PERFORMANCE OF AUTOMOTIVE AIR CONDITIONING SYSTEM USING Al_2O_3-SiO_2 NANOLUBRICANTS

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Doctor of Philosophy

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRACT

Enhancement in the coefficient of performance (COP) of the automotive air conditioning (AAC) system is necessary to reduce fuel consumption. A novel approach for improvement in refrigeration system performance is by dispersing nanoparticles in the conventional lubricant of AAC compressor. However, single-component lubricant applications contribute limitations on stability, compressor work, wear rates and AAC performance. The recent trend in nanoparticle dispersion technology is by utilizing two or more metal or metal oxide nanoparticles in existing lubricant and is known as composite nanolubricants. The composite nanolubricants is expected to improve the properties of single-component nanolubricants in achieving enhancement in thermal properties, rheological properties, stability, and AAC system performance. The aims of the present study are to evaluate the properties of metal oxide composite nanolubricants and to investigate the optimum condition of the AAC system performance using the best combination of composite nanolubricants. Metal oxide nanoparticles were dispersed in the Polyalkylene Glycol (PAG) 46 lubricant with different combinations of two types of nanoparticles using the two-step method of preparation. The composite nanolubricants was prepared up to 0.1% volume concentration with a variation of nanoparticle composition ratios. Thermal physical properties of different metal oxide composite nanolubricants were measured at temperatures of 30 to 80 °C. Then, the thermal physical properties of Al_2O_3-SiO_2/PAG composite nanolubricants were measured with a variation of nanoparticle composition ratios and volume concentrations. Tribological properties of the composite nanolubricants were evaluated for different loads and speeds. The experimental investigation for the AAC performance was carried out using Al_2O_3-SiO_2/PAG composite nanolubricants (best metal oxide combination) by varying the composition ratios and volume concentrations. Compound optimization technique using the Taguchi and Response Surface Methodology (RSM) methods were selected to optimize the AAC system. Stability evaluation showed Al_2O_3-SiO_2/PAG composite nanolubricants having an excellent stability condition with no sedimentation observed within a month. It was proven by the measurement of the zeta potential up to 61.1 mV and maintenance of the concentration ratio of UV-Vis spectrophotometer of more than 90%. Thermal conductivity and dynamic viscosity of the composite nanolubricants increased with volume concentration and decreased with temperature. The tribological properties observation with optimal conditions of coefficient of friction (COF) and wear rates were found at 0.02% volume concentration. The COF and wear rates were reduced to 4.49% and 12.99%, respectively. The composite nanolubricants at 60:40 composition ratio was observed to be the most effective composition ratio and recommended by the properties evaluation of the nanolubricants. The maximum COP enhancement was achieved up to 28.10% with 0.015% volume concentration and 60:40 composition ratio of Al_2O_3-SiO_2/PAG composite nanolubricants. Consequently, the AAC system parameter namely composition ratio, compressor speed, initial refrigerant charge, and volume concentrations of 60:40, 900 rpm, 155 g and 0.019% respectively were optimized using the compound optimization technique. The optimization results yield optimum cooling capacity, compressor work, COP, and power consumption of 0.94 kW, 19.20 kJ/kg, 9.05 and 0.62 kW, respectively, with highest desirability of 81.60%. Finally, it can be concluded that 0.019% is the optimum volume concentration for Al_2O_3-SiO_2/PAG nanolubricant. Therefore, 0.019% Al_2O_3-SiO_2/PAG with composition ratio of 60:40 was highly recommended for the optimum performance in AAC system.

ABSTRAK

Peningkatan pekali prestasi (COP) sistem penyaman udara automotif (AAC) adalah perlu untuk mengurangkan penggunaan bahan api. Pendekatan baru untuk peningkatan prestasi sistem penyejukan adalah dengan menyebarkan nanopartikel dalam pelincir konvensional pemampat AAC. Walau bagaimanapun, aplikasi pelincir komponen tunggal menyumbang kepada ketidakstabilan, peningkatan kerja pemampat dan kadar haus serta pengurangan prestasi AAC. Trend terkini dalam teknologi penyebaran nanopartikel adalah dengan menggunakan dua atau lebih nanopartikel logam atau logam oksida di dalam pelincir sedia ada dan dikenali sebagai nanopelincir komposit. Nanopelincir komposit dijangka akan meningkatkan sifat-sifat nanopelincir komponen tunggal dalam mencapai peningkatan dalam sifat terma, sifat rheologi, kestabilan, dan prestasi sistem AAC. Tujuan kajian ini adalah untuk mengkaji sifat-sifat logam oksida nanopelincir komposit dan untuk mengkaji keadaan optimum prestasi sistem AAC menggunakan gabungan terbaik nanopelincir komposit. Nanopartikel logam oksida disebarkan ke dalam pelincir *Polyalkylene Glycol* (PAG) 46 dengan gabungan dua jenis nanopartikel yang berbeza menggunakan kaedah penyediaan dua langkah. Nanopelincir komposit telah disediakan sehingga kepekatan isipadu sebanyak 0.1% dengan variasi nisbah komposisi nanopartikel. Sifat termal fizikal nanopelincir PAG logam oksida yang berbeza diukur pada suhu 30 hingga 80 °C. Kemudian, sifat-sifat termal fizikal nanopelincir Al_2O_3-SiO_2/PAG diukur pada variasi nisbah komposisi nanopartikel dan kepekatan isipadu yang berbeza. Sifat-sifat tribologi nanopelincir komposit dinilai pada beban dan kelajuan yang berlainan. Ujikaji prestasi AAC dijalankan menggunakan Al_2O_3-SiO_2/PAG nanopelincir komposit (kombinasi logam oksida terbaik) dengan mengubah nisbah komposisi dan kepekatan. Teknik pengoptimuman berganda menggunakan kaedah Taguchi dan *Response Surface Methodology* (RSM) dipilih bagi mengoptimumkan parameter sistem AAC. Ujikaji kestabilan menunjukkan nanopelincir komposit Al_2O_3-SiO_2/PAG mempunyai keadaan kestabilan yang sangat baik tanpa pemendapan sehingga sebulan. Ia terbukti dengan nilai potensi zeta sehingga 61.1 mV dan mengekalkan nisbah kepekatan daripada spektrofotometer UV-Vis lebih daripada 90%. Kekonduksian haba dan kelikatan dinamik nanopelincir komposit meningkat dengan kepekatan dan menurun dengan suhu. Pemerhatian sifat tribologi dengan keadaan optimum pekali geseran (COF) dan kadar haus didapati pada kepekatan isipadu 0.02%. Kadar COF dan kehausan dikurangkan sehingga 4.49% dan 12.99%. Nanopelincir komposit dengan nisbah komposisi 60:40 diperhatikan sebagai nisbah komposisi yang paling berkesan berdasarkan penilaian sifat-sifat nanopelincir. COP mencapai maksimum pada 28.10% dengan kepekatan isipadu pada 0.015% dan nisbah komposisi 60:40 untuk Al_2O_3-SiO_2/PAG nanopelincir komposit. Seterusnya, parameter sistem AAC iaitu nisbah komposisi, kelajuan pemampat, jisim penyejuk awal dan jumlah kepekatan masing-masing pada 60:40, 900 rpm, 155 g dan 0.019% dioptimumkan menggunakan teknik pengoptimuman berganda. Ujikaji pengoptimuman menghasilkan kapasiti penyejukan, kerja pemampat, COP dan penggunaan kuasa masing-masing optimum pada 0.94 kW, 19.20 kJ/kg, 9.05 dan 0.62 kW dengan nilai keinginan tertinggi sehingga 81.60%. Akhirnya, dapat disimpulkan bahawa nanopelincir Al_2O_3-SiO_2/PAG dengan kepekatan isipadu 0.019% adalah kepekatan isipadu optimum. Oleh itu, 0.019% nanopelincir komposit Al_2O_3-SiO_2/PAG dengan nisbah komposisi 60:40 sangat disyorkan untuk prestasi optimum kepada sistem AAC.

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LIST OF SYMBOLS

ϕ	Volume concentration, %
ρ	Density, kg/m^3
μ	Dynamic viscosity, mPa.s
μ_k	Coefficient of kinetic friction
k	Thermal conductivity, W/mK
F_k	Applied forces
N	Normal load
ΔV	Volume loss
ω	Specific wear rate
s	Sliding distance, km
Q_L	Heat absorb, kJ/kg
$\dot{Q}_L$	Cooling capacity, kW
W_{in}	Compressor work, kJ/kg
W	Power consumption, kW
T	Temperature, °C
$\overline{X}$	Mean of samples
σ	Standard deviation
m_{RC}	Mass refrigerant charge, g
$\overline{A}$	Absorbance
λ	Wavelength, nm
γ	Sheer rate, rpm

LIST OF ABBREVIATIONS

AAC	Automotive air conditioning
AD	Average deviation
ANN	Artificial neural network
ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
CCD	Central composite design
CFC	Chlorofluorocarbon
CNC	Computer Numerical Control
cnl	Composite nanolubricants
COF	Coefficient of friction
COP	Coefficient of performance
DOE	Design of experiment
EDX	Energy Dispersive X-Ray Analysis
FCD	Face-centred design
FDC	Fixed-displacement compressor
FESEM	Field emission scanning electron microscope
HEG	Hydrogen exfoliated graphene
l	Lubricant
LVDV	Low viscosity digital viscometer
MO	Mineral oil
MOPSO	Multiple Objective Particle Swarm Optimization
OR	Orthogonal arrays
ORC	Organic Rankine Cycle
PAG	Polyalkylene Glycol
PER	Properties Enhancement Ratio
PMI	Positive Material Identification
POE	Polyester
r	Ratio
rpm	Revolution per minute
RSE	Relative standard error
RSM	Response surface methodology

S/N	Signal/Noise
SAE	Society of Automotive Engineers
SEM	Scanning electron microscopy
TEM	Transmission electron microscopy
UV-Vis	Ultraviolet-Visible spectrophotometer
XRD	X-ray powder diffraction
SBPWM	Simple Boost Pulse Width Modulation
ZSI	Z source inverter
VCRS	Vapour compression system
LPM	Litre per minute

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