INVESTIGATION OF BASE FLUID AND NANO FLUID USED FOR REFRIGERATION/AIR-CONDITIONING OF SMALL SPACE

by

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بسم الله الرحمن الرحيم

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LIST OF SYMBOLS

Symbol	Description	Unit
A_{si}	Inner cylinder area of the pipe	m^2
A_{ci}	Cross sectional area of the pipe	m^2
Cp_{bf}	Specific heat of base fluid (distilled water)	J/kgK
Cp_{nf}	Specific heat of nano-fluid (CuO / distilled water)	J/kgK
Cp_p	Specific heat of nanoparticle (CuO)	J/kgK
K_{bf} , K_f	Thermal conductivity of base fluid (distilled water)	W/m˚C
K_{nf}	Thermal conductivity of nano-fluid (CuO/distilled water)	W/m˚C
K_p	Thermal conductivity of nanoparticle (CuO)	W/m˚C
r	Radius	M
D,d	Diameter of the tube	M
d_P	Diameter of nanoparticle	M
l	Length of tube	M
f	Friction factor	
ΔP	Pressure drop	Pa
h_l	Head loss	m
Re	Reynolds number	
Pr	Prandtl number	
Pe	Peclet number	

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Nu	Nusselt number	
h	Heat transfer coefficient	W/m².˚C
V	Velocity	m/s
V_m	Mean velocity	m/s
T	Temperature	˚C
Vol	Volume	m^3
Q	Volume flow rate	m^3/s
$\dot{Q}$	Heat transfer rate	W
ΔT_{lm}	Log mean temperature difference	˚C
h_l	Head loss	m
$(h_l)_T$	Total of head loss	m

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LIST OF NOMENCLATURE

ϕ , ϕ_p	Nanoparticles volume concentration	%
S_1	Distance between two centers of tubes	m
$\dot{m}$	Mass flow rate	kg/s
μ_{bf} , μ_f	Dynamic viscosity of base fluid	Pa.s
μ_{nf}	Dynamic viscosity of nano-fluid	Pa.s
ρ_{bf}	Density of base fluid	kg/m^3
ρ_{nf}	Density of nano-fluid	kg/m^3
ρ_p	Density of nanoparticle	kg/m^3
α	Thermal Diffusivity	m^2/s

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Siasatan Cecair Asas Dan Nano-Cecair Yang Digunakan Untuk Pendingin Penyejukan / Penghawa Dingin Ruang Yang Kecil.

ABSTRAK

Kajian ini melihat pembangunan penyejukan kehadiran sebuah penukar haba yang diperbuat daripada paip tembaga untuk menyejukkan sistem kenderaan elektrik (EV) sistem daripada bateri kereta, dan kesan asas cecair dan nano-cecair (sebagai penyejuk) diarahkan di dalam penukar haba untuk memindahkan haba antara kereta elektrik petak kereta penukar haba. Nano-cecair (CuO / air suling) melalui nanopartikel bersurai (CuO) dalam asas cecair (air suling) boleh disediakan. Garis pusat nominal saiz kepekatan 50 nm daripada 0.27 vol. % Digunakan dalam bateri suhu kabin "untuk siasatan ini. Analisis ini menunjukkan bahawa sistem penyejukan dibina dengan menggunakan nano-cecair (CuO / air suling) mempunyai kelebihan dalam meningkatkan pemindahan haba oleh pekali 61,89% berbanding dengan apa yang ia telah menggunakan asas cecair (air suling) dan juga yang terhasil Pada nombor Winslet bahagian atas. Ini membawa kepada mengurangkan kadar kehilangan tenaga elektrik dalam bentuk tenaga haba dari bateri. Ini membawa ke Siasatan Cecair Asas Dan Nano Cecair Yang Digunakan Untuk Pendingin Penyejukan / Penghawa Dingin Ruang Yang Kecil. Siasatan Cecair Asas Dan Nano Cecair Yang Digunakan Untuk Pendingin Penyejukan / Penghawa Dingin Ruang Yang Kecil.pada peningkatan dalam kecekapan kenderaan elektrik (EV) bateri kereta. Oleh itu, ia meningkatkan kereta prestasi kenderaan elektrik (EV) dan umur baterinya .

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Investigation of Base Fluid and Nano-Fluid Used for Refrigeration /Air-Conditioning of Small Space

ABSTRACT

This study examines the development of cooling system having a heat exchanger made of copper tubes for cooling electric vehicle (EV) car battery system and the effects of base fluid and nano-fluid (as coolants) channeling inside the heat exchanger to transfer heat between the compartment of the electric vehicle car and the heat exchanger. The nano-fluid (CuO / distilled water) can be prepared by dispersing nanoparticles (CuO) in base fluid (distilled water). Nominal diameters of 50 nm were volume concentration of 0.27 Vol. % at batteries' compartment temperature was used for these investigations. The analysis shows that the cooling system adopted using nano-fluid (CuO / distilled water) has advantages in improving the heat transfer coefficient by 61.89 % compared to that using base fluid (distilled water) and also resulting in higher Nusselt number. This results in reducing the electric power loss in the form of thermal energy from batteries. This led to increase in the efficiency of the electric vehicle (EV) car battery. Hence, it improved the performance of the electric vehicle (EV) car and its battery lifetime.

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CHAPTER 1

INTRODUCTION

1.1 Background

Nano-fluid process is a recent development in heat transfer area. A considerable amount of past research and experiments have been published on nano-fluid; covering the aspect of improving heat transfer performance (Li et al. 2009) and miniaturization designs (Choi et al. 1995). Recently, most industries have become aware of its significance. Researchers have identified many different ways to determine the abilities of heat transfer for nano-fluid through experimental data. In relation to this, the availability of nano-fluid in liquid phase provides more reliable application.

The usage of forced convective heat transfer application varies in its utilization in automotive, industrial cooling, solar devices and chemical industry (Wong and Leon 2010).

Nano-fluid can be understood as nano-particle in base fluid and has the ability to transfer heat better than other conventional heat fluids such as, ethylene glycol, water and oil (Yang et al. 2011).

In light of these researches and experiments, the work of an analytical study on the operations of the heat transfer in cooling EV car system battery by using conventional fluid (distilled water) and also nano-fluid (CuO/ distilled water) to improve heat transfer is concluded.

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1.2 Problem statement

Maintaining the battery compartments of electric vehicle to operate in specific range from temperature (20-36) ˚C is quite difficult. Figure 1.1 shows the variation of compartment and battery temperature, as a function of time. This is an experimental result of the actual proton BLM EV car battery system that has been done previously. When the temperature rises quickly with the time, this in turn consumes battery power in the form of thermal energy which is a shortfall. Consequently, this decreases the efficiency of the electric car and decreases the lifetime of the battery.

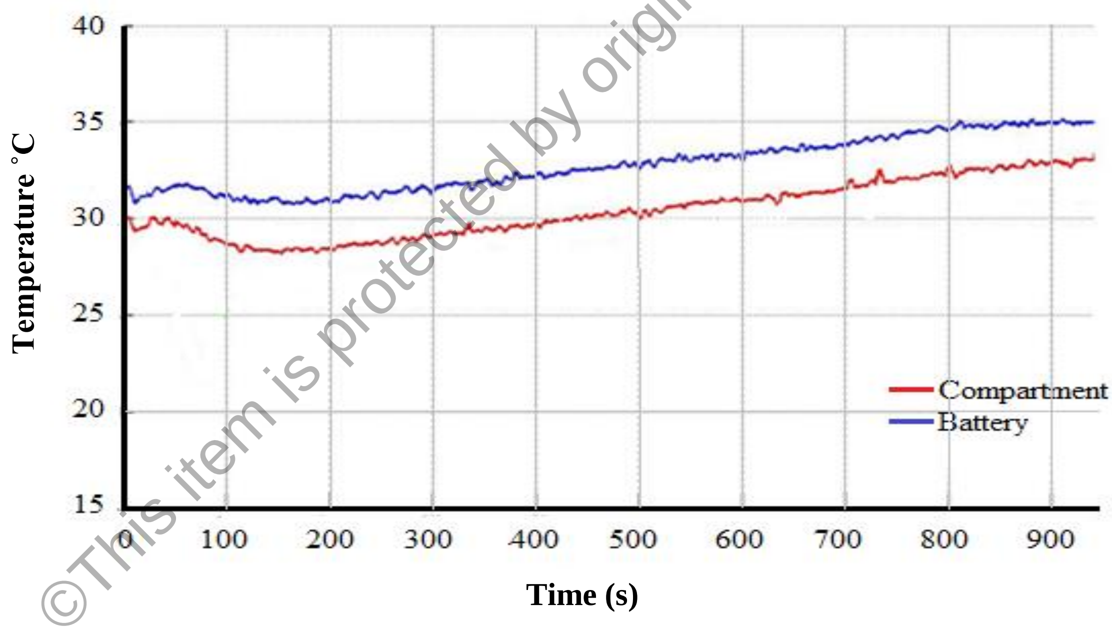

Figure 1.1: Experimental result of compartment and battery temperature vs the time for proton (BLM) EV car.

This thesis is developed to overcome the deficiencies in the processes of heat transfer by exploiting the beneficial features of nano-fluids (CuO/ distilled water) such as the suspended nano-particle in conventional fluid (distilled water) increases the surface area and the heat capacity of the fluid, also improves the thermal conductivity

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and other thermal properties. Properties of nano-fluid (CuO/ distilled water) can be changed by varying concentration of nano-particles (CuO).

1.3 Significance of the study

There is a large dissipation of electrical energy into heat energy in the EV car battery system. This study makes a contribution to research on application of nano-fluids (CuO/ distilled water) for maintaining the temperature of the batteries in a scope range which will solve the problems faced by most electric cars. The development of design and calculations of heat exchanger are given in detail. The comparison between the base fluid (distilled water) and nano-fluid (CuO/ distilled water) for their performance of heat transfer, also been studied.

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1.4 Research objectives

The main objectives of the research project are:

1- To develop an experimental set-up where different cooling fluids such as a base fluid (distilled water) and nano-fluid (CuO/distilled water) can be used for cooling EV car battery system.

2- To ensure that the temperature of coolant fluid at inlet of the heat exchanger is much lower than the temperature in the EV car battery system for its effective cooling.

3- To compare the rate of heat transfer when the conventional fluid (distilled water) is used with that when nano-fluid (CuO/ distilled water) is used in the heat exchanger.

1.5 Research scopes

This research intends to analyze the thermal properties and volume flow rate for both the conventional fluid (distilled water) and nano-fluid (CuO/ distilled water) which are used to transfer heat in the secondary cooling system for batteries designed consistent with the space available in the compartment installed in Electric Vehicle (Proton BLM). Therefore, the following elements are the important scopes in this study:

1- The determination of the types of conventional fluid and nano-particle.

2- The physical properties of nano-particle.

3- The volume concentration of nano-particle in nano-fluid.

4- The design of heat exchanger.

1.6 Thesis overview

The study aims to improve the heat transfer rate of the electric vehicle battery system by designing a heat exchanger made of copper tubes. The coil enclosure of diameter 6.5 mm, number of coils equal 12 and each length is 1.4 m, which dissipates heat from their surfaces. Base fluid (distilled water) and nano-fluid (CuO / distilled water) are used as coolants. The thesis is presented in five chapters.

Chapter two summarizes the literature review; some experimental studies and analytical work are described in detail. In addition, this chapter presents the review of relationships for thermophysical properties of nano-fluids.

Chapter three presents details of the proposed analytical study, as well as the main components and materials used for test rig, and fabrication of the proposed heat exchanger model.

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Chapter four describes analytical studies for the design of heat exchanger model dependent on the small area available and using base fluid and nano-fluid as coolants. It considers two main research topics; the first topic focuses on analytical studies of the project and divided to five parts:

1- Calculation of thermophysical properties.
2- Calculation of head losses and pressure drop for a heat exchanger model.
3- Calculation of non-dimension numbers of cooling coils.
4- Calculation of the heat transfer coefficient.
5- Calculation of the heat transfer rate.

The second topic discusses the results analysis.

The last chapter; chapter five, presents the conclusions and some suggested future work.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews some of the previous work on improving the thermal conductivity and heat transfer coefficient by using nano-fluid (CuO/water) in secondary cooling system, which concentrates on improving the heat transfer of its main devices, e.g., heat exchanger. Also reviews of the nanofluid preparation methods and summary of some relationships of thermo-physical properties and experimental results of nanofluid.

2.2 Preparation methods for nano-fluid

Nano-fluids are prepared according to three categories: by using chemical method or physical method in one-step or by using two-step method.

One-step methods involve the simultaneous creation of nanoparticles and colloidal dispersion in situ; two-step methods involve the production of dry powders and dispersion in base fluids on shape two separate steps (Gupta et al., 2012). Figure 2.1 shows the two step method preparation process of nanofluid, and that adopted in this research.

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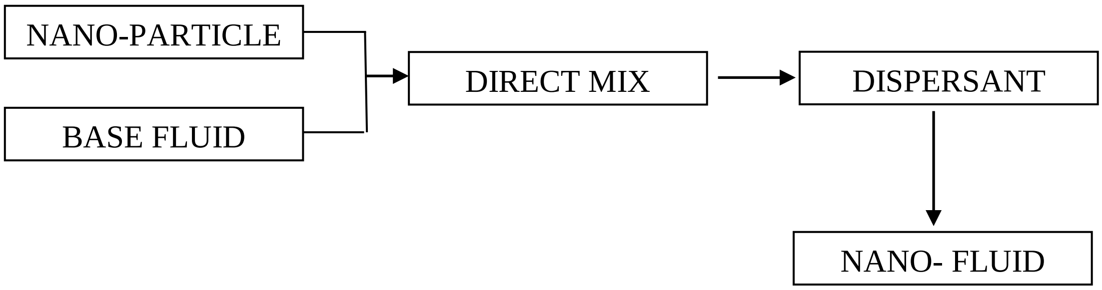

Figure 2.1: Two step preparation process of nano-fluid

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2.3 Overview of previous studies

Performance of heat transfer equipment can be improved with studies related to a significant increase in heat flux and miniaturization. Studies on heat transfer have been investigated in many industrial applications such as thermal control in power generation, microelectronics, heating and cooling and chemical processes (Wong & De, 2010). Water, mineral oil and ethylene glycol are used as heat transfer fluid. It is obvious that solid particles have several hundred times higher thermal conductivities than the conventional fluids which must be used in the heat transfer applications. To improve thermal conductivity of a fluid, suspension of ultrafine solid particles in the fluid can be a creative idea. Many published articles show that the heat transfer coefficient of nano-fluids is much higher than the conventional fluid and gives little or no penalty in pressure drop (Dalkilic et al., 2012).

The main reasons for the heat transfer enhancement of the nano-fluids may roughly be due to the suspended nano-particles increasing the thermal conductivity of the fluids, and the chaotic movement of ultrafine particles increasing fluctuation and turbulence of the fluids that accelerates the energy exchange process. Generally, many researchers indicated that nano-fluids behave like pure fluids because the suspended nano-particles are ultrafine, allowing them to absorb and transfer heat efficiently (Han, Z., 2008). Transporting the heat by means of a flowing fluid within a hermetically sealed container is improved by using nano-fluids, driven either by capillary forces or mechanical pumps.

This is therefore needed in order to respond to the described thermal control design challenges.

Maxwell (1873) introduced a new concept of dispersing solid particles in conventional fluids to change the basic limit of heat transfer fluids in conditions of low thermal conductivities. Most previous studies prescribed to this concept of millimeter or micrometer solid particles, experienced main problems such as clogging in micro channels; surface scratch and pressure drop caused by these particles.

Wang et al. (1999) worked on dispersed nano-fluid (CuO of 28 nm particle size) in both water and ethylene glycol and predicted an improvement of 35-55% in thermal conductivity.

Das et al. (2003) dispersed Al_2O_3 in water and obtained a maximum improvement of thermal conductivity of up to 25% and dispersed CuO in water and obtained a maximum improvement of thermal conductivity of up to 36%.

Hwang et al. (2006) noted that the thermal conductivity for nano-fluid is higher when nano-particles dispersed in base fluid. The study used four types of nano-fluids: multi-walled carbon nano-tube (MWCNT) in water; CuO in water; CuO in ethylene glycol and SiO_2 in water. They measured the thermal conductivities using transient hot-wire method.

Heris et al. (2006) investigated the laminar flow convective heat transfer of nano-fluids containing Al_2O_3 and CuO oxide in base fluid (water) through constant wall temperature and circular pipe. The experiment concluded that homogeneous model

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should be used of the forecasting of nano-fluids properties in order to determine the single phase heat transfer coefficient improvement. They noted that maximum of heat transfer improvement is 1.29 % with CuO and 1.23 % with Al_2O_3 when using nano-fluid at 2.5 % volume concentration under the Peclet number of 5000.

Karthikeyan et al. (2008) worked on synthesizing CuO nano-particles having average diameter of (8 nm) by using a simple precipitation technique and observed thermal properties of the suspensions. They used base fluids (ethylene glycol and water) and volume concentration 1 % nano-particle (CuO). Their results showed that thermal conductivity increased with rising accurate particle size and dispersity of nano-particles. The thermal conductivity is found to be affected from the nano-particles size, polydispersity size and the volume concentration of particles.

Namburu et al. (2009) studied heat transfer of three different types of nano-fluids (CuO, SiO_2 and Al_2O_3) and conducted a numerical analysis of turbulent flow in water and an ethylene glycol mixture, flowing in a circular tube under constant heat flow. They correlated new correlations of viscosity up to10% volume concentration for these nano-fluids volume concentration and temperature from the experiments. They noted that calculation results had formalized with known correlations. They obtained that nano-fluids including smaller diameter nano-particles had higher viscosity and Nusselt number. They compared the convective heat transfer coefficients of CuO, SiO_2 and Al_2O_3 nano-fluids with each other. It is also highlighted that Nusselt number enhances by 35% when volume concentration is 6% CuO over the conventional fluid at a constant Reynolds number.

Pantzali et al. (2009) (b) studied the effectiveness of nano-fluids as coolants. When mixing nanoparticles for testing thermo-physics properties of nano-fluids, their experiment used nano-fluid model CuO (4%vol.) suspended in water and investigated

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nano-fluid's performance in a commercial type PHE. They showed the type of flow inside the heat exchanger equipment and also its influence on the efficiency of a nano-fluid as coolant. The performance of heat exchanger depended on the fluid viscosity because of its significance. They obtained large volumes of required nano-fluids and noted that turbulent flow was usually developed at industrial heat exchangers.

Pantzali et al. (2009) (a) studied the effect of the use of nano-fluid in modulated surface with a miniature plate heat exchanger (PHE) both numerically and experimentally. Initially, they worked on thermo-physical properties by means of the method operating nano-fluid (CuO) in water, 4% vol), then the effect of surface modulation on heat transfer augmentation and friction losses were researched by simulating the existing miniature PHE as well as a notional similar PHE with flat plate using a CFD code. Conclusively, they studied the effect of the nano-fluid on the PHE performance in comparison to that of a base fluid (water). From the result of the study, they noted that volumetric flow rate of nano-fluid within a given heat duty was found to be lower than water causing lower pressure drop. Overall, they concluded that the use of smaller equipment and less pumping power were required and this is provided by nano-fluid.

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Vajjha and Das (2009) investigated the nature of thermal conductivity of three types of nano-fluids comprising aluminum oxide, zinc oxide and copper oxide nano-particles dispersed in conventional fluid such as water or ethylene glycol mixture of certain proportions by mass. The study noted that the temperature range of the experiments varied from (298 - 363) K and volumetric concentration being up to 10% , the results showed an increase in the thermal conductivity of nano-fluids compared to the conventional fluids with an increasing volumetric concentration of nano-particles and also, the thermal conductivity increased substantially with an increase in temperature.

Vajjha et al. (2010) analyzed heat transfer and three-dimensional laminar flow with some nano-fluids containing nano-particles such as CuO and Al_2O_3 in conventional fluid such as water and ethylene glycol, and also compared these nano-fluids performance to the conventional fluid. They developed a new correlation in the determination of viscosity and thermal conductivity of nano-fluids. It was found that the friction factor and the heat transfer coefficient increased with the increasing in nano-fluids' volumetric concentrations with Reynolds numbers value.

Huminic and Huminic (2011) found that 14 % heat transfer improvement is attained by using 24 nm diameter of nano-particles dispersed in water with volume concentrations of 2.0 % of nano-fluid (CuO / water) in double-tube helical heat exchangers, when processed under the laminar flow.

Corcione (2011) imposed two empirical correlations for predicting dynamic viscosity and effective thermal conductivity of nano-fluids. This study relied on many experimental results in the related literatures. The researcher provided the ratio between the pure conventional liquid and the thermal conductivities of the nano-fluid, and focused a greater deal on nano-particles and sizes, as well as changes in temperature, and concluded with the equations useful for all designs of heat transfer and simulation purposes.

Leong et al. (2012) focused on the application of nano-fluids in working fluids in tube heat and shell recovery exchangers in a biomass heating plant. Heat exchanger specification, mathematical equations and thermo-properties for nano-fluid were taken from the existing literature to calculate energy and thermal performance of the heat

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