HEAT TRANSFER AND ENERGY EFFICIENCY ANALYSIS OF DOMESTIC REFRIGERATOR USING NANOREFRIGERANT

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Abstract

Until 200 years ago, refrigeration was achieved by natural ice from mountains. In the past fifty years, refrigeration system has experienced massive technological change. It has gone from the era of the iceman to that of the advanced technology. Nanotechnology as a modern invention can be a promising technological leap in refrigeration. Nanorefrigerant, as a new and complicated application of nanofluid in the refrigeration system remains unknown because of the complex process that happens in the refrigeration system. This study focuses on the performance of the domestic refrigerator using nanorefrigerant based on energy approach. In this study, stability of nanofluid, effects of using nanorefrigerant on refrigeration system, energy and heat transfer analysis of domestic refrigerator in case of using nanorefrigerant have been experimentally investigated. It is found that the stability of nano-lubricant oil decreases by increasing the nanoparticle concentration in basefluid (R134a). Evaporator temperature gradient is increased by increasing the nanoparticle concentration. The maximum temperature gradient increased in the evaporator was 20.2% in case of using 0.1%-Al_2O_3 and was about $1.9\,^{\circ}C$. It has been found that the compressor consumes 3.821 *kWh/24h* by using basefluid. The results show that the energy consumption of refrigerator decreased by around 2.69% when the 0.1%-Al_2O_3 nanoparticle was added to the system.

Abstrak

Sehingga 200 tahun yang lalu, penyejukan telah dicapai oleh ais asli dari gunung. Dalam lima puluh tahun yang lalu, sistem penyejukan telah mengalami perubahan teknologi besar-besaran. Ia telah pergi dari era yang tukang es dengan teknologi canggih. Nanoteknologi sebagai ciptaan moden boleh menjadi lonjakan yang menjanjikan teknologi dalam penyejukan. Nanorefrigerant, sebagai suatu permohonan baru dan rumit nanofluid dalam sistem penyejukan kekal cabaran kerana proses yang kompleks yang berlaku dalam sistem penyejukan. Kajian ini memberi tumpuan kepada prestasi peti sejuk domestik menggunakan nanorefrigerant berdasarkan pendekatan tenaga. Dalam kajian ini, kestabilan nanofluid, kesan menggunakan nanorefrigerant pada sistem penyejukan, tenaga dan haba analisis pemindahan peti sejuk domestik dalam kes menggunakan nanorefrigerant telah uji kaji disiasat. Ia mendapati bahawa kestabilan minyak nano pelincir berkurangan dengan meningkatkan kepekatan nanopartikel dalam basefluid (R134a). Kecerunan suhu penyejat meningkat dengan meningkatkan kepekatan nanopartikel. Suhu maksimum kecerunan peningkatan dalam penyejat adalah 20.2% dalam kes menggunakan 0.1% Al2O3 dan adalah kurang 1.9 $^{\circ}C$. Ia telah mendapati bahawa pemampat menggunakan 3,821 kWh/24h dengan menggunakan basefluid. Keputusan menunjukkan bahawa penggunaan tenaga peti sejuk menurun sekitar 2.69% apabila 0.1% Al2O3 nanopartikel telah ditambah kepada sistem.

Acknowledgement

First and foremost, I would like to thank Allah for giving me this opportunity to do this dissertation. I would like to take this opportunity to extend my deepest gratitude and appreciation to my project supervisor, Professor Dr. Saidur Rahman Abdul Hakim for his constructive advice, guidance, commitment, and supportive encouragement throughout my studies.

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List of Symbols and Abbreviations

CFC	Chloro-flouro-carbon
COP	Coefficient of performance
GWP	Global warming potential
HCFC	Hydro-chloro-flouro-carbon
HFC	Hydro-flouro-carbon
h_c	Heat transfer coefficient ($kW/m^{2\cdot}K$)
MO	Mineral oil
ODP	Ozone depletion potential
POE	Polyol ester
C_p	Specific heat capacity at constant pressure (kJ/kg.K)
G	Mass flux (kg/m^2)
h	Specific enthalpy of the refrigerant (kJ/kg)
h_c	Heat transfer coefficient (kW/m2K)
m	Mass flow rate (kg/s)
T	Temperature
P	Pressure in bar (kN/m^2)
q	Heat removal rate (kJ/kg)
W	Work of compression (kJ/kg)

η	Energy efficiency (%)
μ	Viscosity (Pa.s)
ρ	Density of fluid (kg/m^3)
ϕ	Volume fraction (%)

1. Introduction

1.1 Research background

Around 200 years ago, the refrigeration was achieved by natural ice from the mountain. Making ice by nocturnal cooling and evaporating cooling were used to prepare a cold space to store and cool down foods. The first artificial refrigerating machine made by Professor William Cullen in the year 1755 in his laboratory. Vapor compression systems, vapor absorption systems, and gas cycle systems are the various types of refrigeration systems. The domestic refrigerator which used natural ice (domestic ice box) was invented in 1803 and was used for almost 150 years without much alteration (Althouse et al., 2004).

In the past fifty years, refrigeration system has experienced massive technological change. It has gone from the era of the iceman to that of the advanced technology (Figure 1.1).

Many of the recent changes in the refrigeration system are due to rapid changes in technology and a significantly increasing concern for the environment. Besides, of the harmful effect of refrigerant on the environment, scientists have warned that the continuous release of refrigerants to the atmosphere will destroy the earth's ozone layer. Actually, ozone layer prevents earth against the damaging ultraviolet rays of the sun, and destruction of this protective layer would affect humans, animals, plants, and sea life.

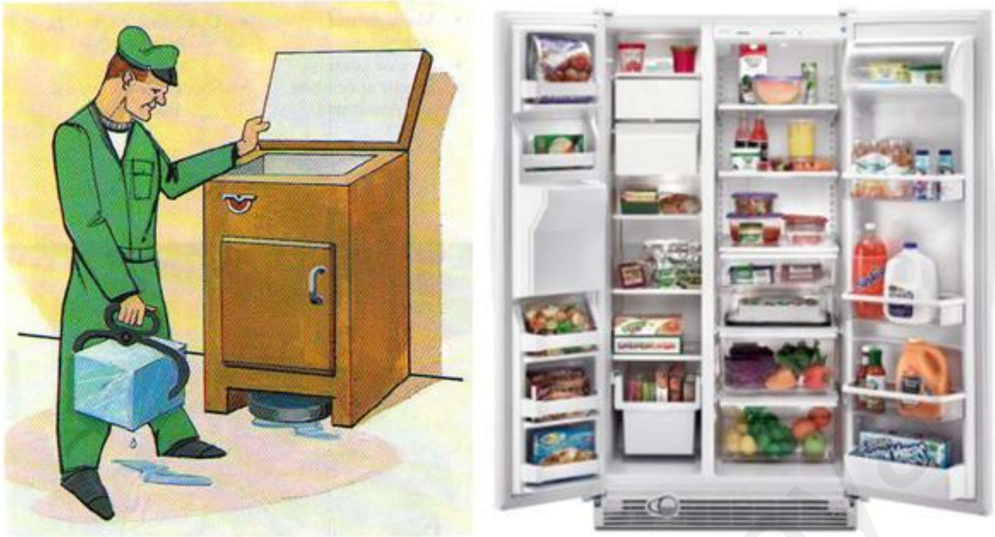

Figure 1.1 Only a half century ago and today's refrigeration system

In a realistic point of view, the modern life has been touched by refrigeration. Cooling and freezing of meat and meat products makes possible their handling in a much more sanitary way than would be possible without mechanical refrigeration. Beverage, desserts, and even staple foods are all at least partially processed by refrigeration equipment. Many fruits and vegetables are refrigerated immediately upon being harvested. The quality of such products is much better for this reason. Since refrigeration is used in so many enterprises, improving overall performance should be taken into account.

1.1.1 Refrigeration technology

Several disadvantages of the ice box that caused to start to develop domestic refrigerators using mechanical systems since 1887. The first domestic electric refrigerator produced by General Electric Company in 1911. Sulphur dioxide, methyl chloride, and methylene chloride used as refrigerant. Then they replaced by Freon-12 in 1930s. After a short time, water-cooled base condenser replaced by air-cooled condenser. The first absorption based domestic refrigerator, which was proposed by

Platen and Munters, was made by Electrolux Company in 1931 in Sweden. Nowadays, a domestic refrigerator becomes an essential appliance around the world. The modern refrigerators use either hydro-fluoro-carbon (R-134a) or iso-butan as refrigerant.

1.1.2 Nanotechnology

Application of nanoparticle in various fields of engineering has become more important in some aspects and remains in challenges. Nanofluid as suspended nano size particles in the fluid has faced with some difficulties due to differences in the fundamental properties of fluid and solid particles. Although these differences make the mixture properties too much different compared to the base fluid, and it can be a positive point of this mixture, instability of nanoparticle in a basefluid as a main problem of this new fluid is taken into account. By the way, incredible increasing in some thermal properties of the mixture puts it to the center of attention. Meany researches have been done with different aspects like fundamental investigation, application, and characterization of a different kind of nanoparticles in different fluids. Nanorefrigerant, as a new and complicated application of nanofluid in the refrigeration system remains unknown because of a complex process that happens in the refrigeration system. The status of the fluid is changed several times between liquid and vapor. Therefore, the action of nanorefrigerant in a phase-change process such as migration of nanoparticle with basefluid, sedimentation, and thermophysical characteristics in different phases is very controversial.

1.2 Scope of Study

This study focuses on the performance of the domestic refrigerator using nanorefrigerant based on energy approach. To analyse the heat transfer and energy efficiency of the refrigeration system experimental study is conducted and analytical calculation is performed based on the experimental data. Since there is not enough information about the impact of using nanorefrigerant in the refrigeration system, this experiment can be a good mean to judge the effect of nanoparticles on the performance of the refrigeration system.

1.3 Significance of the study

Comparatively few investigations have been considered to the certain effect of nanorefrigerant on the refrigeration system, and most of them have been worked on fundamental properties of nanorefrigerant or effect of using nanorefrigerant on the thermal performance of a simple pipe. In addition, the effect of nanorefrigerant concerning the usability of nanorefrigerant in the real refrigeration system is very important. The results from this study can open the eyes to the future works, which can increase confidence to continu investigation on nanorefrigerant applications or stop it and come back to the fundamental investigations. The present study has also investigated the effect of using different mass fractions of nanoparticle in the refrigeration system. It is expected that results from this study can help researchers and engineers who are interested in working in this field.

1.4 Objective of the study

- To examine the stability of nanoparticle in lubricant oil
- To analyze the effect of nanorefrigerant on heat transfer of domestic refrigerator
- To investigate the energy consumption of the refrigeration system in case of using nanorefrigerant
- To compare the effect of different mass fractions of nanoparticle on heat transfer rate of domestic refrigerator

1.5 Organization of the study

In the context of this study, the concept and importance of using nanorefrigerant in refrigeration system are explained in Chapter 1. A comprehensive review of the refrigeration system, nanorefrigerant and fundamental properties of the nanorefrigerant and nano lubricant oil that is used in refrigeration system based on the existing studies in the literature is presented in Chapter 2. The applied methodology, experimental set-up, facilities, condition, and procedures in this study are explained in Chapter 3, where the experimental set-up, facilities, conditions, and procedures are explained. The achieved results that contain the analysis of heat transfer and energy efficiency of evaporator and condenser, and the overall efficiency of domestic refrigerator using nanofluid with different mass fraction compared to the basefluid are presented in Chapter 4. Finally, the concluding remarks of the study are summarized in the conclusion and recommendation in Chapter 5.

2. Literature Review

2.1 Overview

This chapter gives an overview of the relevant literatures on heat transfer and energy efficiency analysis of domestic refrigerator where vapor compression systems and nanotechnology are used.

2.2 Refrigeration Process

In order to understand the effect of nanorefrigerant in refrigeration process, it is necessary to understand the principle of a normal vapor-compression refrigeration cycle. A prevalent vapor compression cycle, which encompasses of a compressor, evaporator, condenser, and expansion device, is shown in Figure 2.1.

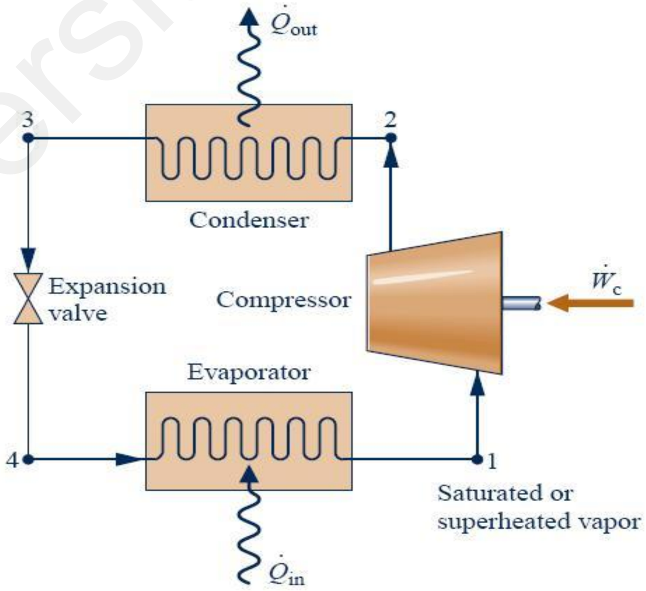

Figure 2.1 Schematic of a Vapor Compression System

(Micael et al., 2011)

Refrigeration cycle, which is shown in Figure 2.1 and Figure 2.2, works as a process to transfer heat from a cold space (evaporator) to the hot space (condenser). Evaporator as a heat absorption device is placed in the cold space, and condenser as a heat rejection device is placed in the ambient air. Refrigerant enters the compressor (point 1) as a gas and is compressed to a higher temperature. The superheated vapor refrigerant leaves the compressor and enters the condenser (point 2). Condenser rejects heat to the surroundings during a constant pressure process. Saturated liquid refrigerant leaves the condenser (point 3) and enters the expansion device. Expansion device can be a valve or capillary tube. During this process, temperature of refrigerant decreases, because of decreasing the pressure, and reaches to the temperature lower than the desired temperature of evaporator (point 4). Vapor-liquid mixture of refrigerant enters the evaporator in order to remove heat from the refrigerated space; at a near constant pressure. Heat is absorbed by the refrigerant from the refrigerated space; because the temperature of the refrigerant is lower than the desired temperature of the cold space; and allowing the refrigerated space to cool down. Saturated vapor leaves the evaporator (point 1) and returns to the compressor to start the cycle once again.

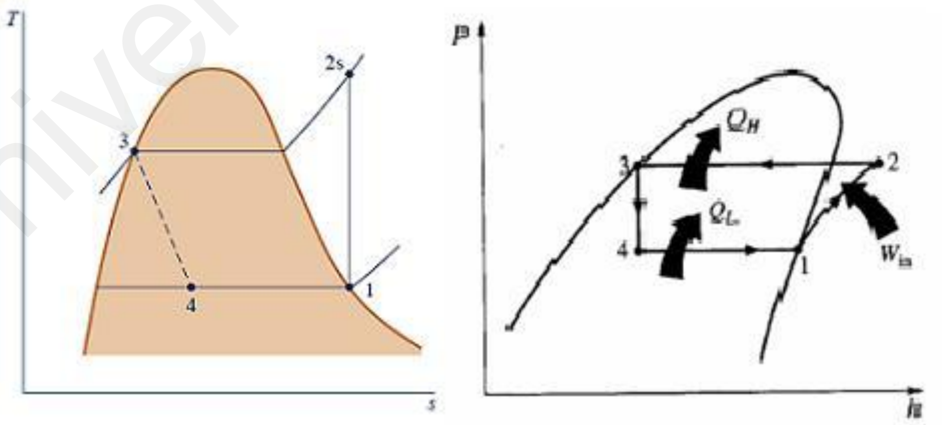

Figure 2.2 T-S and P-h diagram of an Ideal Refrigeration Cycle

(Micael, et al., 2011)

The above explanation refers to the ideal refrigeration cycle. There is some deviation in the actual refrigeration cycle compared to the ideal cycle, which indicated in Figure 2.3.

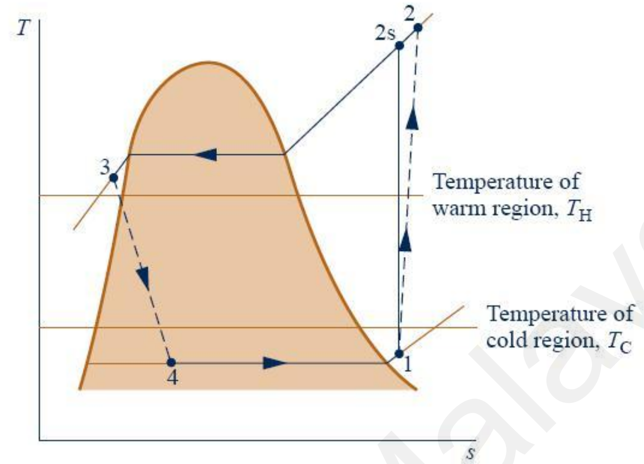

Figure 2.3 T-S diagram of an Actual Refrigeration Cycle

(Althouse, et al., 2004; Micael, et al., 2011)

The most deviations in the actual vapor-compression cycle occur due to the irreversibilities that occur in various components. Fluid friction (causes pressure drop) and heat transfer to or from the surroundings are the most common sources of irreversibility. The *T-s* diagram of an actual vapor-compression refrigeration cycle (Figure 2.3) shows the deviation between the ideal and actual vapor-compression cycles in different point of the cycle. These deviations include, 1) slight overdesigning the system to ensure that the refrigerant is slightly superheated at the compressor inlet, 2) heat gain in the connecting line, and pressure drops in the evaporator and connecting line is an increase in specific volume, 3) involving the frictional effect, which increases the entropy, and heat transfer, which may increases or decreases the entropy, depending on the direction and, 4) some pressure drop in the condenser as well as in the line connecting the condenser to the compressor and to the throttling valve (Cengel & Boles, 2007).

2.3 Refrigeration Medium

A refrigerant is a compound that is used to provide cooling or freezing by its phase change capability (gas/liquid) at low temperature. Mostly, it is used in refrigerators/freezers and air-conditioners.

2.3.1 Refrigerant

A refrigerant is a heat transfer medium, which is used in refrigeration system that undergoes a phase change between gas and liquid. Generally, there are three common types of refrigerants: *choloro fluoro carbons* (CFCs), *hydro chloro fluoro carbon* (HCFCs), and *hydro fluoro carbon* (HFCs). CFCs were replaced by HCFCs and HFCs because of high ozone depletion potential.

The ozone layer is a fairly thin layer of the earth's atmosphere that protect all life forms on the earth from damaging ultraviolet rays of the sun and assist in maintaining stable temperature. CFCs (such as R 11) are a family of chemicals containing chlorine, fluorine, and carbon that cause depletion of the ozone layer. This concern is define as a number for each refrigerant to express its ozone depletion potential (ODP) and it is equal to the ratio of the rate of ozone depletion of 1 lb of any halocarbon to that of 1 pound of CFC-11. The ODP of CFC-11 is assigned a value of one. This value is zero for HFC-134a. It means there is no negative effect of using this refrigerant to the depletion of ozone layer (Althouse, et al., 2004; Wang, 2000)

Refrigerants may also have contribution on global warming which is expressed by GWP (Global Warming Potential) and it is the ratio of calculating warning for each unit mass of gas emitted to the calculated warming for a unit mass of reference gas HFC-11 (or CO_2)- calculated. GWP is about 0.28 for R-134a (Althouse, et al., 2004; Wang, 2000). The ODP and GWP of various refrigerants are shown in Table 2.1.

Table 2.1: The Ozone Depletion Potential (ODP) and global warming potential (GWP) of various refrigerants

Refrigerant	Chemical Composition	Ozone Depletion Potential (ODP)	Global Warming Potential (GWP)
Carbon Dioxide	CO2	0.0	1.0 (base)
R-11	CFC	1.0 (base)	1.30
R-12	CFC	0.93	3.7
R-22	HCFC	0.05	0.57
R-113	CFC	0.83	1.9
R-114	CFC	0.71	6.40
R-115	HFC	0.38	13.80
R-123	HCFC	0.02	0.28
R-125	HFC	0.0	
R-134a	HFC	0.0	0.40
R-401A	HCFC	0.03	
R-401B	HCFC	0.035	
R-402A	HCFC	0.03	
R-402B	HCFC	0.02	
R-507A	HFC	0.0	

Household refrigerators typically use R134a as a refrigerant, because it has zero ozone depletion potential, favourable thermodynamic properties, and is non-flammable.

2.3.2 Nanorefrigerant

There are a limited number of investigations on nanorefrigerant available in the literatures. Peng et al. (Peng et al., 2009) have investigated the heat transfer characteristics of refrigerant based nanofluid flow boiling inside a horizontal smooth tube. They have found that the heat transfer coefficient of refrigerant-based nanofluid is larger than that of pure refrigerant. The nucleate pool boiling heat transfer enhancement of refrigerant-based nanofluid with low concentration of additives was reported by Peng et al. (Peng et al., 2011). The experiment by Henderson et al. (Henderson et al., 2010) on the flow-boiling of R-134a/polyolester mixture showed that the heat transfer coefficient increases more than 100% over baseline R-134a/polyolester by adding CuO nanoparticle into the mixture of R-134a and polyolester oil. In addition, they have found excellent dispersion of R-134a/polyolester oil with CuO nanoparticle. Several experimental articles investigated the characterization of refrigerant-based nanofluid (Ding et al., 2009; Mahbubul et al., 2011, 2012; Saidur et al., 2011). There are two articles available in literatures that investigate on the effect of refrigerant-based nanofluid in a refrigeration system. According to the work done by Bi et al. (Bi et al., 2008), R-134a/mineral oil with TiO2 nanoparticle work normally in the refrigerator. The performance of refrigerator was better than R-134a and POE oil system. Another experiment that has done by Bi et al. (Bi et al., 2011) showed better refrigerator performance with TiO2-R600a nanorefrigerant compareable to pure R600a.

2.3.3 Lubricant Oil

Lubricant oil should move with refrigerant in the system and finally return to the compressor. Even when the refrigerant evaporates; lubricant remains in liquid phase and keeps going to the system. Lubricant oil has to be compatible with refrigerant to return a proper amount of oil to the compressor. Otherwise, this causes to reduce the performance of the system.

Polyester (POE), alkyl-benzene, and polyalkylene glycol lubricants are used for new-generation refrigerants (HFCs refrigerants). The domestic refrigerators with a hermetic system (motor and compressor in a sealed unit) are closed system; therefore, if the presence of moisture and other contaminants strictly avoid from the system, POE oil is the most suitable lubricant.

2.3.4 Nanolubricant oil

Influence of CuO nanoparticles on the boiling performance of R134/polyolester lubricant oil mixture was investigated experimentally by Kedzierski et al. (Kedzierski & Gong, 2009). The experiment was done on a roughened, horizontal, and flat surface. They found 50% to 275% heat transfer improvement of R134a/polyolester by adding 0.5% mass fraction of CuO nanoparticle. This average boiling heat transfer enhancement was 19% and 12% in case of using 1% and 2% nanoparticle, respectively. They also conclude that the thermal conductivity of the lubricant was increased around 20%. The result of the same investigation that was done by Kedzierski (Kedzierski, 2011), showed 400% heat transfer improvement relative to the heat transfer of R134/polyolester by adding 0.5% Al2O3 nanoparticle mass fraction into the R134a/polyolester lubricant oil.

2.4 Material Compatibility

In order to evaluate the material compatibility in a system, different parameters related to the material that are used in the system should be examined. These parameters are miscibility of refrigerant, lubricant oil and the other materials that are existing in the fluid, solubility of refrigerant and lubricant oil, compatibility of fluid and materials in the system, and stability of nanoparticle-fluid mixture. These items are explained in the following sections.

2.4.1 Miscibility

Miscibility is an important property of lubricant at the evaporator portion of the refrigeration circuit. In systems that are not equipped with oil separator, the oil must be sufficiently miscible with the refrigerant at the evaporator temperature when it carried over from the compressor into the evaporator. Therefore, the refrigerant fluid-lubricant blend remains in one phase after expansion in the evaporator and at a sufficiently low viscosity to travel through to the compressor. If the lubricant separates in the evaporator due to poor miscibility with the refrigerant fluid, or the blend viscosity is high, fluid is likely to get trapped in the evaporator and adversely affect the system's cooling capacity and efficiency. Miscibility curves are used to ensure that the lubricant selected match miscibility requirements for the application. Miscibility charts are specific to lubricant-refrigerant combinations and are read based on the evaporator temperature and the percentage of oil carried over into the evaporator for the application in question (Mobil, 2009).

When a small amount of oil is mixed with refrigerant, the mixture helps to lubricate the moving parts of a compressor. Oil should be returned to the compressor from the condenser, evaporator, accessories, and piping, in order to provide continuous lubrication. On the other hand, refrigerant can dilute the oil, weakening its lubricating effect; and when the oil adheres to the tubes in the evaporator or condenser, it forms a film that reduces the rate of transfer (Wang, 2000).

Normally, polyester oil is used in domestic refrigerators. Because it is completely miscible with R134a. In order to use a blend of nanoparticle-R134a in domestic refrigerator, miscibility of new mixture with lubricant oil should be considered. Material compatibility test that has been done by Bi et a, shows that the R134a and mineral oil are compatible with TiO2 nanoparticle.

2.4.2 Solubility

Solubility is an important property of lubricant at the compressor portion of the refrigeration circuit. It is very important to ensure after absorption of a gaseous refrigerant at high compressor temperature, the viscosity of the lubricant is sufficient for effective lubrication of the compressor (Mobil, 2009).

Solubility of refrigerant-lubricant mixtures working in the refrigerating system influences several characteristics: viscosity of the working fluid, oil return to the compressor, heat transfer coefficient of the heat exchangers, lubricity, etc. it is actually, expressed as the refrigerant concentration in oil at saturated liquid condition. The effect of SWCNH (Single Wall Carbon Nanohorns) and TiO_2 nanoparticle dispersion in the base lubricant SW32 on the solubility of R134a. The result obtained show that the nanolubricant oil has no significant effect R134a solubility (Bobbo et al., 2010).

2.4.3 Compatibility

Compatibility of the material in a system is an important item to indicate the possibility of using new material in a system or not. In order to add nanoparticles to the refrigeration system, compatibility of the new blend with the material have to be examined to ensure that there is no negative effect on the material in the refrigeration system.

Material compatibility test, between R134a-POE oil and R134a-mineral oil-nanoparticle (TiO_2), that has been done by Bi et al. (Bi, et al., 2008)shows that the R134a and the mineral oil with TiO_2 nanoparticle are compatible with the refrigeration system materials.

2.4.4 Stability

Bartlet et al. (Bartelt et al., 2008) have done research on two-phase flow heat transfer of nanofluid. They reported uncoated metal, ceramic, and carbon nanoparticle agglomerate and settle rapidly. But hydrophobically treated Silica nanoparticles sediment with a slower rate.

2.5 Thermal properties of nanofluid

The important thermal properties, which influence the heat transfer characteristics of nanofluid are, include enthalpy, specific heat, and thermal conductivity. These properties are very important to understand the effect of suspended nanoparticles in the basefluid into the thermal behavior of the nanofluid.

2.5.1 Enthalpy

Enthalpy of the refrigerant is one of the most important parameters to calculate the performance of the refrigeration system. As will explain the next sections, the performance of the refrigeration system is calculated based on enthalpy differences between the outlet and inlet of each part of the system. When the effect of oil on the refrigeration system is considered, the enthalpy of a refrigerant-oil mixture should be taken into account. A fraction of oil carries with refrigerant and passes through the system and finally back to the compressor. Therefore, calculation of refrigerant-oil mixture enthalpy is essential to evaluate the performance of the system. Youbi-Idrissi et al. (Youbi-Idrissi et al., 2003; Youbi-Idrissi et al., 2004) suggest the following equation to calculate the total enthalpy of the refrigerant-oil mixture:

$$h_t = (1 - X' - C_g)h_{L,r} + C_g h_{oil} + X' h_V \tag{2.1}$$

where $h_{L,r}$ and h_V are the specific enthalpy of the saturated liquid and saturated vapor of refrigerant, respectively, for a given pressure and temperature and h_{oil} is the oil enthalpy at the system temperature.

When the mixture consists of oil, the vapor quality (X') is calculated by the following equation:

$$X' = \frac{\dot{m}_V}{\dot{m}_{L,r} + \dot{m}_{oil} + \dot{m}_V} \tag{2.2}$$

In addition, oil mass fraction (C_g) which is circulated into the refrigeration system is calculated by:

$$C_g = \frac{\dot{m}_{oil}}{\dot{m}_{L,r} + \dot{m}_{oil} + \dot{m}_V} \tag{2.3}$$

The other model to calculate the enthalpy gradient, which is used by Zhelezny at al. (Zhelezny et al., 2009), is added the heat of mixing of the refrigerant-oil solution given by:

$$\Delta h = -C_L \frac{RT^2}{2M_r} \left[\frac{\partial \ln\left(\frac{p}{p_0}\right)}{\partial T} \right]_{C_g} \tag{2.4}$$

Medvedev et al. (Medvedev et al., 2004) used this model and the results of their calculations show that the excess enthalpy for a R-134a/POE mixture is about $-0.5 \pm 0.5 kj/kg$, which means the contribution of mixing heat of refrigerant-oil in the total enthalpy is less than 0.2% and can easily be neglected.

The enthalpy of refrigerant at saturated liquid and saturated vapor state is a function of saturated temperature or pressure. Actually, saturated temperature T_s and saturated pressure P_s of the refrigerant are dependent upon each other. Therefore, it is more convenient to evaluate the enthalpy of refrigerant in terms of saturated temperature within a certain temperature range (Wang, 2000):

$$h = f(T_s) \tag{2.5}$$

Enthalpy of the fluid in any point can be calculated by $C_p T$ (Das et al., 2008). In case of using nanofluid, specific heat is related to the specific heat of both base fluid and nanoparticle, therefore, can be calculated by:

$$h = C_{p,nf} T \tag{2.6}$$

2.5.2 Specific heat

Specific heat capacity of nanofluid is calculated by using different models. One of the best models with a good justification is based on the assumption of thermal equilibrium between the particles and surrounding fluid. The specific heat capacity per unit mass of nanofluid that is proposed by Pak and Cho (Pak & Cho, 1998) is determined by:

$$C_{p,nf} = \frac{\phi(\rho c_p)_n + (1-\phi)(\rho c_p)_f}{\phi\rho_n + (1-\phi)\rho_f} \tag{2.7}$$

This formula has been validated by experimental work, and the results show that this model is more accurate that the other model to calculate the specific heat of nanofluid (Hanley et al., 2012).

2.5.3 Thermal conductivity

Many investigations have been done on thermal conductivity of nanofluid. Maxwell was one of the first persons to investigate the conduction of nanofluid analytically. Many studies have been done to calculate the thermal conductivity of different types of nanofluid, also many experimental works has been done based on literatures. Maxwell (1892) (Maxwell, 1981) and Wasp (1977) (Xuan & Li, 2000) proposed models to calculate the thermal conductivity of nanofluid, that is presented in Equations 2.8 and 2.9, respectively.

$$k_{nf} = k_{bf}\left\{\frac{[1+2\phi(1-(k_{bf}/k_{np}))/(2(k_{bf}/k_{np})+1)]}{[1-\phi(1-(k_{bf}/k_{np}))/((k_{bf}/k_{np})+1)]}\right\} \tag{2.8}$$

$$k_{nf} = k_{bf}\left\{\frac{[k_{np}+2k_{bf}-2\phi(k_{bf}/k_{np})]}{[k_{np}+2k_{bf}+2k_{np}(k_{bf}-k_{np})]}\right\} \tag{2.9}$$

Hamilton and Crasser (1962) (Hamilton & Crosser, 1962) proposed a model to calculate the thermal conductivity. This model valid when the ratio of conductivity is more than 100 and is calculated by the following correlation

$$k_{nf} = k_{bf}\left\{\frac{k_{np}+(n-1)k_{bf}-\phi(n-1)(k_{bf}-k_{np})}{k_{np}+(n-1)k_{bf}+\phi(k_{bf}-k_{np})}\right\} \tag{2.10}$$

Where n is the shape factor ($n = 3/\varphi$) and φ is sphericity that is equal to surface area of a sphere with a volume equal to that of the average particle/surface area of the average particle.

2.6 Physical properties of nanofluid

The most important physical properties of nanofluid, which influence on the convective heat transfer coefficient, are its density and viscosity. In addition, these properties influence on pressure drop and power consumption of the system. Physical properties of nanofluid evaluate based on volume concentration of nanoparticle in a basefluid.

2.6.1 Volume fraction

While nanofluids were diluted and prepared according to their weight fraction, calculated were performed using volume fraction. Using the nanoparticle volume, V_n, and the basefluid volume, V_f, the volume fraction can be calculated as:

$$\phi = \frac{V_n}{V_n + V_f} \tag{2.11}$$

Substituting in nanoparticle mass, m_n, and density ρ_n, and basefluid mass, m_f, and density, ρ_f, can be rewritten as (Hanley, et al., 2012):

$$\phi = \frac{m_n / \rho_n}{m_n / \rho_n + m_f / \rho_f} \tag{2.12}$$

2.6.2 Density

The density of nanofluid is a physical property of the mixture, which is related to both density of basefluid and nanoparticle. The following equation suggested by Pak and Cho (Pak & Cho, 1998) to estimate the density of nanofluid and validated by Khanafer and Vafai (Khanafer & Vafai, 2011) and Ho et al. (Ho et al., 2010) based on experimental studies.

$$\rho_{eff} = \left(\frac{m}{V}\right)_{eff} = \frac{m_f + m_p}{V_f + V_p} = \frac{\rho_f V_f + \rho_p V_p}{V_f + V_p} = \left(1 - \phi_p\right)\rho_f + \phi_p \rho_p \tag{2.13}$$

Where f and p mention fluid and nanoparticle respectively.

2.6.3 Viscosity

Several models have been proposed by researchers to calculate the viscosity of nanofluid. Generally, these temperature-independence models are based on the viscosity of basefluid and volume fraction of nanoparticle in basefluid. The classic Brinkman model (Kamyar et al., 2012) is one of the popular correlations that is used by many researchers when the viscosity of nanofluid is in consideration:

$$\mu_{nf} = \frac{\mu_f}{\left(1 - \phi\right)^{2.5}} \tag{2.14}$$

Temperature-dependence correlations also proposed in some literatures to investigate the effect of temperature on viscosity of nanofluid. Because of these correlations are based on experimental work, there just valid for the case of the experiment (Abu-Nada & Chamkha, 2010; Namburu et al., 2007). There is no available temperature-dependence correlation for nanorefrigerant in literatures.

2.7 Heat Transfer Characteristics

The feasibility of creating refrigerant-based nanofluid as well as characterizing their thermal behavior must be explored whether the potential heat transfer enhancements are to be understood in air-conditioning and refrigeration application.

In recent years, some studies have been reported on phase-change heat transfer of nanofluid. Most of them were focused on pool boiling heat transfer of nanofluid. Two-phase flow heat transfer investigation was studied by Bartelt et al. (Bartelt, et al., 2008). The effect of CuO nanoparticle on the flow boiling of R134a/POE mixtures in a horizontal tube was examined. At least, 42% and 50% heat transfer enhancements were concluded o s the effect of using 1% and 2% mass fraction of nanoparticles, respectively. There was no effect on the heat transfer coefficient observed in case of using 0.5% mass fraction of CuO nanoparticle.

2.8 Performance of Refrigeration System

Vapor-compression refrigeration cycle has been the most frequently used refrigeration cycle in which the refrigerant is vaporized and condensed alternately and is compressed in the vapor phase. Carnot cycle is a totally reversible cycle that has the maximum thermal efficiency for giving temperature limits, and it serves as a standard based on which actual power cycles can be compared (Cengel & Boles, 2007).

2.8.1 Carnot Refrigeration Cycle

In Carnot refrigeration cycle which works between a region at low temperature (T_c) and another region at a higher temperature (T_H), a refrigerant circulating steadily through a series of components that all the process are internally reversible. The energy transfer of the Carnot refrigeration cycle is shown on Figure 2.4.

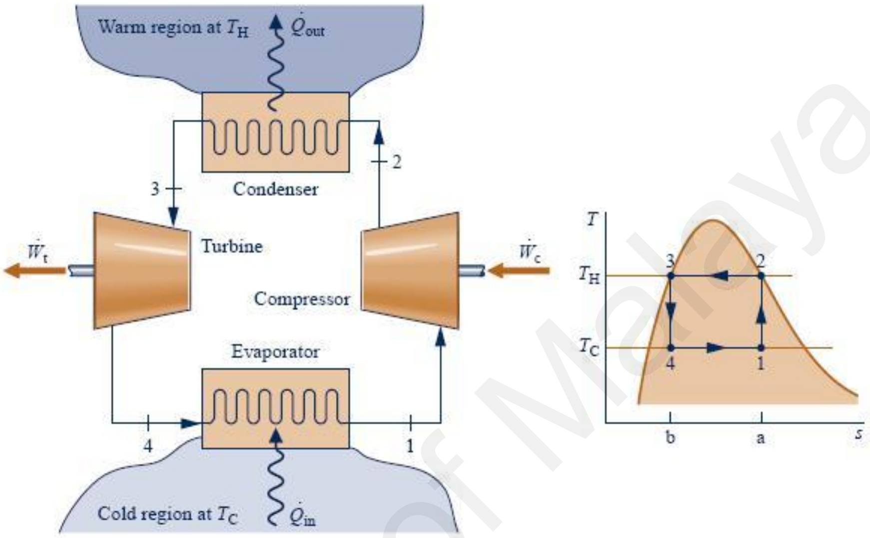

Figure 2.4 Carnot vapor refrigeration cycle

(Micael, et al., 2011)

The maximum theoretical coefficient of performance of refrigeration cycle, which, operates between regions at T_C and $T_{H,}$ happens in Carnot refrigeration cycle and it is calculated by:

$$COP_{\max} = \frac{\dot{Q}_{in} / \dot{m}}{\dot{W}_C / \dot{m} - \dot{W}_L / \dot{m}} \tag{2.15}$$

2.8.2 Vapor Compression System

Vapor-compression refrigeration systems are the most common refrigeration system worldwide. The steady-state operation of this system is illustrated in Figure 2.1

Vapor-compression refrigeration system includes compressor, condenser, expansion valve, and evaporator. The principle work and heat transfer are shown in Figure 2.1. The refrigerant is compressed to a relatively high pressure and temperature by the compressor. Assuming no heat transfer to or from the compressor, the mass and energy rate balances for a control valve enclosing the compressor are calculated by

$$\frac{\dot{W}_c}{\dot{m}} = h_2 - h_1 \tag{2.16}$$

where $\dot{W}_c / \dot{m}$ is the rate of power input per unit mass of refrigerant flowing.

Heat is transferred from the refrigerant to the cooler surrounding when the refrigerant passes through the condenser. The rate of heat transfer from the refrigerant per unit mass of refrigerant is

$$\frac{\dot{Q}_{out}}{\dot{m}} = h_2 - h_3 \tag{2.17}$$

The refrigerant expands to the evaporator pressure in the expansion valve. This process is usually modelled as a *throttling* process for which

$$h_4 = h_3 \tag{2.18}$$

During the irreversible adiabatic expansion in the expansion valve, the refrigerant pressure decreases and it causes to increase specific entropy. The refrigerant exits the expansion valve as state 4 as a two-phase liquid-vapor mixture.

Finally, the refrigerant enters the evaporator at state 4. When the refrigerant passes through the evaporator, the heat from the cold space absorb by the refrigerant. The vaporization of the refrigerant is occurred due to the heat absorption from cold space. The mass and energy rate balances of refrigerant for the evaporator give

$$\frac{\dot{Q}_{in}}{\dot{m}} = h_1 - h_4 \tag{2.19}$$

In the vapor-compression system, the only power consumption is the compressor power. Therefore, based on the above explanation, the coefficient of performance of the vapor-compression refrigeration system of Figure 2.1 is calculated by

$$COP = \frac{\dot{Q}_{in} / \dot{m}}{\dot{W}_c / \dot{m}} = \frac{h_1 - h_4}{h_2 - h_1} \tag{2.20}$$

Provided states 1 through 4 are fixed, Eqs. 10.3 through 10.7 can be used to evaluate the principal work and heat transfers and the coefficient of performance of the vapor-compression system shown in Fig. 10.3. Since these equations have been developed by reducing mass and energy rate balances, they apply equally for actual performance when irreversibilities are present in the evaporator, compressor, and condenser and for idealized performance in the absence of such effects. Although irreversibilities in the evaporator, compressor, and condenser can have a pronounced effect on overall performance, it is instructive to consider an idealized cycle in which they are assumed absent.

2.8.3 Performance of Ideal Vapor Compression System

Frictional pressure drops in the evaporator and condenser are considered irreversibility in refrigeration system. The refrigerant flows at constant pressure in the evaporator and condenser, if irreversibilities are not considered. If consider to these two parts without taking into account into irreversibilities, the refrigerant flows at constant pressure through these two heat exchangers. In this case, frictional pressure drop is ignored within the evaporator and condenser. If irreversibility within compression through heat lost to the surroundings is also ignored, the vapor-compression refrigeration cycle follows *1-2s-3-4-1* on the *T-s* diagram of Figure 2.5 and call ideal vapor-compression system.

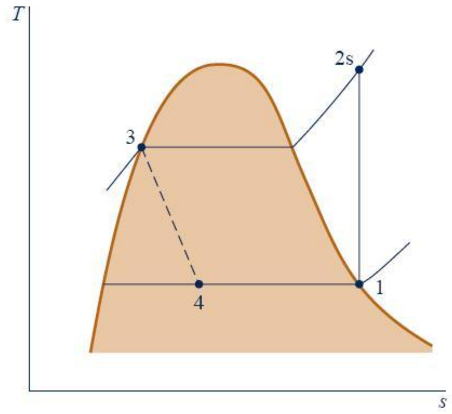

Figure 2.5 *T-s* diagram of an ideal vapor-compression cycle

In this case, all process of the cycle, except of expansion valve, are internally reversible.

2.8.4 Performance of the Actual Vapor Compression Cycle

In actual vapor-compression system, all irreversibilities, such as heat transfer between the refrigerant and the warm and cold regions, heat loss in the compression section to the surrounding, and pressure drop in the evaporator and condenser are taken into account. These irreversibilities have a significant effect on the performance of the system. For example decreases the average temperature of the refrigerant in the evaporator and increases the average temperature of the refrigerant in the condenser are caused to decrease the coefficient of performance of the system. Figure 2.6 shows T-s diagram of the actual vapor-compression system.

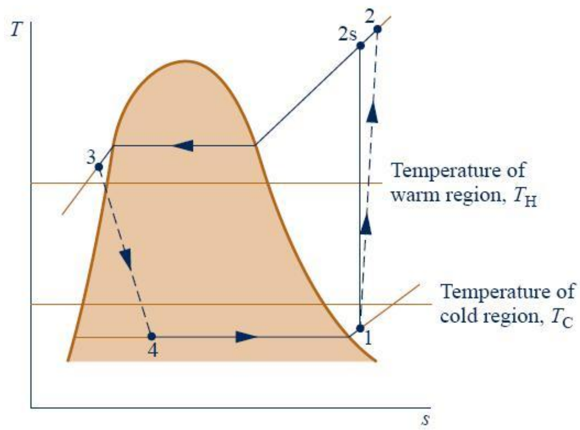

Figure 2.6 *T*-*s* diagram of the actual vapor-compression cycle

In this case, the condenser and the evaporator do not involve any work, and the compressor can be approximated as adiabatic. Then the coefficient of performance's (COPs) of refrigeration cycle can be expressed as

$$COP = \frac{\dot{Q}_L}{\dot{W}_{in}} \tag{2.21}$$

The rate of heat removal from the refrigerated space and the power input to the compressor are determined from their conditions

$$\dot{Q}_L = \dot{Q}_{in} = \dot{m}(h_1 - h_4) \tag{2.22}$$

$$\dot{W}_{in} = \dot{W}_c = \dot{m}(h_2 - h_1) \tag{2.23}$$

Where the *h* is the enthalpy and subscript numbers mention the enthalpy related to the situation of the refrigerant fluid in the system, based on Figure 2.1.

2.8.5 Energy consumption

Household refrigerator freezer market is one of the major segments of the refrigeration industry. The widespread use of household refrigerator freezers provides an opportunity for sustainable energy saving, and the 100 million new units sold annually around the world represent a considerable potential of energy consumption in this field. Consequently, it can lead to huge amounts of energy saving by considering into the energy consumption reduction method. To estimate the amount of energy saving, energy consumption tests before and after changes to the system should be taken into account.

3. Methodology

3.1 Introduction

Experimentation is an important method in all phases of engineering applications that involves with the method of measurement and analysis techniques for interpreting data. Successful experiment needs many engineering principles including knowledge of the governing principles of a broad range of instruments, knowledge of combination of keen insight into the physical principles of the processes, and knowledge of the limitations of the data. Experimental research involves a combination of analytical and experimental work (Holman, 2001).

3.2 Experimental Set-up

Experimental set-up should be utilized based on proper instruments to measure variables that need to be investigated, and experimental uncertainties should be considered by selecting appropriate equipments based on related standards. Experimental set-up should be constructed according to the respective standards and considered answering these questions by running the set-up: What are we looking for? Why are we measuring this? Does the measurement really answer any of our questions? The overall objective of planning and executing experimental set-up is to produce meaningful data (Holman, 2001).

3.3 Experimental Facilities

3.3.1 Experimental apparatuses

3.3.1.1 Domestic Refrigerator

In this study, the domestic refrigerator used in experiments was a SR 30NMB type manufactured by Samsung Company Limited, which was a double-door, Freezer/Refrigerator, thermostatic temperature control, automatic defrosting (Start-Finish by timer), evaporator fin type, natural convection condenser type. The picture of the refrigerator which is used as a test-rigs, is shown in Figure 3.1. This refrigerator is designed to work with R-134a refrigerant and the technical specifications are shown in Table 3.1.

Figure 3.1 Test-Rig Domestic Refrigerator

Table 3.1 Technical specifications of refrigerator freezer test unit

Item		Specification
Model name		SR 30NMB
Type		2-Door Freezer/refrigerator
Power source		230~240V/50Hz
Net Capacity Lit (cu.ft.)	Freezer	68 (2.4)
	Refrigerator	186 (6.6)
	Total	254 (9.0)
Refrigerant		R 134a (140g)
Temperature control		Dial (Thermostat)
Compressor model		SD162CL1U/T3

The refrigerator's performance has been investigated with no load and closed door condition. The refrigerator was fitted with the thermocouples and pressure transducers. The other components of the refrigerator remained intact except the installation of sensors.

3.3.1.2 Vacuum Pump

A refrigerating system must contain only the refrigerant (liquid or vapor state) along with dry oil. All other vapors, gases, air, moisture, and fluids must be removed from a system. Refrigerants must be kept dry and clean. All exposed surfaces absorb moisture if left in the open. If a compressor turns down, overhauled, and reassembled, it must be completely dried before it can be charged with refrigerant. On the other hand, air in the refrigerating system increases the total head pressure, so the refrigerant will have to condense at the higher temperature and pressure. In this case, the compressor has to pump the vapor to a higher temperature and pressure, so it needs more power.

Therefore, evacuate the system before charging refrigerant is essential. It is done by vacuum pump (Figure 3.2), which is removing all substances from the system through charging points. Vacuum pump run continuously for some times while a deep vacuum is drawn on the system (Althouse, et al., 2004).

Figure 3.2 Vacuum pump

3.3.1.3 Digital Electrical Charging Scale

Charging the refrigerant into the system should be done with a maximum accuracy in all experiments, otherwise the results will not be accurate. *"Metric Programmable Charging Scale (0-100 kg)"* which is manufactured by *"Ritchie Engineering Company Inc,(YELLOW JACKET)"* with $\pm 0.030 kg$ weighting accuracy and 0.014% charging accuracy, has been used to charge the system. After each experiment, the refrigerant was recovered from the system, clean inside the system, do evacuation, and then charge the new refrigerant/nanorefrigerant. Shown in Figure 3.3

and Figure 3.4 are pictures of charging scale and schematic of a charging mechanism, respectively.

Figure 3.3 Digital Electrical Charging Scale

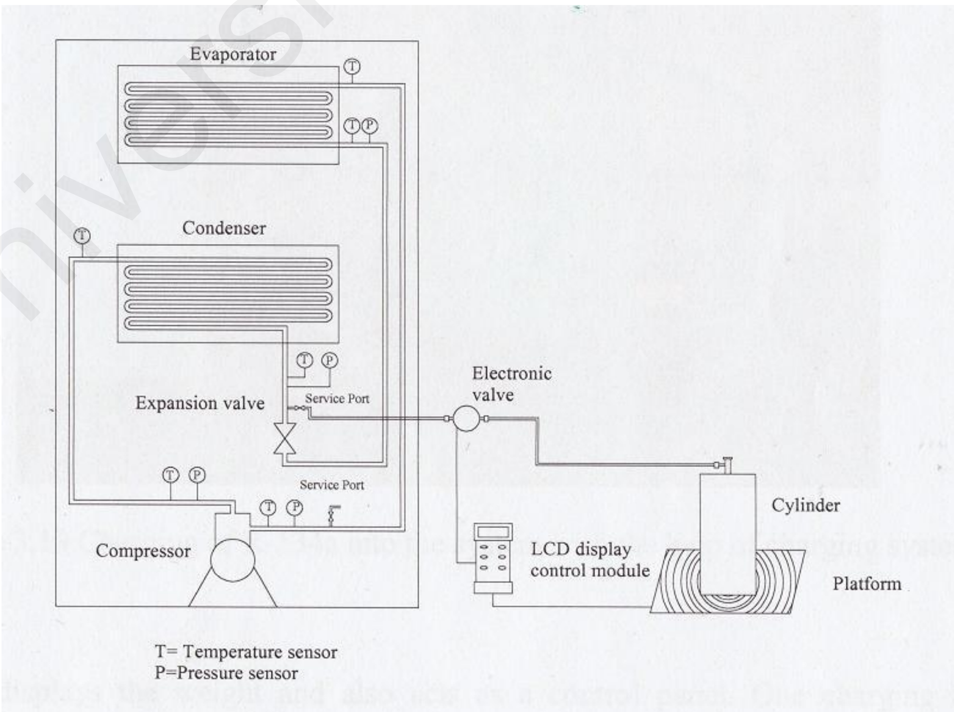

Figure 3.4 Schematic diagram of the charging system

3.3.1.4 Thermocouple

The temperature of the inlet and outlet refrigerant of each component of the refrigerator system measured with resistance thermocouples. Thermocouples were installed through Tee Union connection to the system. The schematic of thermocouple and installation is shown in Figure 3.5.

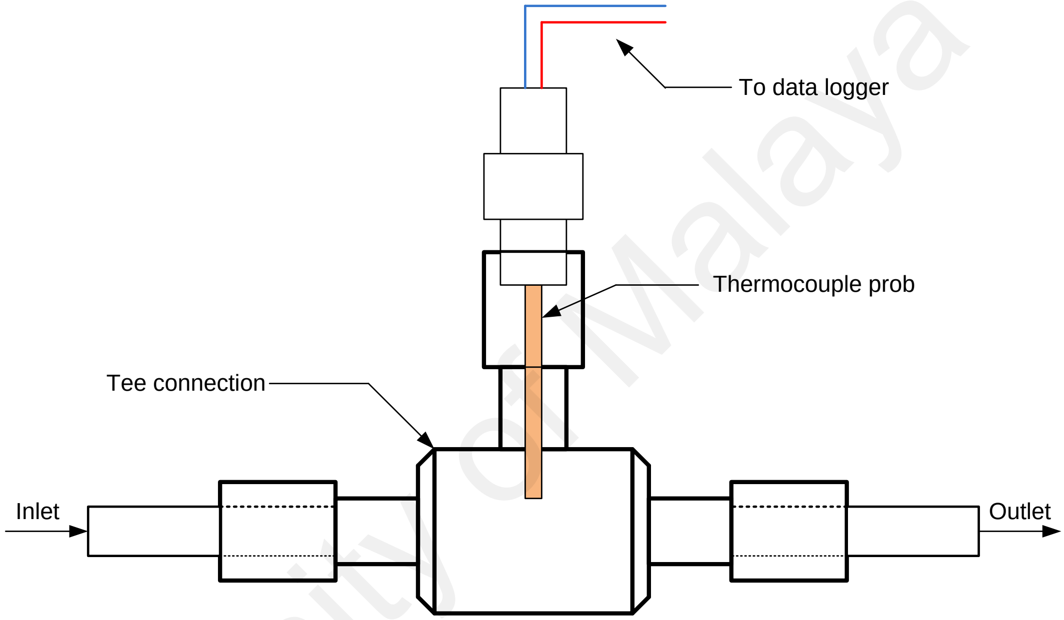

Figure 3.5 The Schematic of Thermocouple and Installation

Tee Union connections are installed and the thermocouples probe are placed inside the connection to measure the exact temperature of the refrigerant directly. The thermocouples which are used in this experiment were K-type, with especial design to ensure that well suited for Tee Union connection without any leakage and make contact with refrigerant inside the tube in order to increase accuracy of measurement. Shown in Figure 3.6 and Figure 3.7 are the installed thermocouples at inlet and outlet of the evaporator and compressor, respectively.

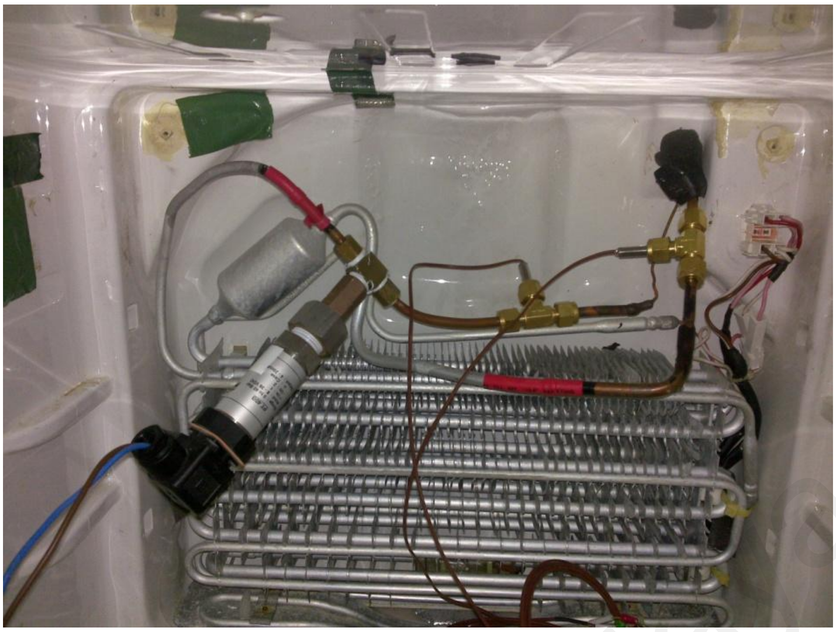

Figure 3.6 Installed Pressure Transducer and Thermocouples at the inlet and outlet of evaporator

Figure 3.7 Installed Thermocouples at the Inlet and Outlet of Compressor

3.3.1.5 Humidity and temperature data logger

The refrigerator and freezer temperatures and room temperature and humidity will also be measured by portable temperature/humidity recorder, Humidity/Temperature Datalogger model RHT20 which is manufactured by EXTECH Instrument with the range of 0 to 100% RH and -40 to 70 $^{\circ}C$. The portable temperature recorders just put in suitable places as is shown in Figure 3.8.

Figure 3.8 Humidity/Temperature Data Logger

3.3.1.6 Pressure Transducer

Pressure transducer (pressure transmitter) is a device that is used to convert pressure into an analog electrical signal. Then the electrical signal sends to a data logger to record the pressure during a process. To install pressure transducer in an experimental setup, Tee-Union (Tee-joint) was fixed at desired points (Figure 3.10) then the pressure transducer was applied to measure a pressure. The schematic diagram of the pressure transducer installation is shown in Figure 3.9. The working range of pressure transducer is *-1 to +39 bars* with an output voltage *0-10 V* and $\pm 0.5\%$ accuracy. Pressure transducers need a power supply to work, that provided by DC Power Supply device.

Pressure transducer installation and using guide are provided in Appendix A. After collecting data from pressure transducers by data logger, they are sent to the computer to do analysis.

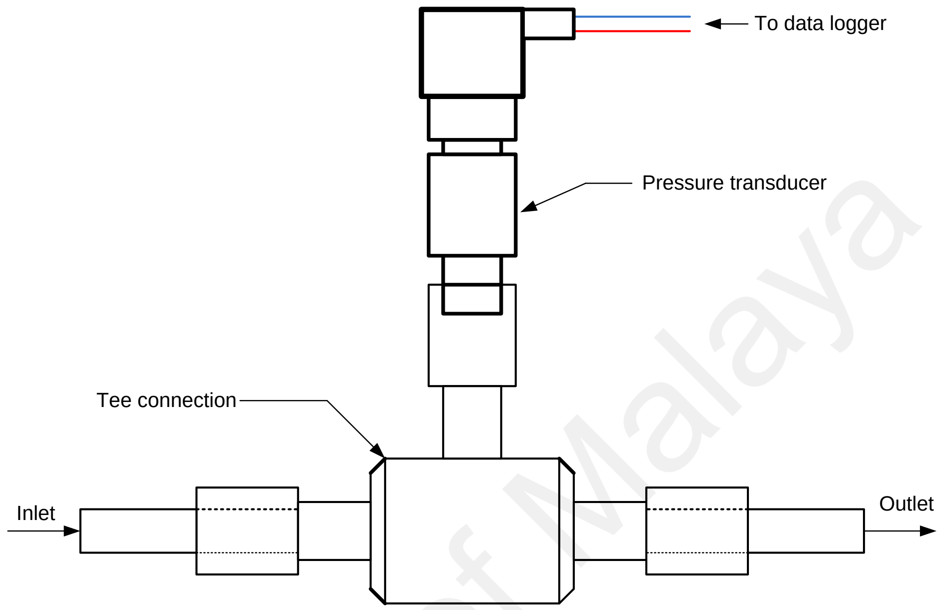

Figure 3.9 Schematic Diagram of the Pressure Transducer Fitting in Tube

Figure 3.10 Pressure Transducer

3.3.1.7 Power Meter

An electronic system was designed in order to measure power consumption of refrigerator which is encompassesed AC voltage transformer transducer, current clamp including AC RMS to DC converter unit. Voltage transducer just transfer the voltage of the system to the data logger with a suitable range that the data logger able to read. Current clamp measures the consumption current of the refrigerator. The output of current clamp was converted to the DC voltage by converter unit. Both voltage and current data send to the data logger and the output of data logger shows the power consumption of refrigerator during the test period. Figure 3.11 shows the power meter system.

Figure 3.11 Power Meter System

3.3.1.8 Data Logger

One of the most important parts of the experimental process is the manner of collecting data. With a simple plan, acquisition of data is to read a number of equipments and recording the observation on a data sheet. When the number of equipment increases and/or many numbers of data need to collect, recording with people is so difficult or impossible. The objective of using the acquisition data system is to collect the data, process them in the desired style, and record the results in a suitable form for storage or presentation. The major elements of data acquisition and processing system are shown in Figure 3.12.

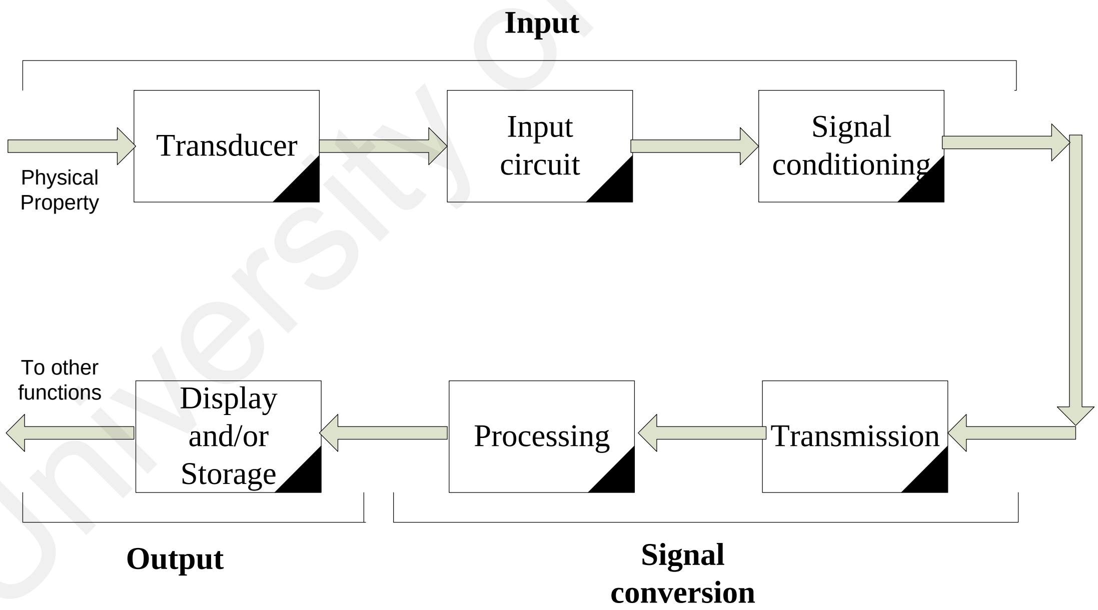

Figure 3.12 General Data Acquisition System

Temperature, pressure, and power data send to the data logger (data acquisition device) from related sensors to display and storage. In this study, data logger was *“Midi LOGGER GL820”* which is manufactured by Graphtec Corporation, that is shown in Figure 3.13. It includes 20 input channels to capture a different kind of data such as temperature, pressure, power, resistance, etc. It can be connected to the PC by USB port to transfer data to the computer. It was able to show data in table and graph forms in its own LCD. The pressure and temperature were used to calculate enthalpy of the refrigerant with and without a nanoparticle in different points of the system. The voltage and current were used to calculate power consumption in case of normal refrigerant and nanorefrigerant.

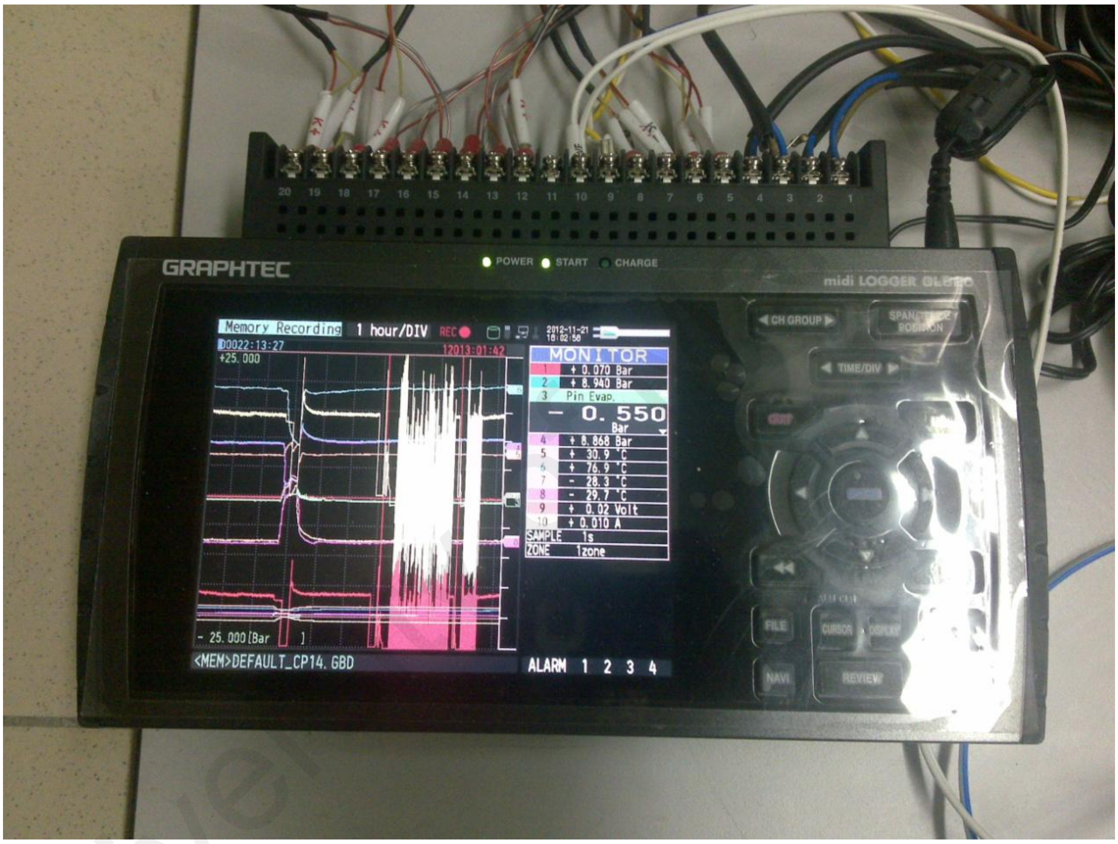

Figure 3.13 Data Logger

3.3.1.9 Service Port

Service port mounted on the hermetic compressor may be used for many purposes such as:

- To check the internal pressure
- To discharge the system or add refrigerant
- To add oil

- To evacuate the system
- To recharge the system

Usually a flexible charging line is connected to the service valve adaptor. It is also attached to a service manifold mounted to the other end of this tubing. This makes service easier. Refrigerant charging and removing into/from the system is done trough service point. Evacuation of the system is necessary before charging refrigerant. All the evacuation, charging, recovery, and recharging of refrigerant are done trough this port. The place of charging ports and the Schematic of Service Valve are shown in Figure 3.14 and Figure 3.15.

Figure 3.14 Service Port of Hermetic Compressor

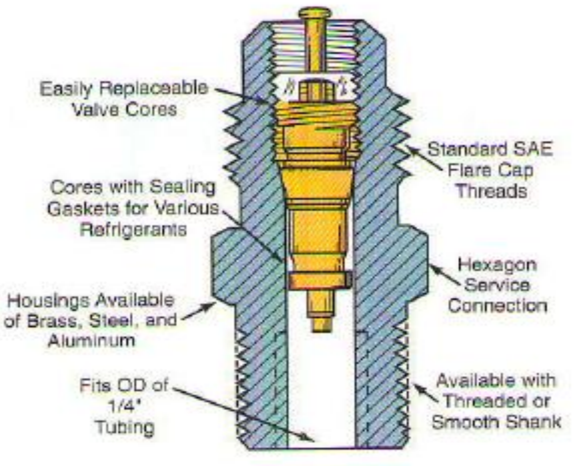

Figure 3.15 Schematic of Service Valve

3.3.1.10 Digital balance

Digital precision balance was used for weighing nanoparticle and lubricant oil (Figure 3.16). The quantity of nanoparticle that is needed for each experiment is calculated based on the density of lubricant oil and nanoparticle and volume fraction of the nanoparticle. The measurement range is *200 g* with 4 decimal measurement accuracy.

Figure 3.16 Digital Balance

3.3.1.11 Sonicator

In order to make a well nanofluid, sonication is one of the proper ways to mix nanoparticle into the basefluid. It was done by digital sonicator, which is manufactured by *Madell Technology Corp.* (Figure 3.17). After adding nanoparticle to the fluid, sonication was done for a period of time with different amplitude depends on particle concentration and basefluid viscosity.

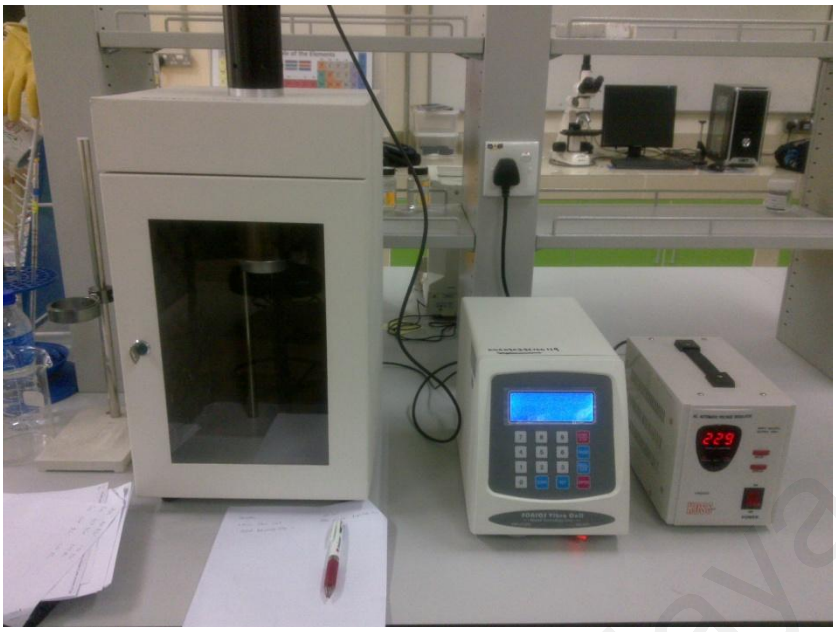

Figure 3.17 Sonicator system

3.3.2 Refrigerant Medium

3.3.2.1 Normal refrigerant

Refrigerant medium in this experiment was R134a. As a baseline experiment, the system was charged with R134a and polyolester (POE) oil as a lubricant oil. This normal condition is used in most of household refrigerators. This test was run and data acquisition from the system was considered as a baseline.

3.3.2.2 Nanorefrigerant

Nanorefrigerant can be directly made by adding nanoparticle into the refrigerant as a base fluid. In some kind of refrigeration system, like household refrigerator, fluid that is circulated through the system consists of refrigerant and lubricant oil. This mixture moves through the system and makes the cooling effect. Accordingly, the final output of the system –cooling the cold space- is the effect of thermodynamic activities of both refrigerant and lubricant oil. Therefore, the term of “nanorefrigerant” is used in both cases of mixture of a nanoparticle/refrigerant and nanoparticle/lubricant oil in refrigeration system.

In this study, nanorefrigerant that was made by adding nanoparticles into lubricant oil (POE), was injected into the system and finally R134a charged into the system.

3.4 Experiment condition

In order to carry out the tests, the sequence of the clauses in international standard (Household Refrigerating Standard, Refrigerator-Freezers Characteristics and Test Methods- ISO 8187) was considered. Ambient temperature for measuring the energy consumption for appliances in tropical climate should be $+32^{\circ}C$. Relative humidity shall be kept between 45% and 75%. The refrigerator was placed in a room and the condition of the room was kept constant as much as possible to make sure that all tests were done in the same condition. There was no ceiling fan, and air conditioning system that can force air movement in the room. Therefore, heat transfer was done by natural convection in condenser and refrigerator walls (ISO 8187, 1991).

Leakage test was done before and after filling system with refrigerant. Vacuum test and pressurize test before and after injection refrigerant were taken into account for at least 15 minutes to ensure that there was no leakage in the system.

3.5 Experimental Procedure

For all tests, the same procedure was used. Nanofluids were prepared based on the proposed method in the literatures, which is explained in the next session. The temperature and pressure at various points in the system were measured during a complete standard cycle. According to the international standard (ISO 8187, 1991), the electricity consumption shall be calculated from the measured value for a period of exactly 24 hours, running under stable operating conditions at an average ambient temperature of $+30^{\circ}C$, and shall be expressed in kilowatt hours per 24 h (kWh/24 h).

All thermocouples and pressure transducers were connected to the data logger to record data during experiments. Electrical power line of compressor also was connected to the data logger through the transformer system (voltage and current transducer) to record the required data to calculate energy consumption of the compressor. The other portable temperature measurement devices, which are installed in the refrigerator and test room, were measured temperature and humidity and recorded in their internal memory. After each experiment, all the data were transferred to the computer to do calculation and make tables and graphs to analyze the system.

To prevent the effect of refrigerant fluid from the previous experiment to the next experiment, the fluid in the system drove out and the system was washed with based lubricant oil. It was done by charging the base lubricant oil into the compressor, evacuating the system from air and moisture, charging the system with refrigerant, and finally run the system for a few hours to flow the base oil within the system and clean the system. At the end, the system was empty from refrigerant, and the oil drove out from the compressor.

3.6 Nanofluid preparation

Based on the mass fraction of nanoparticle that was used in each experiment, the required amount of Al_2O_3 nanoparticle was weighted by digital balance. Then, it was added to the required amount of lubricant oil and poured into the beaker. The mixture was stirred by using sonicator. Sonication was done for 15 to 30 minutes with 50 to 70% amplitudes based on the percentage of nanoparticle and the amount of solution. Finally, nanofluid was kept to investigate the stability of nanoparticle inside the fluid.

3.7 Refrigeration System Performance

Generally, heat travels from a hot space to a cold space due to a certain temperature difference. However, in refrigeration system it is done in opposite, heat transfers from a lower temperature region to a higher temperature one. It is done by using a substance called a refrigerant. Figure 2.1 shows a schematic of a vapor compression refrigeration system.

The cooling effect in Btu values in a refrigeration cycle compared to the Btu equivalent of the energy put into the system is called the coefficient of performance. *Coefficient of performance* (COP) is the ration of desired output (cooling effect) divided by the required input (work input), and expressed as:

$$COP = \frac{Cooling.effect}{Work.input} = \frac{Q_L}{W_{net,in}} \tag{3.1}$$

According to Figure 2.1, the refrigeration cycle is divided into four stages. In each stage, the properties of refrigerant change due to the act of related devices. Based on heat transfer characteristics and energy efficiency in each stage, the performance of each device is explained in this section:

3.7.1 Compressor

The refrigerant enters the compressor from the evaporator as slightly superheated vapor. The pressure rises by the compressor and simultaneously, the temperature of vapor refrigerant increases when it leaves the compressor, because of transferring energy to the refrigerant during the compression process. The compressor is the main power-consuming device in the refrigeration system. This energy applies to increase the pressure of refrigerant and circulate it through the system. Consequently, the temperature of vapor refrigerant rises and causes to increase the enthalpy of the refrigerant at the outlet of the compressor.

The compressor work is determined with the help of *P-h* diagram and can be written as:

$$q_c = (h_2 - h_1) \tag{3.2}$$

Where the h_2 and h_1 are the enthalpy of nanorefrigerant at outlet and inlet of compressor respectively.

The compressor that is used in the refrigerator of this experiment is a hermetic reciprocating type, 220 Volts, 50 Hz, 168 Watt cooling capacity at $-23.3^{\circ}C$, 133 W power input, $COP = 1.26$, thermally protected, and design for use with R-134a.

3.7.2 Condenser

A condenser acts as a heat transfer device to release the heat from high pressure superheated vapor refrigerant (discharge from the compressor) to the surrounding. As a result of heat rejection in the condenser, vapor refrigerant becomes a liquid. Heat transfer rate in the condenser is calculated by:

$$q_{con} = (h_3 - h_2) \tag{3.3}$$

In this study, condenser is natural convection cooling type.

3.7.3 Capillary tube (Expansion device)

Capillary tube is a device, which acts as expansion valve. The pressure of the liquid refrigerant is reduced by the capillary tube. The pressure of the liquid drops slightly in the first two-thirds of the length of the capillary tube. In this refrigerator it has 0.75 inside diameter and 3400 mm length.

3.7.4 Evaporator

The evaporator absorbs heat from its surroundings (inside refrigerator space) and transfers it to the refrigerant inside the evaporator. The refrigerant status changes during the evaporation process from a liquid to a vapor, and at the evaporator exit is slightly superheated. This slight overdesign ensures that the refrigerant is completely vaporized when it enters the compressor. The refrigeration effect (q_{rf} *(J/kg or kJ/kg)*) is defined as heat rejected by a unit mass of refrigerant during the evaporating process in the evaporator. It can be written as:

$$q_{rf} = h_{lv} - h_{en} \tag{3.4}$$

Where h_{lv} and h_{ev} are the refrigerant enthalpy at outlet and inlet of the evaporator, respectively.

Refrigerating capacity, or cooling capacity, Q_{rf} , Btu/h (W), is the actual rate of heat removed by refrigerant in the evaporator. It can be calculated by:

$$Q_{rf} = \dot{m}_r (h_{rlv} - h_{ren}) \tag{3.5}$$

Where h_{rlv} and h_{rev} are enthalpy of refrigerant actually entering and leaving the evaporator respectively, Btu/lb (J/kg) (Wang, 2000).

3.8 Nanorefrigerant properties

3.8.1 Enthalpy

The enthalpy of refrigerant at saturated liquid and saturated vapor state is a function of saturated temperature or pressure. Actually, saturated temperature T_s and saturated pressure P_s of the refrigerant are dependent upon each other. Therefore, it is more convenient to evaluate the enthalpy of refrigerant in terms of saturated temperature within a certain temperature range (Wang, 2000):

$$h = f(T_s) \tag{3.6}$$

Enthalpy is all the heat in one pound of a substance calculated from an accepted reference temperature, $32^\circ F$ can be used for water and water vapor calculations. For refrigerant calculations, the accepted reference temperature is $-40^\circ F$ (Althouse, et al., 2004).

Enthalpy of the fluid in any point can be calculated by $C_p T$ (Das, et al., 2008). In case of using nanofluid, it can be calculated by:

$$h = C_{p,nf} T \tag{3.7}$$

In common refrigeration cycle calculation, the effect of oil in enthalpy of the fluid is ignored. Therefore, in this case assume that the fluid in the system is refrigerant plus nanoparticle, because evaluate the quality of the mixture (refrigerant and oil) is completely difficult in each point. Assumptions of liquid refrigerant at the inlet of the evaporator and at the outlet of the condenser, and the complete vapor of the refrigerant at the outlet of the evaporator and inlet of the condenser are taken into account.

3.8.2 Specific heat

The specific heat of nanorefrigerant is calculated by using following formula:

$$C_{p,nf} = \frac{\varphi(\rho c_p)_n + (1-\varphi)(\rho c_p)_f}{\varphi\rho_n + (1-\varphi)\rho_f} \tag{3.8}$$

3.9 Physical properties of nanorefrigerant

3.9.1 Volume fraction

The volume fraction of nanoparticle in basefluid is calculated by the following equation:

$$\varphi = \frac{V_n}{V_n + V_f} \tag{3.9}$$

It can be written as a function of nanoparticle mass, m_n, and density ρ_n, and basefluid mass, m_f, and density, ρ_f:

$$\varphi = \frac{m_n/\rho_n}{m_n/\rho_n + m_f/\rho_f} \tag{3.10}$$

In this experiment, Al_2O_3 nanoparticle were used with 0.05 and 0.1% mass concentration.

3.9.2 Density

The density of nanorefrigerant, as a physical property of mixture, expressed by following equation:

$$\rho_{eff} = \left(\frac{m}{V}\right)_{eff} = \frac{m_f + m_p}{V_f + V_p} = \frac{\rho_f V_f + \rho_p V_p}{V_f + V_p} = (1-\phi_p)\rho_f + \phi_p \rho_p \tag{3.11}$$

Where f and p mention fluid and nanoparticle respectively.

3.9.3 Viscosity

Dynamic viscosity of nanofluid μ_{nf} is determined using following equation:

$$\mu_{nf} = \frac{\mu_f}{(1-\phi)^{2.5}} \tag{3.12}$$

Which is related to the viscosity of refrigerant and the volume fraction of the nanoparticle.

In this study, viscosity of basefluid and nanofluid with different mass fraction was measured by *Vibro Viscometer SV-10* with a range of 0.36-10’000 *m.Pa.s* manufactured by A&D Company, Limited, Japan. The Viscometer is shown in Figure 3.18.

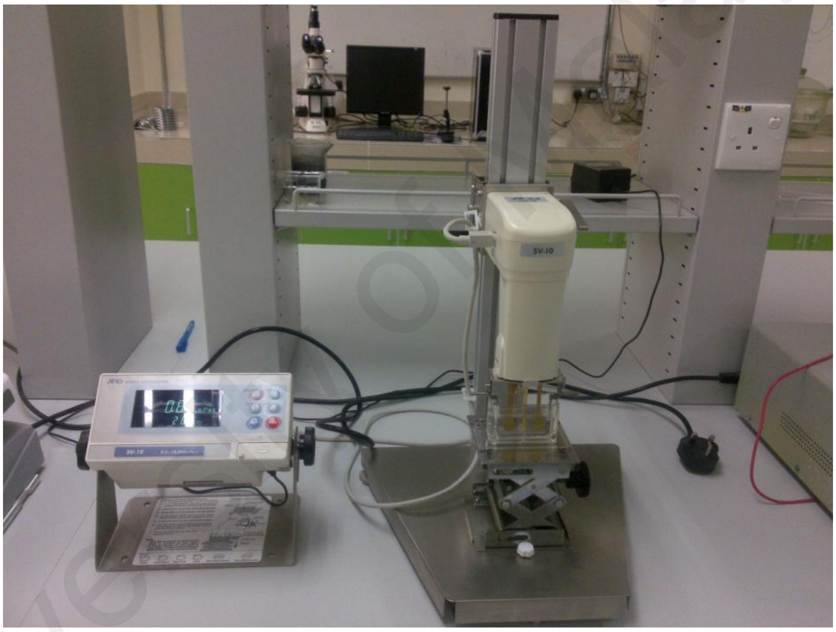

Figure 3.18 Viscometer

3.10 Energy consumption and energy efficiency of refrigerator

The purpose of the energy consumption test is to check the energy consumption of refrigerator under a specified test condition according to the International Standard of household refrigerating appliances (Refrigerator-Freezer) Characteristics and test methods (ISO8187).

The energy consumption has been measured for a period of exactly 24 *h* after stable operating conditions have been attained in average operating ambient temperature $30^{\circ}C$. Each test repeated several times to increase reliability of results. The measurement of energy consumption has been carried out under empty condition with all compartments simultaneously being in operation. The energy consumption of electricity operated refrigerator is expressed in kilowatt hours per 24 h (*kWh/24 h*), to two decimal places (ISO 8187, 1991).

4. Results and Discussions

4.1 Introduction

Each experiment was conducted for three times in order to decrease uncertainty. Three groups of data were measured and collected which are temperature, pressure, and power consumption and were analysed according to the theory of refrigeration.

4.2 Performance characteristics

All experiments were done in the same ambient temperature and relative humidity based on the international standard. Figure 4.1 and Figure 4.2 show the relative humidity and ambient temperature of the test room during experiments, respectively.

Figure 4.1 Relative humidity of test room during experiment

Figure 4.2 Ambient temperature of test room during experiment

4.3 Stability of nanofluid

Stability of the prepared nanofluids (Figure 4.3) was investigated while keeping the samples at the same condition.

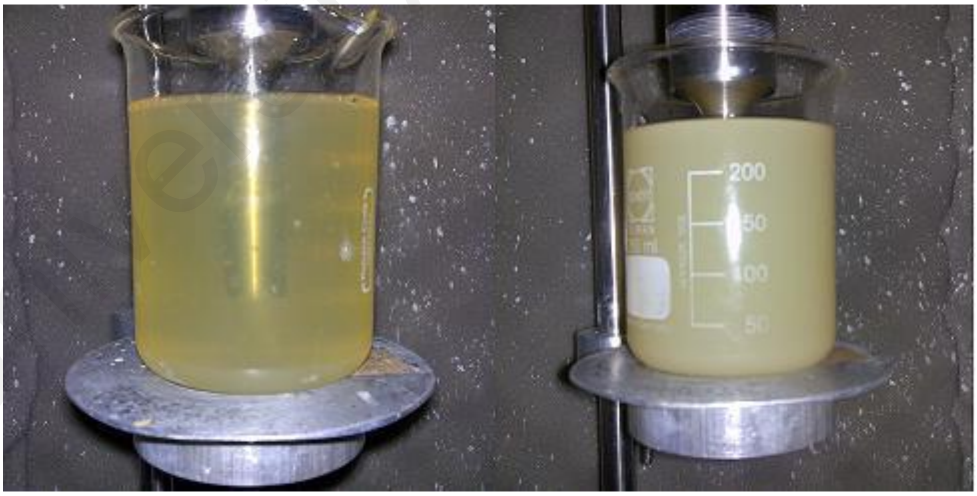

Figure 4.3 Sonication of nanofluids

Experiments show that the stability of nanofluid decreases with increasing the concentration of the nanoparticle. Samples of Al_2O_3 lubricant oil with different mass fractions are demonstrated in Figure 4.4.

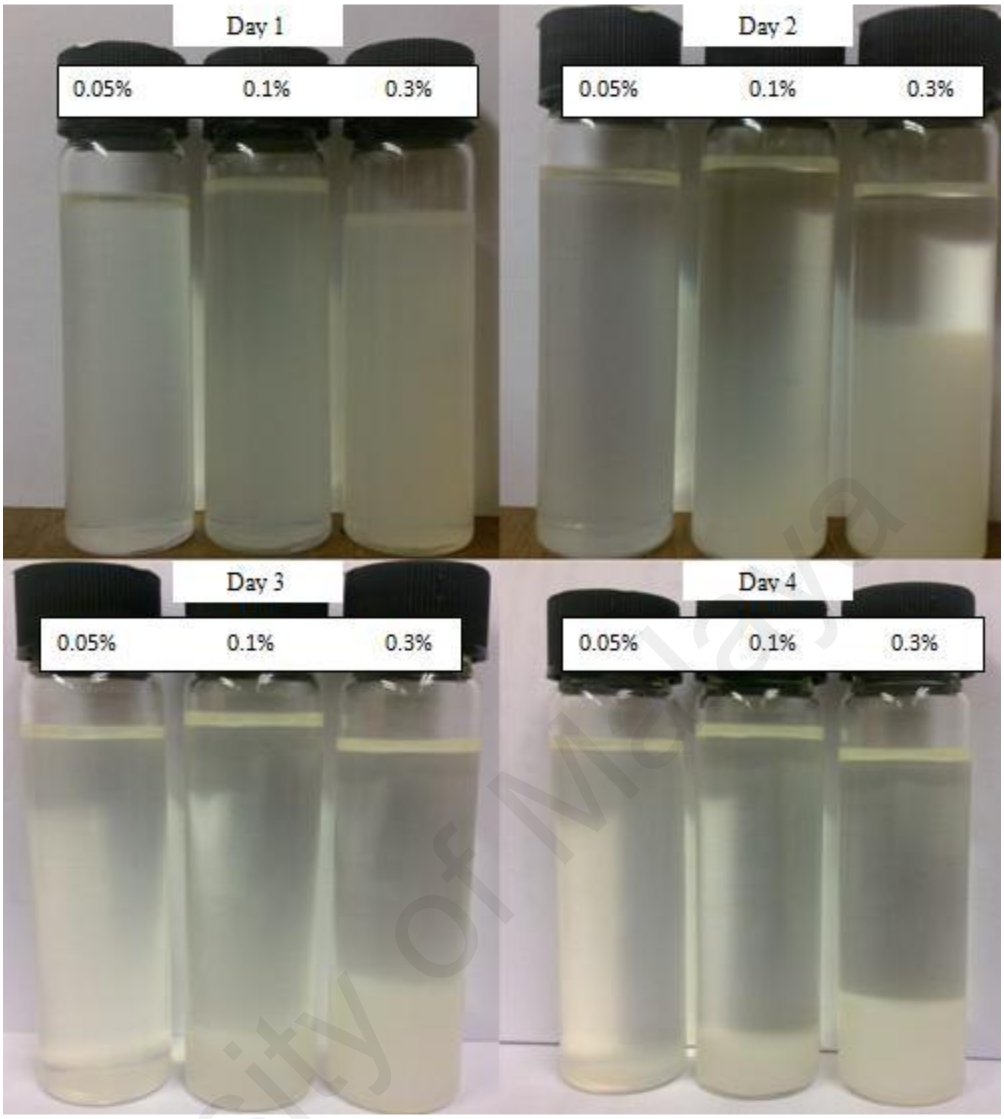

Figure 4.4 Stability of Al_2O_3-POE Lubricant Oil with different concentration

Stability of the mixture of 0.05%, 0.1% and 0.3% mass fraction Al_2O_3 and polyolester lubricant oil is shown in Figure 4.4. All mixtures are stable in the first hours after preparation. Nanofluid with 0.3%-Al_2O_3 was started to sediment after some hours. It seems it is not stable enough to be used in the system. Sedimentation of mixture with 0.1%-Al_2O_3 was increased at the end of day 1 and it was mostly sedimented in day 3. 0.05%- Al_2O_3 was stable after 4 days. Results show that the stability of nanofluid decreases by increasing nanoparticle concentration. Therefore, mixture of 0.1% Al_2O_3 and lubricant oil was chosen for this experiment.

4.4 Effect of nanorefrigerant on evaporator temperature gradient

Evaporator temperature is one of the most important parameters to investigate the heat transfer analysis in refrigeration system. The heat is transferred from the cold space into the refrigerant due to change the phase of refrigerant from liquid to vapor. In this case, heat transfer is related to the phase change of the refrigerant and temperature gradient of refrigerant between the inlet and outlet of the evaporator.

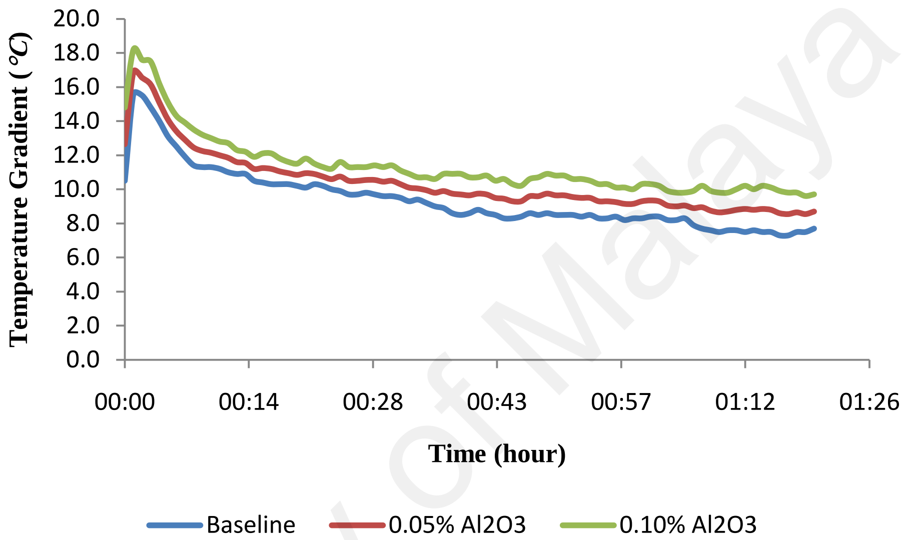

Figure 4.5 Temperature gradient in evaporator

Figure 4.5 shows the temperature gradient of refrigerant during one on-off cycle in the evaporator. As it can be seen, the temperature gradient of nanorefrigerants is bigger than baseline (R134a). It proves that the heat transfer was improved in case of using nanorefrigerant. The maximum temperature gradient improvement in the evaporator was 1.9 $^{\circ}C$ in case of using 0.1%-Al_2O_3 corresponding to.

4.5 Energy consumption by the compressor

The energy consumption of all the tests is shown in Figure 4.6 and Figure 4.7. The graphs show that the energy consumption of the system with nanofluid is less than that of the system without nanoparticle. The energy consumption of baseline (R134a-

POE) was 3.821 kWh/day. On the other hand, the minimum energy consumption was in the case of using nanofluid with 0.1%-Al_2O_3 nanoparticle concentration. The energy consumption decrement was around 2.69%. The other nanoparticle concentration also consumes less energy to compare with basefluid. However, that decrement was not too much to compare with 0.1% nanofluid. In case of using 0.05% nanoparticle in the system, energy consumption was decreased 1%.

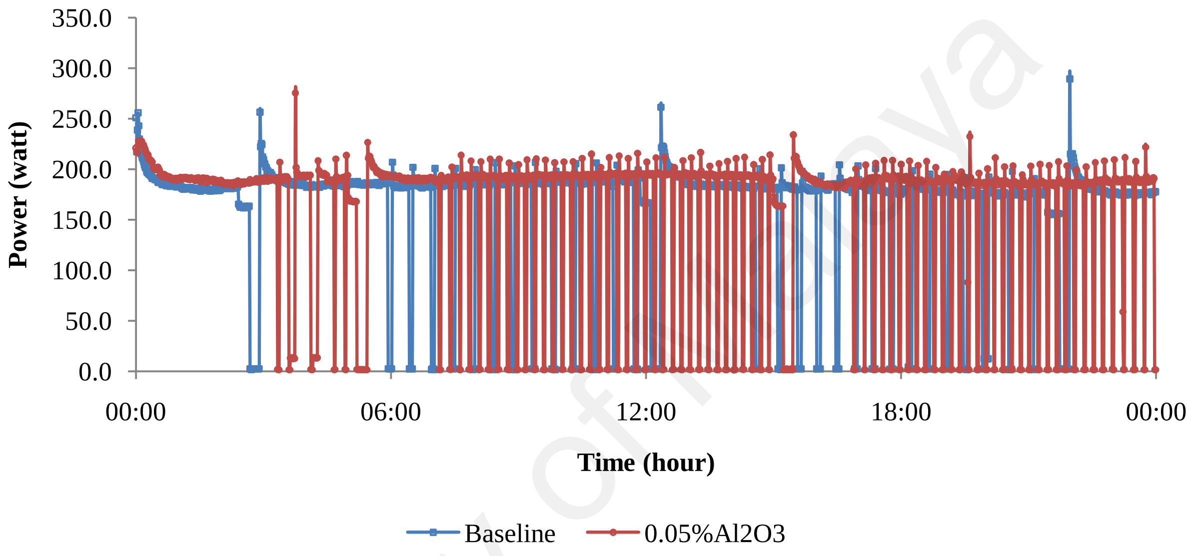

Figure 4.6 Energy consumption of refrigerator with 0.05%-Al_2O_3 and without nanoparticle

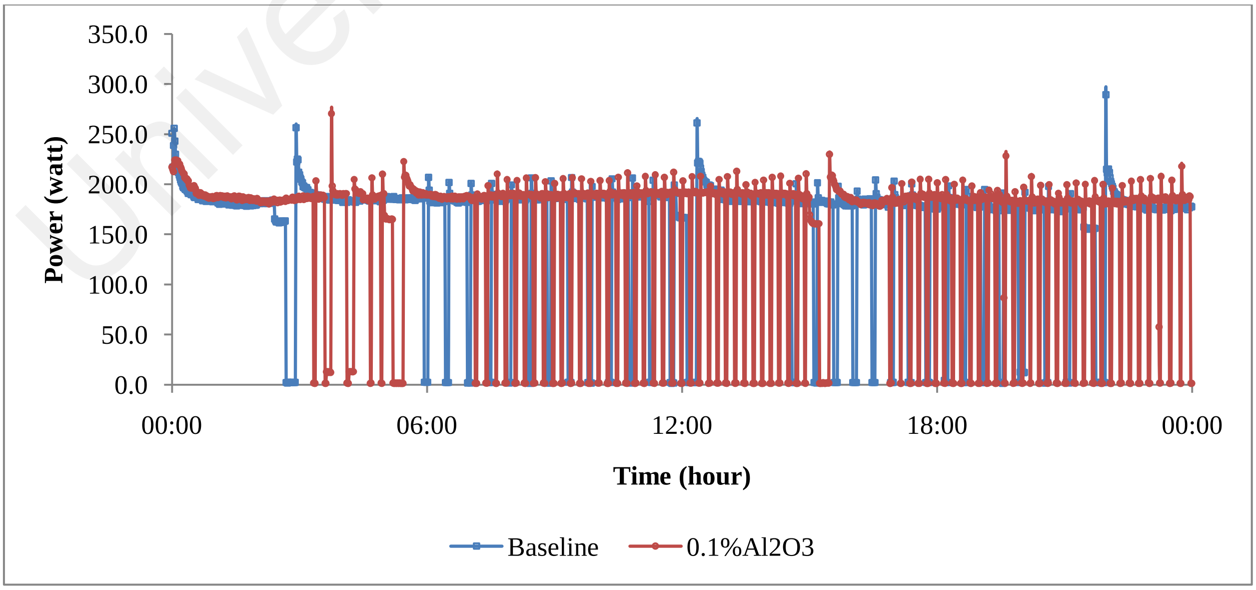

Figure 4.7 Energy consumption of refrigerator with 0.1%-Al_2O_3 and without nanoparticle

It is apparent from the data shown in Figure 4.6 and Figure 4.7 that the off-cycle duration is nearly the same between the baseline and nanofluid. The data also shows that the on-cycle duration is less in nanorefrigerant cases.

4.6 Compressor discharge and suction pressure analysis

Figure 4.8 and Figure 4.9 compared the compressor discharge and suction pressures of the refrigeration system over one on-off cycle, respectively. These figures show that both pressures were reduced because of the effect of nanoparticle to the R134a system.

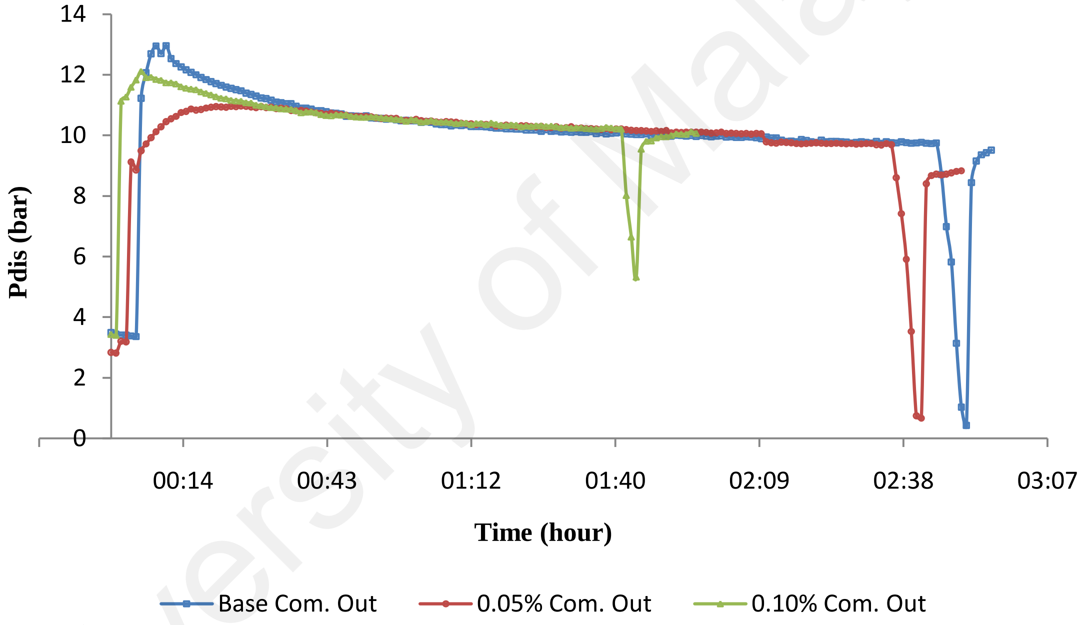

Figure 4.8 Compressor discharge pressure

The discharge pressure of compressor in case of 0.05% nanoparticle is lower than basefluid at the first minutes of compressor working time, but it is almost the same as a basefluid after the pressure becomes stable. It shows that small amounts of particle does not have much effect on discharge pressure, but improves lubrication and decreases the maximum discharge pressure. 0.1% nanofluid also follows the same as 0.05%, but it is working in higher discharge pressure, which is almost between basefluid and 0.05% nanofluid. On the other hand, Figure 4.8 demonstrates that the working time of compressor in cases of using nanofluid is less than basefluid. It causes to reduce energy consumption of the compressor. The reason may be that the nanoparticle improves the heat transfer characteristics of the refrigerant and also enhances the friction characteristics of the lubricant.

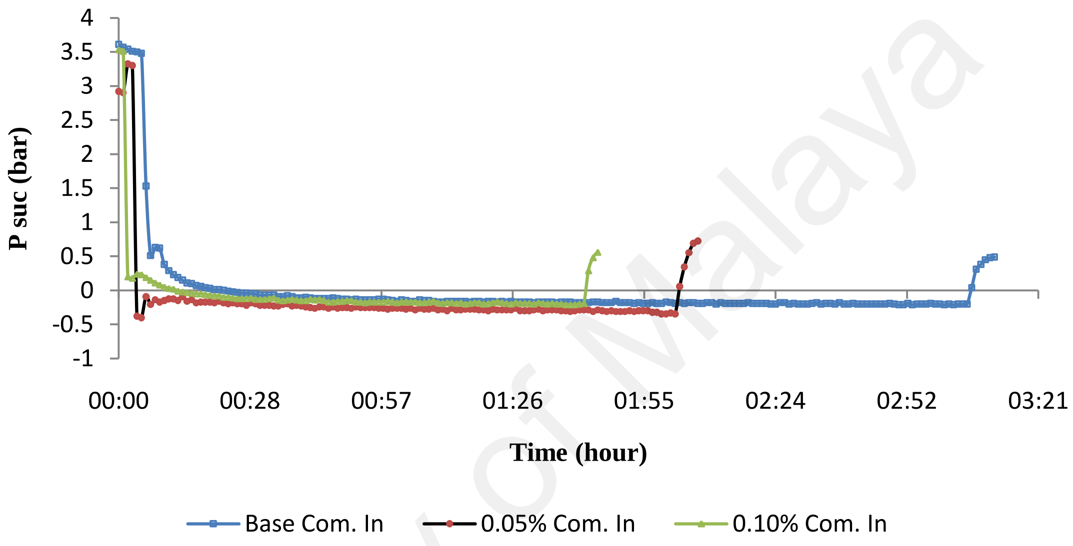

Figure 4.9 Compressor suction pressure

Figure 4.9 also demonstrates that existing of nanoparticle in the refrigeration system help the system to reduce suction pressure and also working time of the compressor. It may due to improve heat transfer characteristics of refrigerant by adding nanoparticle.

4.7 Pressure drop in the system

Pressure drop is one of the important items in fluid systems, especially when the fluid is changed by a new fluid which includes solid particles (nanoparticle). Figure 4.10 shows the pressure drop in the system between the outlet and inlet of the compressor. This includes the summation of the pressure drop of condenser, evaporator, capillary tube, and pipes in the system from outlet of the compressor to the inlet of the compressor.

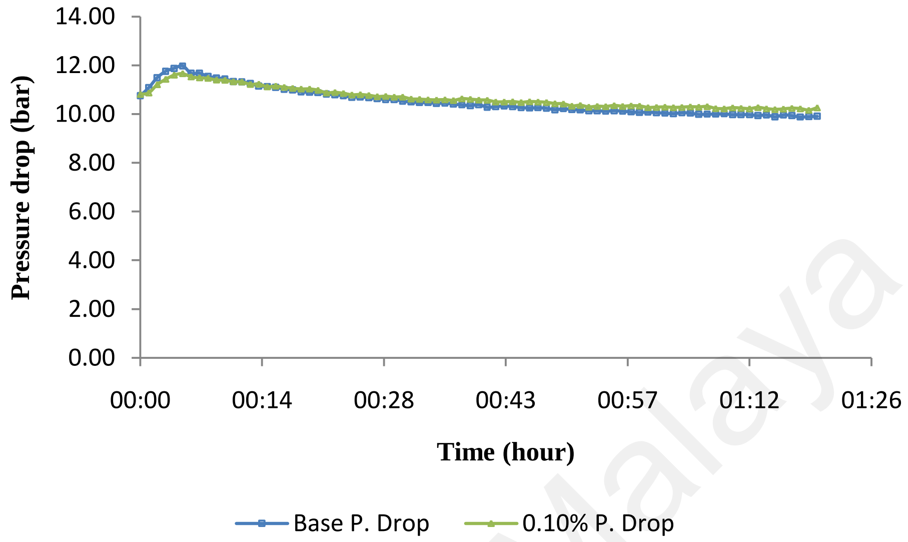

Figure 4.10 Pressure drop in the system

Figure 4.10 indicates the pressure drop in the system for basefluid and nanofluid with different nanoparticle concentration over one one-off cycle, showing that basefluid and 0.05% nanoparticle has almost the same pressure drop. 0.1% nanoparticle indicates less pressure drop at the first of the cycle but it increased slightly and reached to more than baseline at the end of cycle. The maximum pressure drop occurred in the case of 0.1% nanoparticle concentration. This result confirms that increasing the concentration of nanoparticle in the fluid causes to increase pressure drop and more energy consumption in each on-off cycle, this may because of the effect of solid particle into the fluid.

5. Conclusions and Recommendations

5.1 Conclusions

A test rig was constructed in order to evaluate the performance of a household refrigerator-freezer, which was used the refrigerant R-134a as a working fluid. The test rig included instrumentation to measure all of the thermodynamic properties relevant to the system performance. The energy consumption test was used to evaluate energy consumption of the refrigerator. The system was tested by the normal working fluid as well as nanorefrigerant with different nanoparticle concentration. Finally, all data were compared to evaluate the effect of using nanorefrigerant on heat transfer and energy efficiency of the refrigerator. After the successful investigation on the measured parameters, the following conclusions have been drawn based on the obtained results:

- Stability of nano-lubricant oil decreases by increasing the nanoparticle concentration in base fluid. It demonstrates that application of nanofluid with high nanoparticle concentration is limited, unless the stability of nanofluid would increase by using a different preparation method or using additives. However, nanofluid with small nanoparticle concentration is stable in long-term.
- Evaporator temperature gradient is improved by using nanorefrigerant. It proves that heat transfer characteristics of fluid increase by adding nanoparticle in basefluid. The evaporator temperature gradient is increased by increasing the nanoparticle concentration. The maximum

temperature gradient improvement in the evaporator was 20.2% in the case of using 0.1%-Al_2O_3 and was about 1.9 $^\circ C$.

- It has been found that the compressor consumes 3.821 kWh/day in case of using basefluid (R134a). The results showed that the energy consumption of refrigerator decreased by around 2.69% when the 0.1%-Al_2O_3 nanoparticle was added to the system.
- It is apparent from the data that the on-cycle duration is less in nanorefrigerant cases, but off-cycle duration is nearly the same between the baseline and nanofluid. It also demonstrates that the energy consumption decreased in case of using nanorefrigerant.
- Suction and discharge pressure of the compressor decreases in the case of using nanorefrigerant compared to the basefluid. It shows that the nanoparticle improves the lubricity of the lubricant oil. On the other hand, the pressure drop of the system was increased. It may happen because of the effect of adding solid nanoparticle into the basefluid and increase the viscosity of the fluid.
- Finally, it can be concluded that using nanoparticle in refrigeration system can improve heat transfer characteristics and decrease energy consumption of the system.

5.2 Recommendations

The present research investigated the performance of the refrigerator using nanorefrigerant. In fact, the feasibility of using nanorefrigerant as a refrigerant in domestic refrigerator was taken into account. Utilization of nanorefrigerant, as a new refrigerant in domestic refrigerator, requires a wide range of information about the properties of nanofluid such as enthalpy, viscosity, thermal conductivity, and compatibility of the nanorefrigerant with the other material in the system. Compatibility is very important and should be examined for all parts of the system to insure that there is no negative effect of nanorefrigerant in refrigeration system components.

The following recommendations can be suggested for the future research on the application of nanorefrigerant as refrigerants:

- Stability is the first parameter and an important characteristic of the nanofluid that should be considered. Using high nanoparticle concentration is limited because of the stability problem. Therefore, by overcoming the stability problem of nanofluid is a priority.
- Direct preparation (single-step preparation method) of nanorefrigerant needs designing a complex system that works at low temperatures (lower than boiling point of refrigerant). This method can be used to measure the fundamental properties of nanorefrigerant.
- Measuring enthalpy, which is needed to calculate the performance of the system at any point, is very complicated for nanorefrigerant. The main problem is the low boiling temperature of the refrigerant. It can be a potential field of research in the future.
- The other effect of using nanoparticle in the refrigeration system, such as compatibility with the equipment of the system, chemical reaction during long time, solubility of lubricant oil and refrigerant should be investigated.

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Appendix A Pressure Transducers – Installation and Use

INTRODUCTION

Common problems or questions concerning the use of pressure transducers are:

1. Transducer outputs and their wiring configurations;
2. Wiring one transducer to multiple readouts, recorders, computers, etc.;
3. Wiring multiple transducers to one readout, recorder, computer, etc.;
4. Using a milliamp signal with voltage input instrumentation;
5. Determining how many transducers can be excited from one power supply.

Each of these problems, or questions are discussed in detail in the following article.

TRANSDUCER OUTPUTS AND THEIR WIRING CONFIGURATIONS

OMEGA transducers have three main types of electrical outputs; millivolts (mV), volts (V), and current (mA). It is important for the user to know which output suits his application to ensure proper selection of a transducer. The following will describe the advantages, disadvantages, and wiring for millivolt, volt and current output transducers.

Transducers with a millivolt output are generally used in laboratory applications. They are low cost, small in size, and require a regulated power supply. Remembering that the millivolt signal is very low level, it is limited to short distances (up to 200 feet is usually considered the limit) and is very prone to stray electrical interference from other nearby electrical signals (other instrumentation, high ac voltage lines, etc.). Typical wiring configuration is shown in Figure A.1.

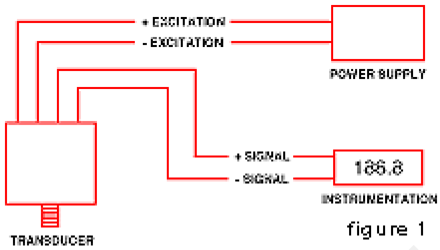


Figure A.1 Typical wiring configuration of transducers with a millivolt output

Transducers with an amplified voltage output are generally used in a light industrial environment and computer interface systems, where a higher level dc signal is required. Due to the built-in signal conditioning, they are higher cost and larger in size than the millivolt output transducers. Amplified voltage signals can travel up to medium distances and are much better in their immunity to stray electrical interference than the millivolt signal. Typical wiring configuration is shown in Figure A.2.

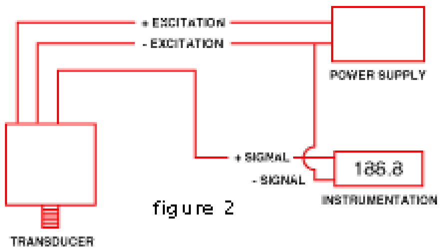


Figure A.2 Typical wiring configuration of transducers with an amplified voltage output

A transducer produces millivolts, amplified voltage, or current output. A transmitter produces current output only. Again, due to the built-in signal conditioning, the transmitters are higher cost and larger in size than the millivolt output transducers. Unlike the millivolt and voltage output transducers, a current signal is immune to any stray electrical interference, a valuable asset in the factory. A current signal also can be transmitted long distances. Typical wiring configuration is shown in Figure A.3.

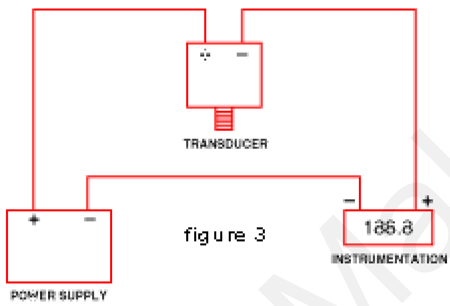


Figure A.3 Typical wiring configuration of transducers produce millivolts, amplified voltage, or current output

WIRING ONE TRANSDUCER TO MULTIPLE READOUTS, RECORDERS, COMPUTERS, ETC.

One of the great advantages of a current signal is the simplicity in setting up a multi-instrument system. Long distance transmission from instrument to instrument without electrical interference make multi-instrument systems easy. For example, a material test centre may have one control room for all the different test labs, enabling operation from one central location. Instrument calibration and troubleshooting are simple in a multi-instrument current loop. The only limitation for the number of instruments is the amount of voltage from the power supply driving the current loop. The minimum voltage required is determined by Ohms law, V-IR (voltage equals current times resistance). This is shown and explained in Figure A.4.

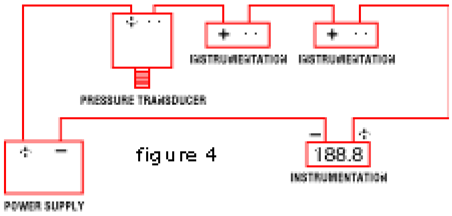


Figure A.4 Multi-instrument current loop

Where R_{LINE} = resistance due to wire, R_{LOAD} = combined instrumentation resistances, $Vs_{TRANSDUCER}$ = minimum supply voltage for transducer

For example, let is assume you have the following: 1. Pressure transmitter (4-20 mA) with 12-30 Vdc supply voltage; 2. Panel meter with a 10 ohm input impedance; 3. Recorder with a 25 ohm input impedance; 4. Computer with a 200 ohm input impedance; 5. Lead wire resistance of 5 ohms.

Minimum voltage required = (.020). (5 + 10 + 25 + 200) + 12 = 16.8 volts 24 volts is the most common power supply in a 4-20 mA current loop. Wiring a voltage or millivolt signal to multiple instruments also can be done, but is not as easy and does not have the calibration and troubleshooting advantages inherent in a current loop system. The voltage or millivolt signal can be wired in parallel to multiple instruments as shown in Figure A.5. This method assumes a very high input impedance in the instruments being wired. If this is not the case, an analog output can be used instead to retransmit the signal.

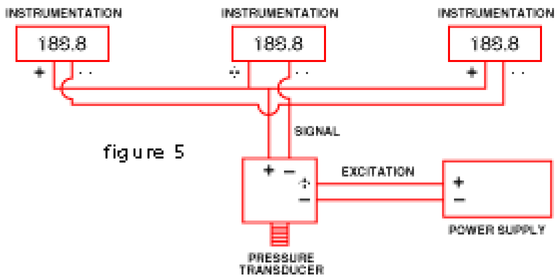


Figure A.5 Parallel wiring of voltage or millivolt signal to multiple instruments

WIRING MULTIPLE TRANSDUCERS TO ONE READOUT, RECORDER, COMPUTER, ETC.

In measuring multiple pressures, it is a common mistake trying to use multiple transducers, a switching device, and just one panel meter, thus saving money on multiple panel meters (or any other instrumentation). The problem is that each transducer has a unique zero point and the readout only has one zero screw. The net result is that the total accuracy increases to about 3%, even though each sensor is 0.5% accurate. In most cases, this larger error is intolerable.

The correct method of using multiple transducers with one readout device is to use transducers that have built-in zero and span adjustments screws, the same output (voltage or current), and the same pressure range. Each transducer is adjusted by applying a known pressure, so that they all have identical outputs. When they all have identical outputs, the meter is scaled and a switch can be used.

Another solution to using multiple transducers with one readout is to use a scanner instead of meter and a switch. There are many types of scanners. The type of scanner that works with multiple pressure transducers must have independent scaling on each channel.

Some scanners, besides having independent scaling on each channel, also offer independent current, voltage, or millivolt inputs to each channel. These types of scanners enable you to use transducers with different outputs as well as different pressure ranges with the same instrument. Figure A.6.shows that the multiple transducers wired to one meter and one switch

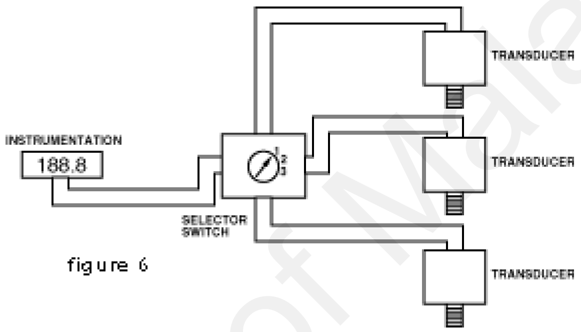


Figure A.6. Multiple transducers wired to one meter and one switch

USING A MILLIAMP SIGNAL WITH VOLTAGE INPUT INSTRUMENTATION

Most instrumentation is set up to receive voltage. A commonly asked question is how to use a current signal with instrumentation set up for voltage. This is simply done by installing a resistor across the input terminals of the instrumentation. The value of the resistor is determined by Ohms law (V = IR). For example, installing a 500 ohm resistor will convert 20 mA to 10 volts (V = IR = .020 x 500). This is shown in Figure A.7. The only other consideration is the zero offset. Since most current loops have a low end of 4 mA, there will be a zero offset. Using the same value resistor as above 4 mA will convert to 2 volts.

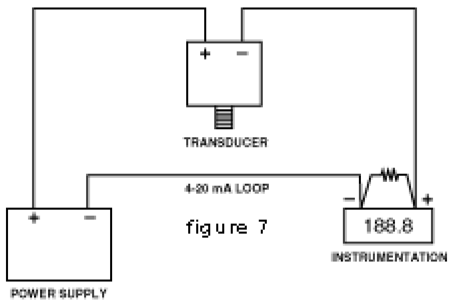


Figure A.7. Converting current into voltage for instrumentation set up for voltage

R=V/I

Where: R = Size of Resistor, V = Desired Voltage, I = Current

Example:

To Convert 4-20 mA into 2-10 V

R = V/I = 10/.02 = 500 Ohms

A 500 Ohm Resistor Would be Installed Across the (+) and (-) Terminals on the Instrumentation

DETERMINING HOW MANY TRANSDUCERS CAN BE EXCITED FROM ONE POWER SUPPLY

Multiple transducers can be excited from one power supply. The number of transducers that can be used is simply determined by the current draw of each transducer and the current capacity of the supply source. The sum of the current draw of the transducers can not exceed the total current capacity of the supply. For example, if you have 50 transducers drawing 13 milliamps, you will need a power supply having at least 650 milliamps (50 x 13). There is also nothing wrong with powering just one transducer with a power supply having high current capacity.

HANDLING, LOCATING AND INSTALLING TRANSDUCERS

A. **Diaphragm** - Do not press or touch the diaphragm as you may damage or alter its calibration, particularly on low pressure range models.

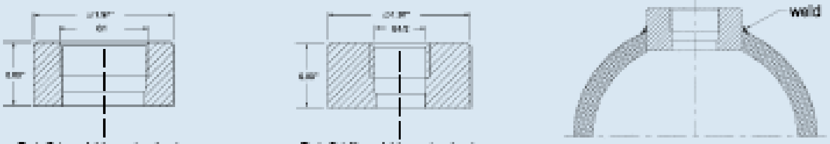
B. **Fittings and Hardware** - Use appropriate pressure rated fittings and hardware. Make sure you have the correct thread type and size fitting. Use pressure limiters, capacity chambers, snubbers, etc., if needed.

C. **Operate at Ambient Temperatures** - Locate the transducer where it can be readily inspected and serviced. Ambient temperature should be within the transducer specifications. The temperature coefficient effects on the overall accuracy of the transducer can be minimized the closer the ambient temperature is to 25°C. Avoid locations with excessive vibration.

D. **Installation** - Installation should be made only by qualified personnel familiar with safety practices and knowledgeable with all industry accepted standard relating to pressure systems.Transducer calibration and/or zero may shift if it is over-torqued when installing. Check for a zero shift after installing. When installing transducers, refer to standard industry torque data for thread size and material type

Reference: http://www.omega.com/techref/press-trans.html

Matching P-1 weld insert adapters for S-11 pressure transmitters



P-1 G1 weld insert adapter
Part # 1206974
for pressure ranges ≤ 30 psi

P-1 G1/2 weld insert adapter
Part # 1097008
for pressure ranges ≥ 50 psi

Cross section view of P-1 adapter installed in pipe.

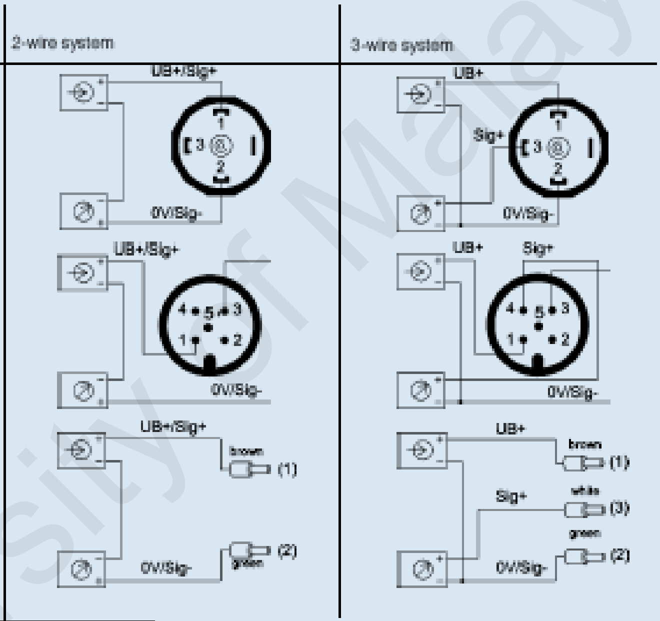
Wiring

2-wire system | 3-wire system

L-Connector, DIN EN 175301-803, Form A (DIN 43 650)

M12x1 Circular connector 5 pin

Vented cable with free ends



Legend:

power supply	
load (e.g. display)	
Sig+	output signal positive
UB+	power supply positive
0V	power supply negative
Sig -	output signal negative

For full specifications, visit www.wika.com to download datasheets S-10, S-11 or call 1-800-381-6549