HEAT TRANSFER CHARACTERICSTIC OF AN EVAPORATOR WITH CuO REFRIGERANT BASED NANOFLUIDS AS WORKING FLUID

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ADMISSION

"I admit this report has been written by me myself except for some quotation that has been noted well for each of them"

Signature : ....

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Date : 01/07/2012

DEDICATION

This report is dedicated to my beloved parents

Abd Halim bin Ismail

and

Zarina bt Ahmad

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APPRECIATION

Thanks to Allah swt upon the completion of this report. Not forgetting my parents who always support me no matter what obstacles came through. Also special thanks to my supervisor, Pn. Fadhilah bt Shikh Anuar in guiding me along this report writing and project computation. Not to mention, Nicholas Lian ak Mujah, my classmate who help me a lot in completing this project.

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ABSTRACT

Nowadays, refrigeration systems have become one of the most important systems for people's daily lives. In Malaysia, it can be seen that nearly each of the house has a room air conditioner installed in it. Based from some research, the use of air conditioners consumes about 40 % of the total of electricity used in a house. This means that the use of air conditioners consumes a lot of electricity. With the potential of the nanoparticles that have been developed in recent years, many researchers believed that nanoparticles can enhance the thermal conductivity and the dynamic viscosity of the conventional basefluid, thus increasing the heat transfer rate and the energy consumption could be reduced. In this project, the effect of the suspended nanoparticles, CuO, into the refrigerant, which can be called as nanorefrigerant, is being investigated using the mathematical modeling in terms of thermal conductivity, viscosity and heat transfer rate of the nanorefrigerant. Simulation is needed in this project to verify the Mathematical Modeling results in order to have reliable data/output. The ANSYS CFD simulation is the preferred simulation software to be used in this project.

ABSTRAK

Pada masa kini, sistem penyejukan telah menjadi salah satu sistem yang paling penting untuk kehidupan seharian masyarakat. Di Malaysia, ia boleh dilihat hampir setiap rumah mempunyai penyaman udara yang dipasang di dalamnya. Berdasarkan dari penyelidikan, penggunaan penghawa dingin menggunakan kira-kira 40 % daripada jumlah tenaga elektrik yang digunakan di dalam rumah. Ini bermakna bahawa penggunaan penghawa dingin menggunakan banyak tenaga elektrik. Dengan potensi nanopartikel yang telah dibangunkan sejak beberapa tahun kebelakangan ini, ramai penyelidik percaya bahawa nanopartikel boleh meningkatkan kekonduksian terma dan kelikatan dinamik bendalir asas konvensional, sekaligus meningkatkan kadar pemindahan haba dan penggunaan tenaga dapat dikurangkan. Dalam projek ini, kesan nanopartikel, CuO yang dimasukkan kedalam penyejuk, yang boleh dipanggil sebagai nanorefrigerant, sedang disiasat menggunakan pemodelan matematik dari segi kekonduksian terma, kelikatan dan kadar pemindahan haba daripada nanorefrigerant. Simulasi diperlukan dalam projek ini untuk mengesahkan keputusan Pemodelan Matematik untuk mempuyai data/output yang boleh dipercayai . Simulasi CFD ANSYS merupakan perisian simulasi pilihan yang akan digunakan dalam projek ini.

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NOMENCLATURE

k	Thermal Conductivity ($W/m.K$)
ρ	Density (kg/m^3)
T	Temperature (^oC or K)
r	Radius (m)
U	Overall heat transfer coefficient (W/m^2K)
h	Heat transfer coefficient(W/m^2K)
A	Area(m^2)
ΔT	Temperature difference
Nu	Nusselt number
Pr	Prandtl number
C_p	Heat capacity($J/kg.K$)
d	Diameter (m)
c	constant
β	Particle motion
f	friction
k_{33}^c	Longitudal equivalent thermal conductivity
k_{11}^c	Transverse equivalent thermal conductivity
L	Length (m)
ϕ	Volume Fraction
n	Shape factor
ψ	Particle sphericity
γ	Ratio of nano layer
λ	Elliptical complex nanoparticles
B_{2x}	Depolarization factor along x- symmetrical axis
α	Volume ratio
v	velocity(m/s)
μ	viscosity($Pa.s$)
Re	Reynold number

Subscripts

p	nanoparticles
b	Base fluid
eff	Effective
pe	modified
in	inlet
out	outlet

CHAPTER 1

INTRODUCTION

1.1 Background Study

An evaporator is a device or a tool that can transform a liquid into vapor or gaseous form. For example, in an air conditioning system, the evaporator transforms the liquid, freon, to evaporate from liquid to gas, absorbing heat in the process.

Nowadays, the development of evaporator has increased largely, thus leading to many different types of evaporator being produced. Two of the main types of evaporator that is commonly being used are Forced Circulation Evaporator and Falling Film Evaporator. Forced Circulation Evaporator is suitably used by liquids which tend to crystallize upon concentration and which have the tendency to scale. This type of evaporator is being used in the food processing industry and making dyes. Falling Film Evaporator is an industrial device to concentrate solutions, especially with heat sensitive components, thus making it the most frequently used type of evaporator. It is being used extensively in chemical process industry, food and paper industry.

Generally, nanofluid can be defined as a fluid that contains particles that are sized in nanometer and it is called nanoparticles. Usually, the nanoparticles that are used in nanofluids are typically made of metals, oxides, or carbon tubes. Furthermore, because of their novel properties, nanofluids have been potentially helpful in many applications of heat transfer nowadays, such as, fuel cells, microelectronics, pharmaceutical processes and hybrid powered engines. By using the software analysis of computational fluid dynamics (CFD), nanofluids can be assumed to be single phase fluids.

In an evaporator, usually there is a working fluid called refrigerant. Refrigerant can be defined as a substance that is used in a heat cycle that undergoes a reversible phase change from a liquid to a gas. Before this, fluorocarbons, especially chlorofluorocarbons were traditionally used as the refrigerants. But as time goes by, these refrigerants are being phased out because of their ozone depletion effects and being replaced by other types of refrigerants. Other common types of refrigerants that are being used in various applications are sulfur dioxide, methane and ammonia.

Regarding to this project, a suitable refrigerant must be considered so that it can be mixed with the nanoparticles, which is CuO to be inserted into the evaporator and act as the working fluid. The used of the CuO as the nanoparticle is to investigate its effect on thermal conductivity and dynamic viscosity of the nanorefrigerant. The used of mathematical model is to investigate the thermal physical properties of the nanorefrigerant and the heat transfer rate of evaporator.

1.2 Objectives of the study

a) To investigate the effect of cooper oxide with volume fraction from 1 to 5 vol% on thermal conductivity of nanofrigerant

b) To study the effects of nanoparticle volume fraction on dynamic viscosity of the nanofrigerant

c) To investigate the heat transfer rate of tube of evaporator using the nanorefrigerant as the working fluid.

1.3 Scope

This study will use mathematical modeling to investigate the thermal physical properties of the nanorefrigerant. A simulation is needed to verify the result. The parameters such as size of nanoparticles, types of refrigerant, nanorefrigerant velocity, and mass flux, heat flux are constants. The variable in this study is only the nanoparticle volume fraction

1.4 Problem Statement

An air conditioning system or a refrigeration system which built with an evaporator where the process of transformation, from liquid into vapor or gaseous phase. The working fluid that is being used on the systems known as refrigerant and mostly used is Tetrafluoroethane (R-134a).

Nowadays, the energy consumptions of the refrigeration are generally high. With the potential of the nanoparticles that have been developed, many researchers believed that nanoparticles can enhance the thermal conductivity and the dynamic viscosity of the conventional basefluid, thus increasing the heat transfer rate and the energy consumption could be reduced.

This project is expected to influence the heat transfer rate in the evaporator by suspending the nanoparticle into the conventional refrigerant. This mixing is then known as nanorefrigerant. Also in this project, the thermal physical properties of the nanorefrigerant will be investigated by using mathematical modeling.

Chapter 2

LITERATURE REVIEW

2.1 History of Nanofluids

Heat transfer fluids (HTFs) have many industrial and civil applications, including in transport, energy supply, air-conditioning and electric cooling, etc. Examples of traditionally HTFs are oils, glycols, water and fluorocarbons. However, these traditional HTFs have poor heat transfer performance due to their low thermal conductivities. Various techniques and development have been proposed to improve the heat transport properties of fluids. At the beginning, researchers tried to blend or suspend the base fluid with solid particles of micrometer, even millimeter magnitudes to increase the thermal conductivity of the base fluid since the thermal conductivity of solid is typically higher than liquids, can be seen from Table 1 (Xiang and Mujumdar, 2006).

Table 2.1: Thermal conductivities of various solids and liquids

Various solids/liquids	Material	Thermal Conductivity (W/m.K)
Metallic solids	Copper	401
	Aluminum	237
Nonmetallic solids	Silicon	148
	Alumina (Al_2O_3)	40
Metallic liquids	Sodium (644K)	72.3
Nonmetallic liquids	Water	0.613
	Ethylene glycol (EG)	0.253
	Engine oil (EO)	0.145

However, due to their large size and high density, these solid particles have limited practical application because of troublesome problems that can occurred such as, abrasion of the surface, clogging the microchannels and increasing the pressure drop (Han, 2008)

Nowadays, the enhancement of nanotechnology has increased rapidly, thus leading to process and produce materials with average crystallite sizes below 50 nm. Fluids with nanoparticles suspended in them are called nanofluids, a term proposed by Choi in 1995 at the Argonne National Laboratory, U.S.A. (Choi, 1995).

Generally, nanofluids are formed by dispersing nanometer-sized particles (1-100 nm) or droplets into HTFs. Nanoparticles have unique properties, such as large surface area to volume ratio, dimension-dependent physical properties, and lower kinetic energy, which can exploited by the nanofluid. At the same time, the large surface area make nanoparticles better and more stably dispersed in base fluids. Compared with micro-fluids or milli-fluids, nanofluids stay more stable, so nanofluids are promising for practical applications without causing problems mentioned above. Nanofluids will keep the fluidic properties of the base fluids, behave like pure liquids and incur little penalty in pressure drop due to the fact that the dispersed phase (nanoparticles) are extremely tiny, which can be very stably suspended in fluids with or even without the help of surfactants (Xuan and Li, 2003). Below are figures of nanoparticles that are widely used by researchers.

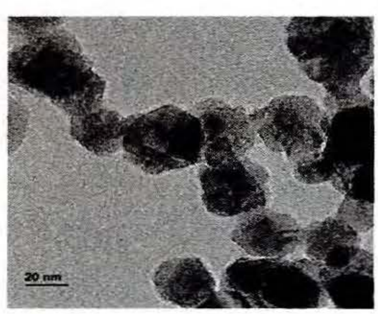

Figure 2.1: Titanium oxide nanoparticles

(Source: http://memagazine.asme.org/articles/2006/September/No_Small_Risk.cfm)

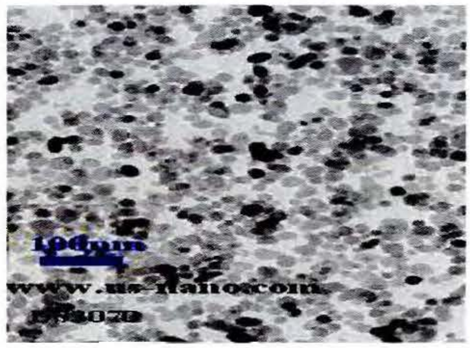

Figure 2.2: Copper oxide nanoparticles

(Source:http://www.us-nano.com/inc/sdetail/222)

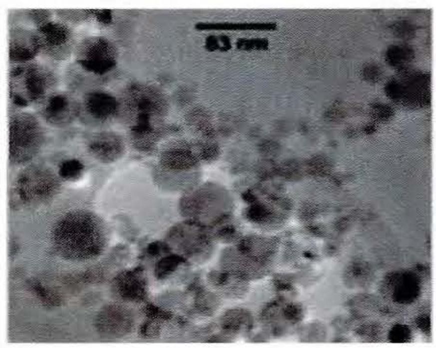

Figure 2.3: Alumina oxide nanoparticles

(Source:http://www.us-nano.com/inc/sdetail/222)

2.1.1 Nanorefrigerant

In recent decades, refrigeration systems have become one of the most important systems for people's daily lives and the output for the refrigeration systems has been increasing rapidly. In the past 10 years, the used of room air conditioners have increased about 15 % per year in China. In some cities like Shanghai, about 40 % of the total electricity consumption has been recorded. This means that the use of air conditioners consumes a lot of electricity (Ding, 2007).

Basically, the working fluid for the refrigeration system is refrigerant and it is one of the HTFs. With the increasing of nanotechnology nowadays, many researchers believed that nanoparticles can enhance the thermal conductivity and the dynamic viscosity of the conventional basefluid, thus increasing the heat transfer rate and the energy consumption could be reduced.

Refrigerant-based nanofluids have been investigated for the possible application as a new kind of working fluid in refrigeration systems (Bi et al., 2008), and were called as nanorefrigerants by Ding et al. (2009). From the research done by Jiang et al. (2007), nanorefrigerant has a higher thermal conductivity than that of a conventional pure refrigerant. Other researches about nanorefrigerant done by Wang et al. (2003) and Bi et al. (2008) shows that with nanoparticles, the mineral oil in the refrigerant can be enhanced and also, the refrigeration system can be improved in terms of its performance respectively.

Recently, investigation on the boiling heat transfer characteristics of nanorefrigerant are focused only on the pool boiling heat transfer, as done by Wu et al. (2008) and according to Peng et al. (2009), there are no published researches on the flowing boiling heat transfer characteristics of nanorefrigerant.

An experiment on the pool boiling heat transfer of carbon nanotube (CNT) that is CNT's/R22, CNT's/R123 and CNT's/R134a was conducted by Park and Jung (2007). They conducted the experiment on a horizontal smooth tube. The results of the experiment showed that the pool boiling heat transfer coefficients of refrigerants improved by using CNT's. Furthermore, at lower heat flux, the enhancement of the heat transfer coefficients became clearer and the maximum enhancement could reach 36.6 %.

Wu et al. (2008) used TiO_2/R11 nanofluid in their experiment to investigate the pool boiling heat transfer on a horizontal copper tube. Their findings were that, when the nanoparticles concentration is low, the boiling heat transfer will enhanced, but faded or decreased under the condition of high nanoparticles concentration.

From the experiment that was conducted by Trisaksri and Wongwises (2009), they used a cylindrical copper tube to investigate the pool boiling heat transfer of TiO_2/HCFC 141b nanofluid. Their results were that, with the increments of the concentrations of nanoparticles, the nucleate pool boiling heat transfer will decreased, especially at high heat fluxes.

2.2 Thermal Conductivity of Nanofluids

In general, thermal conductivity, *k* is a material ability to conduct heat according to its properties. Thermal conductivity is also an important parameter in enhancing the heat transfer performance of a heat transfer fluid, thus leading to many experimental works being conducted involving on this aspect. According to Murshed et al. (2007) the thermal conductivity of nanofluids varies with three attributes; size, shape and material of nanoparticles. For example, nanofluids that are suspended with metallic nanoparticles were found to have a higher thermal conductivity than nanofluids that are suspended with non-metallic (oxide) nanoparticles. Furthermore, nanofluids that are suspended with nanoparticles that are spherical in size, increased only a smaller value of thermal conductivity compared with the nanofluids having cylindrical (nano-rod or tube) nanoparticles (Murshed et al., 2005)

Xiang and Mujumdar (2006) stated that, the most common and cheaper nanoparticles that are widely used by researchers in their experimental investigations are Alumina (Al_2O_3) and copper oxide. Even when the size of the particles and the type of base fluids are different, all the experimental results have demonstrated the enhancement of the thermal conductivity by addition of nanoparticles. Following the experiment conducted by Eastman et al. (1997) the thermal conductivity of nanofluids that contains CuO, Al_2O_3 and Cu nanoparticles with two different base fluids; water and HE 200 oil was measured. It shows 60 % improvement for the thermal conductivity as compared to the corresponding base fluids for only 5 vol% of nanoparticles. They also showed that the use of CuO results in smaller improvements than that of Cu nanoparticles.

From the experiment conducted by Lee et al. (1999), they suspended $Al_2O_3$and CuO (24.4 nm and 38.4 nm, 18.6 nm and 23.6 nm) with two different base fluids that are water and ethylene glycol (EG). They found that CuO nanofluids enhance the thermal conductivity higher than those in Al_2O_3 nanofluids. The experimental result also showed that the thermal conductivity of nanofluids depends on the thermal conductivity of both the particles and the base fluids.

By using the steady-state parallel plate technique, Wang et al. (1999) measured the thermal conductivity of nanofluids that contains $Al_2O_3$and CuO nanoparticles. The particles were dispersed in ethylene glycol, engine oil, water and vacuum pump. The experimental data that they recorded shows that the thermal conductivity for each of the nanofluids was higher than those of their base fluids. The thermal conductivity of the nanofluids increased with increasing volume fraction of the naoparticles. For a specific volume fraction, the increase of thermal conductivity was different for each base fluid.

Ferum (Fe) nanoparticles have also been used in nanofluids. Hong et al. (2005) prepared the Fe nanofluid with ethylene glycol. From the investigation that they have done, they found that the thermal conductivity of Fe nanofluids exhibit higher enhancement than Cu nanofluids. Their experimental result stated that the material with high thermal conductivity is not always the best choice for the suspension to enhance the thermal characteristics of base fluid. Also, they concluded that the thermal conductivity of nanofluids increased non-linearly with the solid volume fraction. Hong et al. (2006) also investigated the effect of the clustering of Fe nanoparticles on the thermal conductivity of nanofluids. The founding of this experiment was that the agglomeration of Fe nanoparticles is directly related to the thermal conductivity of nanofluids, thus causing the nonlinear relation between the thermal conductivity of nanofluids and the Fe volume fraction due to rapid clustering of nanoparticles in condensed nanofluids.

Patel et al. (2003) studied silver (Ag) and gold (Au) nanoparticle with two kinds of coating, thiolate and citrate in water and toluene-based fluids. This study is to check the conductivity improvement effect at low concentrations. For Ag particles at a very low loading of 0.00026 vol%, 5 %-21 % enhancement of the thermal conductivity for water with citrate was found in the temperature range 30 - 60 °C. For a loading of 0.011 % of Au particles, the improvement of thermal conductivity was around 7 % - 14 %. This indicates that the thermal conductivity enhancement of the silver nanofluids were less than that of gold nanofluids because of the larger sizes of the silver particles than the gold particles. Also, from this investigation, the increments in thermal conductivity of the nanofluids were found to be almost linear with particle volume fraction and polynomial with temperature. The nanofluids with particles with thiolate coating had less thermal conductivity enhancement than those with particles with citrate coating. This showed that the effective heat transfer at metal surface contact was decided by the type of coating.

The largest increases in thermal conductivity have been observed in suspensions of carbon nanotubes, which have very high aspect ratio and very high thermal conductivity. Iijima (1991) conducted the first report for the synthesis of nanotubes. Choi et al. (2001) investigated the nanotube (multiwalled carbon nanotubes or MWCNTs)-oil mixture to measure their effective thermal conductivity. The thermal conductivity enhancement ratio was more than 2.5 at approximately 1 vol% of nanotube concentration. Based from the investigation done by Xie et al. (2003), carbon nanotube was dispersed in distilled water, ethylene glycol and decene. In order to form more hydrophilic surfaces, they introduced oxygen-containing functional groups on carbon nanotube (CNT) surfaces. Their results indicated that the thermal conductivity enhancement increased with increasing nanotube concentrations but reduced with increasing thermal conductivity of the base fluids. Comparatively, with other nanostructure materials discussed previously, nanotubes provided the highest thermal conductivity enhancement. The experimental studies on thermal conductivity of nanofluids have been summarized in Table 2.

Table 2.2: Summary of experimental studies on thermal conductivity of nanofluids

Investigator	Particles	Size (nm)	Fluids	Observations
Eastman et al. (1997)	Al_2O_3/CuO/Cu	33/36/18	Water, HE-200 oil	60% improvement for 5 vol% CuO particles in water
Lee et al. (1999)	Al_2O_3/CuO	24.4,38.4/18.6,23.6	Water, EG	20% improvement for 4 vol% CuO/EG mixture
Wang et al. (1999)	Al_2O_3/CuO	28/23	Water, EG, PO, EO	12% improvement for 3 vol% Al_2O_3/water nanofluids

Hong et al. (2005)	Fe	10	EG	18% increase for 0.55 vol% Fe/EG nanofluids
Patel et al. (2003)	Au, Ag	4, 15/70	Water, toluene	Size, temperature and chemical characteristics
Choi et al. (2001)	MWCNTs	Ø25 x 50 μm	Oil	Exceed 250% at 1.0 vol%
Xie et al. (2003)	TCNTs	Ø15 x 30 μm	DW, EG, DE	19.6%, 12.7% and 7.0% increase at 1.0 vol% for TCNT/DE, EG and DW, respectively

Referring to Xiang and Mujumdar (2006), they found that the available experimental data from different research groups vary widely and it can be shown in figures below.

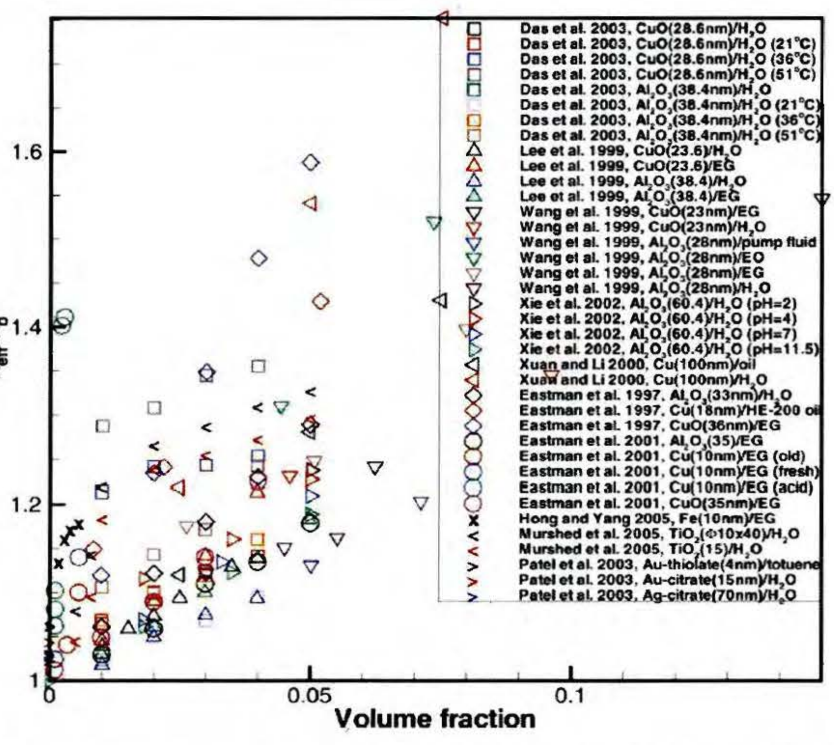

Figure 2.4: Comparison of experimental data on thermal conductivity of nanofluids