PERFORMANCE OF A CONDENSER WITH COOPER OXIDE (II) NANOPARTICLES SUSPENDED INTO HOST REFRIGERANT

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This report is submitted in order to fulfill a part of the requirements for award of Degree in Bachelor of Mechanical Engineering (Thermal-Fluid)

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"I hereby declared that I have read this thesis, and in my opinion, this thesis is sufficient in terms of scope and quality for achieving award of Degree in Bachelor of Mechanical Engineering (Thermal-Fluid)"

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"I hereby declared that this report and all that comes with it is my own work, except the ideas and summaries in which I have clarified their sources"

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Special dedication is dedicated to my family, supervisor, lecturers, friends and all others that aid me in completing this thesis.

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ABSTRACT

The project is about a research on thermophysical properties of copper (II) oxide nanoparticles suspended into host refrigerant and the heat transfer performance of a condenser. Increasing the heat transfer rate of thermal system is something that researchers and engineers are aiming for. This is to increase the thermal efficiency of the system and thus, improves energy consumption savings. So, the idea of having nanoparticles suspended into a refrigerant makes it an important field to be studied due to its amazing enhancement in thermal conductivity and heat transfer rate. In this research, R407-C is selected as the host refrigerant and the design of the condenser is a simple horizontal tube of 0.5 meter in length and 11.7 millimeter in diameter. The mathematical modeling is used to investigate the thermal conductivity, viscosity and heat transfer of the nanorefrigerant with the volume fraction of the nanoparticles as its variable from 1% to 5%. The CFD simulation is also used to investigate the heat transfer performance of a condenser. These methods prove that there is big enhancement in thermal conductivity, viscosity and heat transfer with the effect of copper (II) oxide nanoparticles in R407-C.

ABSTRAK

Projek ini adalah kajian tentang ciri-ciri fizikal thermal nanopartikel-nanopartikel kuprum (II) oksida yang diampaikan ke dalam bahan penyejuk dan prestasi sebuah condenser dalam pemindahan haba. Meningkatkan kadar pemindahan haba di dalam sistem termal adalah suatu hala tuju bagi kebanyakan penyelidik dan jurutera. Ini adalah bertujuan untuk meningkatkan kecekapan termal di dalam suatu sistem dimana ia juga meningkatkan penjimatan dalam penggunaan tenaga. Ide untuk mengampaikan nanopartikel-nanopartikel ke dalam bahan penyejuk menjadi suatu kajian yang sangat penting bagi meningkatkan konduksi termal dan kadar pemindahan haba. Dalam kajian ini, R407-C dipilih sebagai bahan penyejuk dan rekabentuk condenser adalah satu tube mendatar yang panjangnya ialah 0.5 meter dan berdiameter 11.7 milimeter. Model-model matematik digunakan untuk mengkaji konduksi termal, kelikatan dan pemindahan haba oleh nanopartikel-nanopartikel yang telah diampai ke dalam R407-C dimana pecahan isipadu digunakan sebagai pembolehubah dimanipulasikan dalam lingkungan 1% hingga 5%. Simulasi CFD juga digunakan sebagai kaedah untuk memperolehi kadar pemindahan haba oleh kondenser. Kaedah-kaedah ini akan membuktikan bahawa ciri-ciri termal nanorefrigerant tersebut menunjukkan peningkatan yang besar.

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NOMENCLATURE

ϕ	=	Volume fraction
U	=	Overall heat transfer coefficient
h	=	Heat transfer coefficient
T	=	Temperature
A_i	=	Inner area
A_o	=	Outer area
K_{304L}	=	Thermal conductivity of stainless steel 304L (condenser)
x	=	Length
D_i	=	Inner diameter
K_p	=	Thermal conductivity of nanoparticle
ρ_p	=	Density of nanoparticle
d_p	=	Diameter of nanoparticle
K_{bf}	=	Thermal conductivity of base fluid
ρ_{bf}	=	Density of base fluid
c_{pbf}	=	Specific heat of base fluid
μ_{bf}	=	Dynamic viscosity of base fluid
c	=	1.298 (constant)
Re_{bf}	=	Reynolds Number of base fluid
v_{bf}	=	Velocity of base fluid
K_{nf}	=	Thermal conductivity of nanofluid
μ_{nf}	=	Dynamic viscosity of nanofluid
h_{nf}	=	Heat transfer coefficient of nanofluid
Nu_{nf}	=	Nusselt Number of nanofluid
Pr_{nf}	=	Prandtl Number of nanofluid
D_B	=	Brownian diffusion coefficient
k_B	=	Boltzmann constant

CHAPTER 1

INTRODUCTION

1.1 Background

Due to the immense applications of heat transfer in many industries, wanting to increase the efficiency of heat exchanging equipments has become the main purpose for designers of industrial places. In recent years, different approaches have been created by researchers of attempting to enhance heat transfer. Increase the efficiency and improvement of the output of thermal devices can cause energy savings and indirectly decrease the equipment sizes and initial and operation costs (Xuan and Li, 2000a). Unfortunately, most used approaches to achieve this aim is by increasing the equipment's surface area per volume unit and therefore increase the equipment size which leads to increase in pressure loss. As a result, powerful pumps are needed and this leads to higher energy consumption. What the industry wants is to have a better efficiency and also having the equipments run with constant energy consumption or maybe even lesser.

Then there is the nanotechnology field that is introduced. Whereby, using nanotechnology and especially nanofluids can help the researchers make fitting media for heat transfer. This is because nanofluid is a mixture of a base fluid with suspended nanosize metallic or metal oxide particles (Choi, 1995). Common industrial thermal fluids like water, ethylene glycol, and oils have lower thermal conductivity coefficient than metals and metallic oxides. Nanosize metallic or metal

Oxide particles can improve thermal capability of the traditional fluid. There is alot of good reason for nanofluid heat transfer research because of the potential of improving in the thermal conductivity of the fluids due to nanoparticles. With the advancement of thermal field and nanotechnology, researchers are encourage to do more research on nanofluid following major trend in modern science and technology which is miniaturization industries.

1.2 Objectives

i. To investigate the effect of cooper (II) oxide nanoparticle with volume fraction as its variable on Nano-refrigerant thermal conductivity.
ii. To study the effect of nanoparticle volume fraction on dynamic viscosity of the nanorefrigerant.
iii. To investigate the heat transfer performance of a condenser using nanorefrigerant.

1.3 Scope

This study will use mathematical modelling to investigate the thermal physical properties of the nanorefrigerant which are the thermal conductivity, viscosity and its heat transfer performance in a condenser. A simulation is needed to verify the result. The parameters such as the size of nanoparticles, types of refrigerant, flow velocity of nanorefrigerant and mass flux are constant. The variable in this study is only the nanoparticle volume fraction. The diameter of the nanoparticle is 40 nm.

1.4 Problem Statement

Condenser are heat exchangers and is one of the refrigeration devices that accept vaporized refrigerant from an evaporator and then compress and liquefy it for use within a system, typically by cooling it. Increasing its efficiency becomes one of the main purposes for designers in industrial units. Most approach is by increasing the equipment’s surface area per volume unit. Therefore, it increases the equipment’s size which leads to some negative effects. Pressure loss, high cost of equipment and high power consumption are some of the negative effects. In modern era, nanoparticle research is currently an area of strong scientific interest due to a wide variety of potential applications. One of the applications is in the refrigeration system. Due to the lack of knowledge and still not fully understood, researches only believed it has big potential in energy savings for the system. It is said that nanoparticles suspended into host refrigerant improves lubrication and heat transfer performance during the condensing of the refrigerant in condenser but have never been commercialize yet. In this study, the thermal physical properties of the Nano-refrigerant where Copper (II) Oxide, CuO as the nanoparticle; is to be investigated by using the mathematical modelling. This study will show how the performance of the condenser is when nanoparticle is suspended into the host refrigerant in the refrigeration system.

CHAPTER 2

LITERATURE REVIEW

2.1 Nanofluids

Nanofluids are a new type of nanotechnology-based heat transfer fluids that are engineered by dispersing and stably suspending nanoparticles with average length of 1–50 nm in conventional heat transfer fluids. The author, Choi (1995) coined the term nanofluids for this new class of heat transfer fluids.

It should be known that the modern science and technology, “size does matter”. Maxwell’s concept of enhancing the thermal conductivity of fluids by dispersing solid particles is old, but what is new and innovative with the concept of nanofluids is the idea of using the nanometer-sized particles that have become available to investigators only recently.

The idea of dispersing solid particles in a fluid to enhance its thermal properties is not new. But only to have particle sizes of the range of 1 μm to 1 mm; before nanosized particles was introduced, many problems has been restricted such as on the deposition, abrasion, clogging and additional pressure drop, bothered by the fact that high volume fractions of particles were required to attain appreciable results; as stated by Choi (2008). He also stated that nanofluids, on the contrary, require relatively low concentrations to present enhanced thermal conductivity.

For the past decade, many scientists and researchers have made many amazing discoveries that a very small amount (<1 vol %) of guest nanoparticles that is hosted in fluids can provide big improvements in the thermal properties. For example, some nanofluids show evidence of improved thermal properties such as high thermal conductivity at low nanoparticle concentrations, strong size-dependent thermal conductivity, a nonlinear relationship between thermal conductivity and concentration, and a threefold increase in the critical heat flux at a small particle concentration.

Nanofluids have an increasing interest by researchers because these unique thermal transport phenomena that goes beyond the fundamental limits of conventional macroscopic theories of suspensions. For that reason, several mechanisms and models have been proposed to make a more thorough discovery for these unexpected, fascinating thermal properties of nanofluids.

These discoveries of the nanofluids technology also can give many opportunities for development in nanotechnology-based coolants for a diversity of innovative engineering and medical applications. From there, the study of nanofluids becomes a new field of scientific research and innovative applications. Thus, the subject of nanofluids is aworldwide interest for basic and applied research.

Table 2.1: Number of papers on “nanofluids”, “nanofluids and heattransfer”, and “nanofluids and properties” by SCOPUS database.
(Source: OronzioManca, Yogesh Jaluria and Dimos Poulikakos, 2010)

Year	Nanofluids	Nanofluids and Heat Transfer	Nanofluids and properties
1993	1	0	0
1995	1	1	0
1996	2	2	0
1997	2	1	1
1999	2	2	1
2000	4	3	3
2001	5	2	2
2002	5	2	2
2003	19	9	6
2004	35	23	8
2005	90	50	34
2006	124	62	32
2007	175	89	50
2008	225	107	91
2009	222	109	96
2010	95	54	25
Total	1007	516	351

2.2 Nanorefrigerant

Nanorefrigerant is one kind of nanofluid and the host fluid of nanorefrigerant is any type of refrigerant. The thermal conductivity of nanorefrigerant should be studied in order to improve the performance of refrigeration systems. The stability of nanorefrigerant should be known in order to keep the nanorefrigerant's long-term operation in the system.

The nanopowders would diffuse and enter the fluid in the system because of the application of nanorefrigerant. So the electrical conductivity of nanofluid in the system will increase because of the nanopowder's high electrical conductivity. The nanofluid's electrical conductivity should be researched to ensure the insulating properties of system. For this purpose, the experimental and model research is given to nanorefrigerant's thermal conductivity, stability and nanofluids' electrical conductivity. The main contents include:

a. Thermal conductivity of nanorefrigerants containing Cu, Al, Ni, CuO, Al_2O_3 and CNT are measured. Experimental results show that the nanorefrigerant's thermal conductivity increases enormously with the increase of nanoparticle volume fraction. The influences of nanopowder's material and physical dimension on nanorefrigerants' thermal conductivity are analysed.

b. The thermal conductivity model for nanorefrigerants containing nanoparticles, the thermal conductivity model for nanorefrigerants containing nanotubes and the general thermal conductivity model for nanofluids are proposed. Such three models are verified by experimental results. It shows that the three models are better than the other existing models and can be recommended for nanofluids, especially for nanorefrigerant.

c. The stabilities of nanorefrigerants with three kinds of dispersion method, nine kinds of nanopowders and three kinds of nanopowders volume fraction are evaluated by measuring the nanorefrigerant's transmissivity. It shows that nanopowders can be uniformly dispersed in the nanorefrigerants for long time.

d. The stability model for nanofluids is proposed. In the model the nanofluids' transmissivity can be yielded through the calculation of nanopowders' speed. The model is verified by experimental results. It shows that the model can predict the transmissivities of some nanorefrigerants quantificational and predict the transmissivities of other nanorefrigerants qualitatively.

e. Electrical conductivity of nanofluid, i.e. nanorefrigerants and nano-oils containing Cu, Al, Ni, Al_2O_3 and CNT, are measured. Experimental results show that the nanofluids' electrical conductivity increases with the increase of nanopowder volume fraction. However, the nanorefrigerants' and nano-oils' electrical conductivity is still in line with the national standards and the nanorefrigerants and nano-oils have excellent insulating performance. The influences of nanopowder's material and physical dimension on nanofluid's electrical conductivity are analyzed.

f. The electrical conductivity model for nanofluids containing nanoparticles, the electrical conductivity model for nanofluids containing nanotubes and the general electrical conductivity model for nanofluids are proposed. Such three models are verified by experimental results. At last, some deficiencies were pointed out in the paper and some further researches were planned.

2.3 Heat Transfer

Heat transfer can be seen throughout our daily life. Human body as the easiest example, constantly rejecting heat to its surrounding ensuring that it is comfortable with the surrounding. Heat transfer can be classified as the science that deals with the determination of the rates of energy transfer. The interested energy is heat which can be defined as the form of energy that can be transferred from one system to another as a result of temperature difference (Cengel, 2006). For heat transfer to occur, temperature difference is the basic requirement. With the knowledge of heat transfer, the rates of heat transfer to or from a system can be determine thus the times need of heating and cooling as well as the variation can be known either through experimental method theoretical method with some assumption need to be done first.

The conventional method for enhancing heat transfer in a thermal system consists of increasing the heat transfer surface area as well as the flow velocity of the working fluid. The dispersion of solid nanoparticles in heat transfer fluids is a relatively new method. Extended surfaces such as fins and microchannels (width <100 μm) have already been used to increase the heat transfer surface area. Their performance in effectively removing as much as 1000 W/cm^2 has shown a great improvement in the area of cooling. However, further development of this technology is at a standstill because it has already been pushed to its achievable limits. Thus, attention is now turning towards the dispersion of solid particles in fluids. Improving heat transfer characteristics in refrigeration and air conditioning systems has been intensively studied by many investigators.

Increased thermal conductivity will result in higher heat transfer than that of the base (pure) fluid without dispersed nanoparticles. Measurements of the heat transfer coefficient of nanofluids have shown that heat transfer capability if water increased by 15% with a dispersion of less than 1 vol. % copper oxide nanoparticles (Zussman, 1997). Recently, there are about 80% improvements in heat transfer with the dispersion of less than 3 vol. % alumina nanoparticles. It should be noted that the observed heat transfer rates of nanofluids are much higher than those predicted by conventional heat transfer correlation, even when changes in thermophysical properties such as thermal conductivity, density, specific heat and viscosity are considered. It appears that the effect of particle size and number becomes predominant in enhancing heat transfer in nanofluids.

2.3.1 Convective Heat Transfer in Nanofluids

Maxwell first proposed the idea of suspending metallic particles in conventional heat transfer fluids in 1873. He believed that the metallic particles would increase the electrical and thermal conductivity of the fluids. This idea was carried on throughout the next century as scientists attempted to create a fluid with millimeter- and micrometer-sized particles that could be used for practical applications. However, even though their efforts showed that particles did increase the heat transfer properties of their base fluids, they could not overcome problems caused by the large size of the particles. It was not until the advent of nanotechnology that the thought of nanoparticles came about.

2.4 Thermal conductivity of nanofluids (CuO)

It is well known that at room temperature, metals in solid form have orders-of-magnitude higher thermal conductivities than those of fluids (Touloukian et al., 1970). For example, the thermal conductivity of copper at room temperature is about 700 times greater than that of water and about 3000 times greater than of engine oil.

The thermal conductivity of metallic liquids is much greater than that of non-metallic liquids. Therefore, the thermal conductivity of metallic fluids that contain suspended solid metallic particles could be expected to be significantly higher than those conventional heat transfer fluids.

Table 2.2: Thermal conductivity of various solids and liquids

	Material	**Thermal conductivity (W/m.k)**
Metallic solids	Cooper	401
	Aluminium	237
Non-metallic solids	Silicon	148
	Alumina (Al_2O_3)	40
Metallic liquids	Sodium (644K)	72.3
Non-metallic liquids	Water	0.613
	Ethylene glycol (EG)	0.253

Numerous theoretical and experimental studies of the effective thermal conductivity of dispersion that contain solid particle have been conducted since Maxwell's theoretical work was published more than 100 years ago (Maxwell, 1873). However, all of the studies on thermal conductivity of suspensions have been confined to millimetre or micrometre-sized particles then. The major problem with suspensions containing millimetre and micrometer-sized particles is the rapid settling of these particles. Furthermore, such particles are too large for micro systems.

Existing theories in nanofluids cannot fully explain the observed increase in thermal conductivity. Therefore there is a need to come up with a better analytical model which captures the underlying physics accurately. Researchers have been working to develop a model to find explaination of the increase and then possibly design fluids with enhanced thermal conductivity.

There are also some carrying out experimental studies on the thermal conductivity enhancement of water and ethylene glycol containing suspension of various nanoparticles, such as Al_2O_3, CuO, Au, Fe, and carbon nanonotubes. In addition, the study involves the role of surfactants in the absolute measurement of nanofluid thermal conductivity. A transient hotwire method is used to measure the thermal conductivity of fluids. The experimental setup is shown in the figures below.

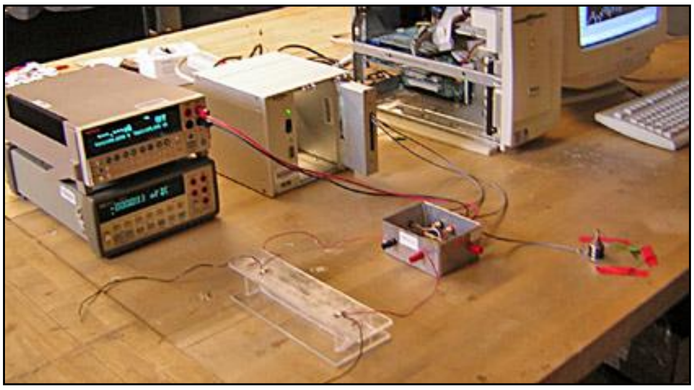

Figure 2.1: The transient hotwire method

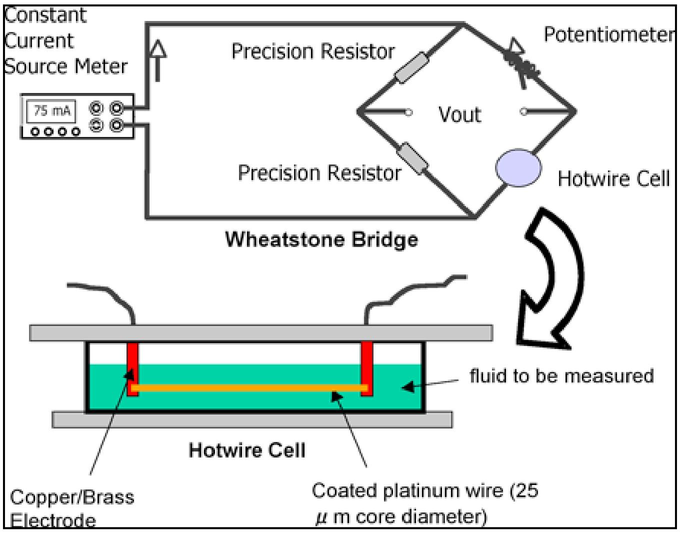

Figure 2.2: Experimental system for nanofluid measurements

Due to the applications of suspended nanoparticles in a base fluid, the thermal properties of nanofluids have been continually studied in the last decade. Various nanoparticles and base fluids are applied to fabricate different kind of nanofluids. Former experimental data have shown that nanofluids have higher thermal conductivity than that predicted by the conventional models like Maxwell model. However, the conventional models did not consider the effects associated with Brownian motion. This may cause the underestimation to the thermal conductivity of nanofluids. New models included the effects associated with Brownian motion are getting more investigated in the recent years.

Some prior studies have indicated that the enhancement of thermal conductivity which directly results from collisions between nanoparticles is not