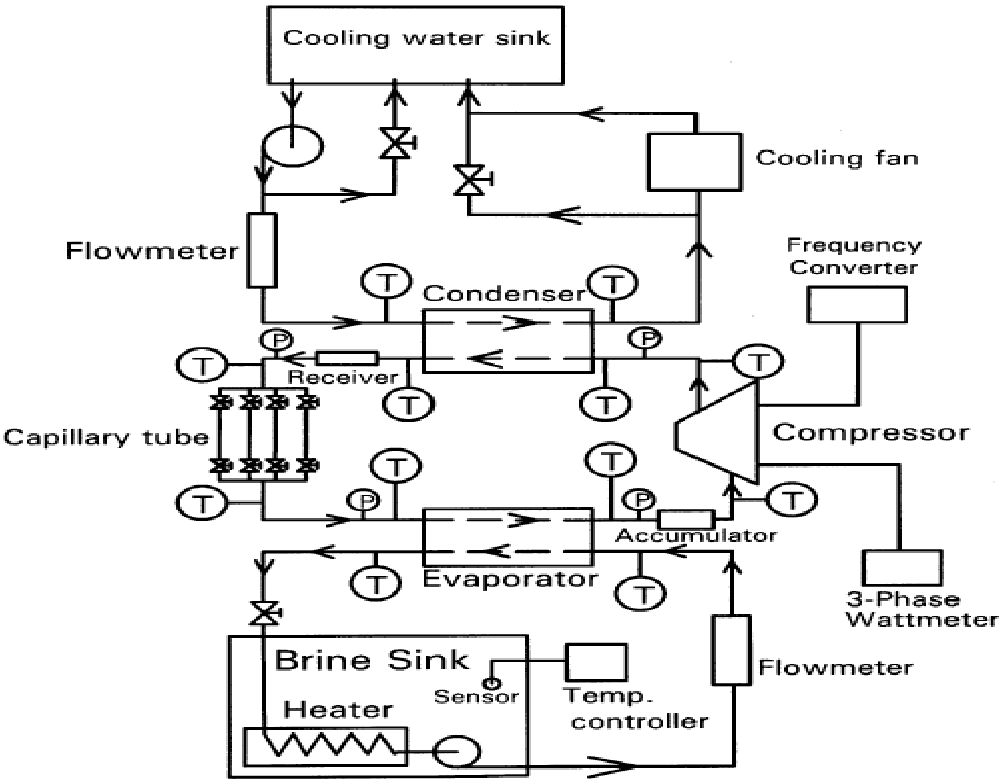


Figure 2: Schematic of vapor compression refrigeration system. [12]

Morsi and Mohamed [5] intended to find exergetic and energetic performance of domestic refrigerator. Aim of the study was to compare energetic and exergetic performance of domestic refrigerator using various hydrocarbon refrigerants as an alternative to refrigerant R134a. various hydrocarbon refrigerants used were R290, R600a and commercial LPG. Comparison of the energetic and exergetic performance of a domestic refrigerator using R290, R600, and commercial LPG as an alternative to R134a were carried out. Energetic and exergetic performance of domestic refrigerator was considered as baseline to compare with hydrocarbon refrigerants. The evaporator temperature ranges from 30 to 0 ˚C while the condenser ranges from 30 to 50 ˚C. Thermodynamic equation and thermodynamic properties were estimated using specific software. MATLAB software is used for solving the thermodynamic equations, while the thermo-physical properties are calculated using REFPROP software. The results show that R600 has the highest COP and exergetic efficiency, while LPG has the lowest. The COP value for R134a is higher than that for LPG by 10%. Also, the exergetic efficiency is higher by 5%. However, LPG has the advantage of being not expensive, available in large amounts and zero ozone depletion potential and low global warming potential.

Hamilic et al.[6] studied the effect of various refrigerants on the performance parameters of the domestic refrigerator. The refrigerants used were R290, R12 R401a and R22. Cooling capacity of R290 was the largest of the refrigerants tested, and higher than the original refrigerant R12. The COP of R290 was found to be similar to that of R12. So it can be used as attractive alternative to existing CFC refrigerants. The refrigerant R401a displayed a level of performance for both capacity and COP that was very similar to R12 thus confirming that it can be considered to be a drop in replacement for R12. The substitution of this refrigerant would allow the original R12 to be disposed of in an environmentally sensitive way but an economic analysis of a retrofit must compare the projected lifetime service and maintenance costs for the system with the original R12 and R401a.

Rasti et al.[17] conducted study on refrigeration system using R436A (mixture of 46% iso-butane and 54% propane) and R600a (pure iso-butane) as hydrocarbon refrigerants. This refrigerants were tested using HFC type compressor (designed for R134a) and HC type compressor (designed for R600a). The results show that for HFC type compressor, the optimum refrigerant charges are 60 g and 55 g for R436A and R600a, respectively. The energy consumption of R436A and R600a at the optimum charges is reduced about 14% and 7%, respectively in comparison to R134a for HFC type compressor. For HC type compressor, the optimum refrigerant charges for R436A and R600a are both 50 g, and the energy consumption of R436A and R600a at the optimum charges are reduced about 14.6% and 18.7%, respectively. It can be concluded that both the refrigerants can be used as an alternative to halogenated refrigerants in terms of performance parameters and environmental impacts.

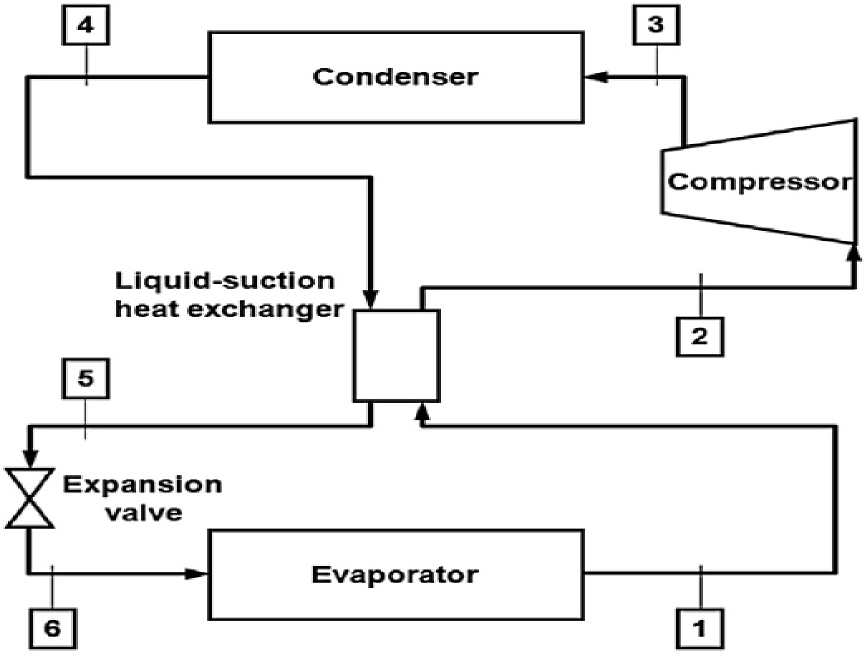


Figure 3: VCR system with suction line heat exchanger. [5]

Jwo et al. [9] investigated home refrigerator with an aim to replace halogenated refrigerant with hydrocarbon mixture. Hydrocarbon used for mixture was R290 and R600a (50:50) as an alternative to refrigerant R-134a for home refrigerators of 440L capacity. The hydrocarbon refrigerants of R290 and R600a are friendly for environmental protection du to its zero ODP and low GWP. And also have good refrigerating behavior in comparison with CFCs, HCFs, or HFCs refrigerants. The results show that refrigerating effect is improved by using hydrocarbon refrigerant. Moreover, the total consumed energy is saved 4.4% and applied mass of refrigerant is reduced 40% compared to 150g mass of R134a.

Mohanraj et al. [15] conducted experimental study on HC mixture of R290 and R600a (45.2:54.8 according to mass, respectively) as an alternative to R134a in 200 L domestic refrigerator. The schematic diagram of the system is shown in Figure 4. Results showed that the system with HC mixtures had lower energy consumption by 11.1%, lower pull-down time by 11.6%, a lower ON-time ratio by 13.2% and higher COP by about 3.25–3.6% than that of R134a. The compressor discharge temperature of the system with HC mixture was about 8.5–13.4 K lower than that of the system with R134a.

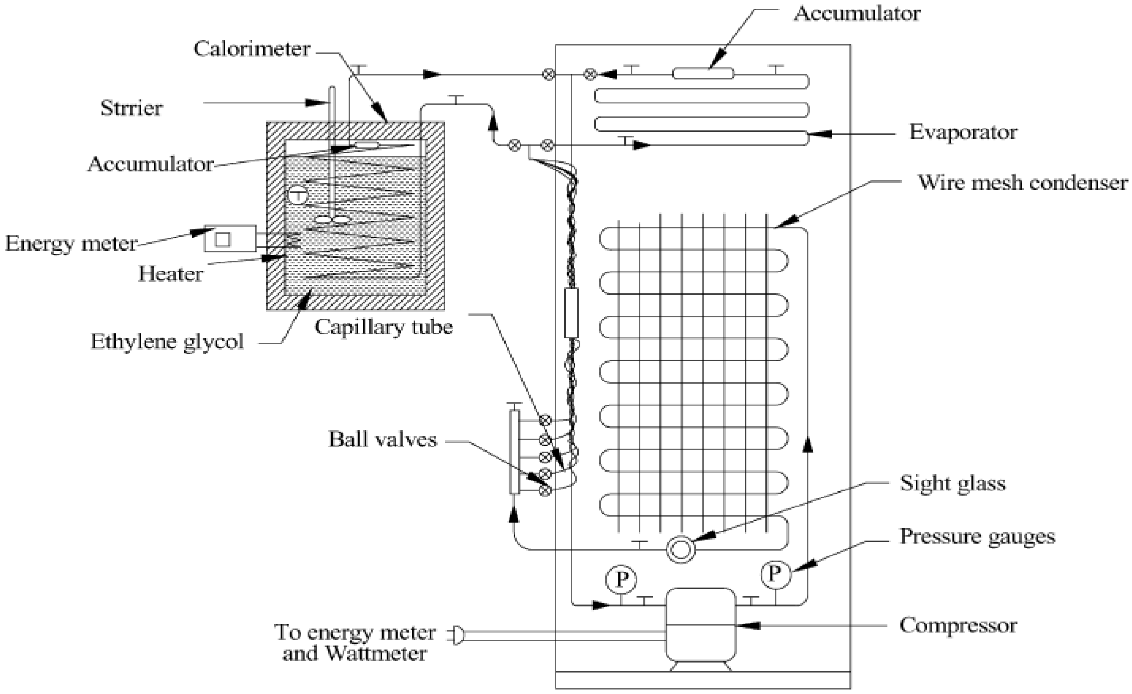


Figure 4: Schematic diagram of domestic refrigerator experimental setup. [15]

Lee et al. [11] studied the performance of a small-capacity directly cooled refrigerator using hydrocarbon mixture as an alternative to halogenated R134a. Mixture of hydrocarbon refrigerants (R290 and R600a) with mass fraction of 55:45 was used as an alternative to R134a. The compressor displacement volume of the alternative system with R290/R600a (55/45) was modified from that of the original system with R134a to match the refrigeration capacity. Experiments were carried out for B\both systems with R290/R600a (55/45) and R134a. Based on results refrigerant charge and length of capillary tube was optimized. After optimization, Pull-down test and the power consumption test were carried out for both the system. The refrigerant charge of the optimized R290/R600a system was approximately 50% of that of the optimized R134a system. The capillary tube lengths for each evaporator in the optimized R290/R600a system were 500mm longer than those in the optimized R134a system. The consumption was found for both the refrigerant and accordingly comparison was made. The power consumption for R134a system was found to be 12.3% higher than that of the R290/R600a. The cooling speed for R290/R600a was found to be improved by 28.8% compared to R134a system.

Wongwises and Chimres [22] studied experimentally the application of HC mixtures (R290, R600, and R600a) in 240 L domestic refrigerator to replace R134a. They concluded that the most convenient alternative refrigerant to R134a was 60%/40% propane/butane mixture. As compared with R134a, the refrigerator requires less energy consumption by 86% per day due to its high latent heat. The refrigerant mass of the system with HC mixture was about 50% of that of the system with R134a (120 g).

Thakar et al. [20] carried out performance on refrigeration system using various refrigerants. Various refrigerants tested was R290a, R600, R600a, R152a, R134a and R436a. Refrigerants R290, R600a, R600 and R152a were found to be a good environmentally refrigerants with desirable environment properties. Ozone Depletion Potential (ODP) for all these hydrocarbons is zero and has low global warming potential (GWP). In comparison with R134a, the COP of the R152a found to be 17% is higher than the R134a while COP of R290 is only 18% less than R134a. During the evaporator temp range of -25 ˚C to - 300 ˚C, R152a has a high COP than another refrigerant while mixture of R 134a and R 600 and R 600a has low COP in compare with another refrigerant. Now power consumption is reduced by 18% for R 152a than the R 134a. Power consumption for R290 and R436a is higher than R134a and R152a. For the refrigerant R600a and R600 and mixing of R134a and R600, the power consumption is found to be higher than that the R134a.

2.2. Studies related to nanorefrigerants and nanolubricants

Jwo et al. [8] investigated effect of nanoparticles on a performance of refrigerator with R12 refrigerator which originally works with R134a. Mixture of R12/Al_2O_3/MO is used as nanorefrigerant with different weight fractions (0.05, 0.1, and 2%) of Al_2O_3 particles R134a was replaced by R12, after POE was replaced by MO and finally, Al_2O_3 nanoparticles were added in the R12/MO mixture, and measurements were performed for each one. Results showed that the system that uses R12 refrigerant has a lower compression ratio as compared to the system with the working fluid of R134a. When the working fluid has 0.1 wt% of nanoparticles, the energy consumption is reduced by 2.4% as compared to pure R134a system.

Subramani and Prakash[19] investigated performance parameters of a vapor compression refrigeration system with R134a/Al_2O_3 nanorefrigerant as an operating fluid. They used POE oil, SUSISO 3GS oil and SUSISO 3GS oil/Al2O3 mixture as lubricant. COP for mixture of R134a and SUSISO 3GS oil/Al_2O_3 found to be higher than other lubricants. The energy consumption of the compressor decreased by 25% and COP of the refrigeration system increased be 33% with SUSISO 3GS oil/Al2O3 mixture instead of POE oil as lubricant. Freezing capacity of the refrigeration system was also increased by using R134a/Al_2O_3 nanorefrigerant in the refrigerant system.

Kumar et al. [10] investigated effect of a nanorefrigerant on a vapor compression refrigeration system. They used Al_2O_3-PAG oil as nano-refrigerant in R134a vapor compression refrigeration system. Energy consumption test and cooling capacity tets were carried out to investigate performance of refrigeration system. The results indicate that Al_2O_3 nano refrigerant works normally and safely in the refrigeration system. The refrigeration system performance was better than pure lubricant with R134a working fluid with 10.32% less energy used with 0.2%V of the concentration used. The results indicate that heat transfer coefficient increases with the usage of nano Al_2O_3. Thus using Al_2O_3 nanorefrigerant in refrigeration system is found to be feasible.

Wang et al. [21] performed experiment on refrigeration system to check solubility of mineral oil with hydrofluorocarbon refrigerants using nanoparticles as additives. TiO2 nanoparticles can be used as additives to enhance the solubility of the mineral oil in the hydrofluorocarbon refrigerant. In addition, refrigeration systems using a mixture of HFC134a and mineral oil with TiO2 nanoparticles appear to give better performance by returning more lubricant oil back to the compressor compared to systems using HFC134a and POE oil.

Bi et al.[3] researched the domestic refrigerator performance which uses R134a as the working fluid and TiO2/Al_2O_3 nanoparticle addicted mineral oil as the lubricant instead of POE oil, experimentally. Energy consumption of the system with 0.1% mass fraction TiO2 nanofluid was 26.1% lower than the POE oil state. Al_2O_3 addicted nanofluid also showed nearly the same performance. Their results also showed that using the mixture of nanoparticle–mineral oil mixture instead of POE oil will increase system efficiency.

Padmanabhan and Palanisamy [16] performed an experiment to increase COP and the energy efficiency of a vapor compression refrigeration system by using the mixture of refrigerant, nanoparticle, and lubricant. They used R134a, R436A, (R290/R600a-56/ 44 wt %) and R436B (R290/R600a-52/48 wt %) as refrigerant. Nano particles selected for testing was TiO_2 and POE and mineral oil was selected as lubricants. They also investigated irreversibility at different processes. The COP of vapor compression refrigeration systems found to be higher for R134a/TiO_2/MO nanorefrigerant when compared to R436A/TiO_2/MO and R436B/TiO2/MO nanorefrigerants. The COP of vapor compression refrigeration systems found to be higher using both R436A/POE oil and R436B/POE oil mixtures compared to R134a/POE oil mixture. Total irreversibility of R436A/TiO_2/MO and R436B/TiO_2/MO nanorefrigerants was higher than R134a/TiO_2/MO. Energy efficiency of the R134a/TiO_2/MO mixture was lower than the R436A/ TiO_2/MO and R436B/TiO_2/MO/mixtures.

Sabareesh et al. [18] presented an experimental study on vapor compression system. Purpose of the study was to increase the COP of a system with the use of nano particles at different volume concentration. They also investigated the viscosity and lubrication characteristics of pure mineral oil lubricant with TiO_2 nanoparticle. They tested nanoparticles having volumetric concentrations of 0.05%, 0.010%, and 0.015% and found that the optimum nanoparticles volumetric concentration is 0.01% when considering viscosity, friction coefficient, and surface roughness measurements. Results showed that power consumption is decreased by 11% and COP is increased by 17% with the usage of nanorefrigerant comprised of R12/TiO2/mineral oil in the vapor compression refrigeration system (instead of R12/mineral oil mixture).

Bi et al.[4] carried out experimental investigation on a refrigerator with TiO_2-R600a nanorefrigerants to test performance parameters which includes using energy consumption test and freeze capacity test. The results showed that TiO_2-R600a nanorefrigerants work ordinarily and securely in the fridge. Energy consumption was reduced by 9.6% with 0.5 g/L TiO_2-R600a nanorefrigerant.

Mahbubul et al. [14] investigated the relation between thermal performance and the increase of COP performance for certain refrigeration systems. Effect of nanoparticles on various performance parameters and on thermo physical properties was analyzed. It was found that thermal conductivity, dynamic viscosity, and density of Al_2O_3/R134a nanorefrigerant increased by 28.58%, 13.68%, and 11%, respectively compared to base refrigerant (R134a) for the same temperature. Additionally, Al_2O_3/R134a nanorefrigerant demonstrates the maximum COP of 15%, 3.2%, and 2.6% for thermal conductivity, density, and specific heat, individually compared to R134a base refrigerant.

Lou et al. [13] investigated the effectiveness of nanolubricants toward enhancing performances in domestic refrigerators. The study also showed power utilization of the domestic refrigerators reduced by 4.55% when utilizing graphite nanolubricants with a mass division of 0.1%.

Table 3: previous studies regarding application of nanorefrigerants/nanolubricants

Researcher	**Refrigerant**	**Lubricant**	**Nano particles**	**Average particle diameter size**	**Evaluation**
Jwo et al. [8]	R134a/R12	POE/MO	Al_2O_3	20-30 nm	2.4% less energy consumption with R12.
Subramani and Prakash [19]	R134a	POE	Al_2O_3	< 50 nm	25% less energy consumption.
Kumar and Elansezhian	R134a	PAG	Al_2O_3	40 , 50 nm	10.32% less energy consumption and increased COP.
Wang et al. [21]	R134a	MO	TiO_2	_	Better performance than R134a and POE oil.
Bi et al. [3]	R134a	MO	TiO_2	50 nm	Energy consumption reduced by 26%.
Bi et al. [4]	R600a	MO	TiO_2	50 nm	Energy consumption and freezing capacity increased by 5.94 and 9.60%
Sabareesh et al. [18]	R12	MO	TiO_2	30, 40 nm	COP increased by 17% compared to R12 system.
Padmanabhan et al. [16]	R134a, R436A	MO	TiO_2	_	TiO_2 nanoparticles can be used to reduce irreversibility.
Mahububul et al. [14]	R134a	MO	Al_2O_3	_	COP increased by 15%.
Lou et al. [13]	R600a	MO	Graphite	50 nm	4.55% less energy consumption.

3. CONCLUSIONS

Based on the results of different studies relevant to hydrocarbons and nanorefrigerants, the following points can be concluded:

i) The use of hydrocarbons as refrigerants can reduce the energy consumption and offer good drop-in replacements for the existing halogenated refrigerants.

ii) Hydrocarbons can be used to improve factors such as energy efficiency, COP, refrigerant charges, and compressor's discharge-temperatures etc.

iii) Charge amount for hydrocarbon refrigerant is less compared to optimized charge of halogenated refrigerants.

iv) Energy consumption can be reduced by using nanorefrigerants. Freezing speed and COP in cooling devices are increased by adding nanoparticles to the refrigerants.

v) Nanofluids help in performance enhancement of compressor and heat exchangers (Condenser and evaporator).

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