

NANOFLUID APPLICATION IN
ELECTRIC MOTOR COOLING

SREE RAMA DASSON VELAYUDLAN

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF ENGINEERING

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

FEBRUARY 2012

UNIVERSITI MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: Sree Rama Dasson S/O Velayudlan (IC No:
Registration/ Matric No.: KGH080014
Name of Degree: M. Eng (Mechanical)
Title of Project Paper/ Research Report/ Dissertation/ Thesis ("this work"):
Nanofluids Application in Electric Motor Cooling
Field Of Study: Heat Transfer

I do solemnly and sincerely declare that:

- (1) I am the sole author/ writer of this work;
- (2) This work is original;
- (3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
- (4) I do not have any actual knowledge nor ought I reasonably to know that the making of this work constitutes an infringement of any copyright work;
- (5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by means whatsoever is prohibited without written consent of UM having been first had and obtained;
- (6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature

Date:

Subscribed and solemnly declared before,

Witness' Signature

Date:

Name:

Designation:

Abstract

Electronics devices such as electric motors generate enormous amount of heat, which disturbs the normal performance of the devices and reduces their reliability. This temperature rise has to be limited for two reasons: mechanical stress and the deterioration of the insulating materials. Heat generation is also caused the life span of the motors to decrease and its cause a new replacement which normally cost high. To overcome the heat transfer problems, many cooling methods were applied to the electric motors but still it cannot be solve effectively due to some limitations in these methods. To improve the heat transfer rate, the water or the other liquids such as ethylene glycol were dispersed and suspended with nanoparticles. This new class of heat transfer fluids is called nanofluids where the high thermal conductivity solid particles were mixed into the heat transfer liquids to gain a higher heat transfer rates. Therefore, a study was conducted and encompasses in cooling of the electric motors by nanofluids. The study has shown that by replacing nanofluids to the base fluids, the heat transfer rate can be improved. Also, this study has opened the opportunity for the researchers to do researches under nanofluids for cooling purposes.

Abstrak

Peranti elektronik terkini seperti motor elektrik menghasilkan sejumlah besar haba panas yang boleh mengganggu prestasi peranti dan mengurangkan kebolehpercayaan peranti tersebut. Kenaikan suhu ini harus terhad untuk dua alasan iaitu: tekanan mekanik dan kerosakan bahan isolasi. Peningkatan haba juga menyebabkan jangka hayat motor tersebut menurun dan ini akan menjurus kepada penggantian motor yang baru yang biasanya akan melibatkan kos yang tinggi. Untuk mengatasi masalah permindahan haba panas, banyak kaedah pendinginan diterapkan pada motor elektrik tetapi ini tidak dapat menyelesaikan masalah tersebut secara berkesan kerana terdapat beberapa keterbatasan pada kaedah ini. Untuk meningkatkan kelajuan permindahan haba, air atau cecair lain seperti glikol etilena dibubarkan dan dihentikan dengan nanopartikel. Cecair perpindahan panas yang digunakan ini disebut nanofluids dimana partikel yang mempunyai konduktiviti panas yang tinggi dan padat dicampur ke dalam cecair permindahan haba untuk mendapatkan tahap permindahan panas yang lebih tinggi. Oleh kerana itu, kajian ini dilakukan dan merangkumi pendinginan motor elektrik oleh nanofluids. Penyelidikan telah menunjukkan bahawa dengan menggantikan nanofluids ke cecair asas, tahap permindahan haba dapat ditingkatkan. Selain itu, kajian ini telah membuka peluang kepada para penyelidik untuk melakukan kajian di bawah nanofluids untuk tujuan pendinginan.

Acknowledgement

First and foremost, I would like to thank to my supervisor of this project, Associate Professor Dr. Saidur Rahman for the valuable guidance and advice.

Besides, I would like to thank the authority of University of Malaya, for providing me with a good environment and facilities to complete my study.

Finally, an honorable mention goes to my families and friends for their understandings and encouragements in completing this project. Without helps of the persons mentioned above, I would face many difficulties while doing this project.

Thank you.

Sree Rama Dasson VELAYUDLAN

Table of Content

Abstract	iii
Abstrak	iv
Acknowledgement.....	v
Table of Content	vi
List of Tables.....	viii
List of Figures	ix
Nomenclature	xi
CHAPTER 1. INTRODUCTION.....	1
1.1 Introduction.....	1
1.2 Back ground of problem.....	3
1.3 Statement of problem.....	4
1.4 Objectives of study.....	5
1.5 Important of study	5
1.6 Scope of the study.....	6
CHAPTER 2. LITERATURE REVIEW	7
2.1 Electric motors and the cooling methods	7
2.1.1 How does an electric motor works and generates heat	7
2.1.2 Heat sources in motors	10
2.1.2.1 The total copper losses, Q_c	10
2.1.2.2 The iron losses, Q_i	12
2.2 Compact heat exchanger for motor cooling	13
2.3 Introduction to nanofluids	15
2.3.1 Preparation of nanofluids	17
2.3.2 Convection of nanofluids	19

2.3.3	Viscosity of nanofluids.....	21
2.3.4	Heat transfer variables in nanofluids.....	24
CHAPTER 3. METHODOLOGY		32
3.1	Work breakdown structures	33
3.2	Input data	34
3.2.1	Thermophysical properties of coolant and air	34
3.2.2	Geometry configuration of compact heat exchanger	36
3.3	Mathematical formulation of ethylene glycol based aluminum oxide nanofluid in electric motors cooling	37
3.3.1	Air side calculation.....	38
3.3.2	Nanofluid side calculation.....	40
3.4	Analysis	42
3.5	Flow chart.....	43
CHAPTER 4. RESULTS AND DISCUSSIONS		44
4.1	thermophysical properties of coolant	44
4.2	Influences of volume fraction of aluminum oxide particles to thermal performance of electric motors	47
CHAPTER 5. CONCLUSIONS.....		53
5.1	Conclusions	53
5.2	Recommendations	54
BIBLIOGRAPHY		56
APPENDIXES.....		62

List of Tables

Table 2.1	The α_{conv} of nanofluids	21
Table 2.2	The α_{visc} of various nanofluids	23
Table 3.1	Thermophysical properties of coolant and aluminium oxide particles	34
Table 3.2	Thermal properties of air	35
Table 3.3	Theoretical formula to calculate heat transfer properties of ethylene glycol-based aluminium oxide nanofluid	35
Table 3.4	Core geometry of flat tubes, continuous fins and operating condition of compact heat exchanger	36
Table 3.5	11.32-0.737-SR surface characteristic of compact heat exchanger	37

List of Figures

Figure 2.1	Hysteresis loops of the magnetic steel	12
Figure 2.2	Examples of compact heat exchanger surfaces	14
Figure 2.3.	Thermal conductivity decreases with time	26
Figure 2.4.	0.1% volume fraction of copper oxide nanoparticles in water	26
Figure 2.5.	Dependence of thermal conductivity enhancement on the reciprocal of the nanoparticle radius	29
Figure 2.6	Experimental results of thermal conductivity dependence on temperature	30
Figure 3.1	Work breakdown structure	33
Figure 3.2	Typical flat tubes, continuous fin compact heat exchanger	38
Figure 3.3	Flow chart	43
Figure 4.1	Effects of volume fraction of aluminium oxide particles to density of ethylene glycol	45
Figure 4.2	Effects of volume fraction of aluminium oxide particles to viscosity of ethylene glycol	46
Figure 4.3	Effects of volume fraction of aluminium oxide particles to specific heat of ethylene glycol	46
Figure 4.4	Effects of volume fraction of aluminium oxide particles to thermal conductivity of ethylene glycol	47
Figure 4.5	Effects of aluminium oxide volume fraction to coolant mass flow rate at constant air and coolant reynold number	49
Figure 4.6	Effects of aluminium oxide volume fraction to coolant volumetric rate at constant air and coolant reynold number	49

Figure 4.7	Effects of aluminium oxide volume fraction to coolant Prantl at constant air and coolant Reynolds number	50
Figure 4.8	Effects of aluminium oxide volume fraction to coolant Nusselt Number rate at constant air and coolant Reynolds Number	50
Figure 4.9	Effects of aluminium oxide volume fraction to heat transfer coefficient at constant air and coolant Reynolds Number	51
Figure 4.10	Effects of aluminium oxide volume fraction to overall heat transfer coefficient based on air side and coolant Reynolds Number	51
Figure 4.11	Effects of aluminium oxide volume fraction to heat transfer rate at constant air and coolant Reynold Number	52

Nomenclatures

η	Efficiency
k	Thermal conductivity of the elements [W/ K·m]
c_p	Specific heat [J/kg. m ³]
K_t	Torque constant [mm/N/amp]
K_v	Voltage constant [rpm/V]
Q_c	Copper losses
Q_i	Iron losses
α	Thermal coefficient [1 / °C]
d	Thickness [nm]
ρ	Fluid density [kg/m ³]
r_p	Nanoparticle radius [nm]
μ	Viscosity [Ns/m ²]
C	Heat capacity
h	Heat transfer coefficient
Pr	Prantl Number
Nu	Nusselt Number
Re	Reynolds Number
ϕ	Volume fraction in percentage

G_a	Mass velocity
D	Hydraulic diameter [cm]
m	Mass [kg]
W	Transfer per unit time [Nm/s]
A	Area [m ²]
σ	Free flow area/ frontal area
v	Volumetric flow
U	Heat Transfer Coefficient
ε	Heat transfer effectiveness for cross flow unmixed fluid
α	Heat transfer area/ total volume [m ² /m ³]
β	Fin area/total area