CHARACTERIZATION, PERFORMANCE AND OPTIMIZATION OF NANOLUBRICANTS IN AUTOMOTIVE AIR-CONDITIONING WITH ELECTRICALLY-DRIVEN COMPRESSOR

MOHD HAMISA BIN ABDUL HAMID

DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

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

(Supervisor's Signature)

Full Name : DR. WAN AZMI BIN WAN HAMZAH

Position : PROFESSOR

Date : 8 MARCH 2023

(Co-supervisor's Signature)

Full Name : DR. MOHD YUSOF BIN TAIB

Position : SENIOR LECTURER

Date : 8 MARCH 2023

STUDENT'S DECLARATION

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.

(Student's Signature)

Full Name : MOHD HAMISA BIN ABDUL HAMID

ID Number : PML18001

Date : 8 MARCH 2023

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ABSTRAK

Sistem penyaman udara kenderaan (AAC) menggunakan banyak tenaga berbanding komponen tambahan lain di dalam kenderaan bagi mencapai keselesaan terma di dalam kabin kenderaan. Beberapa kajian berkaitan kecekapan dan prestasi sistem AAC telah dijalankan tetapi kebanyakannya berkaitan dengan pemampat jenis konvensional yang digerakkan oleh tali sawat dan menggunakan polyalkylene-glycol (PAG) sebagai pelincir utama. Walaubagaimanapun, kajian bagi sistem AAC menggunakan pemampat yang dikuasakan oleh tenaga elektrik (AAC-EDC) dengan pelincir polyol-ester (POE) dan juga nano pelincir agak terhad. Selain meningkatkan prestasi sistem penyaman udara kenderaan hasil peningkatan sifat pelincirnya dengan penggunaan zarah bersaiz nano didalamnya, ia juga dapat meminimumkan saiz bateri dan komponen AAC. Tujuan kajian ini adalah untuk mengkaji sifat-sifat terma fizikal dan tribologikal nano pelincir POE, serta menilai prestasi dan mengoptimumkan parameter pengoperasian sistem AAC-EDC. Sebelum itu, nano pelincir POE perlu dirumus dan dihasilkan sebelum distabilkan menggunakan kaedah penyediaan dua langkah. Nano pelincir mono TiO_2/POE, mono SiO_2/POE dan hibrid TiO_2-SiO_2/POE dikaji pada kepekatan bermula 0.01 sehingga 0.1%. Kaedah kuantitatif dan kualitatif digunakan untuk menilai kestabilan nano pelincir ini. Sifat reologi pula diukur pada suhu 30 hingga 100 °C. Penguji empat bola digunakan untuk menilai sifat tribologikal nano pelincir mengikut piawaian ASTM D4172-18. Prestasi sistem AAC-EDC telah dijalankan dengan kelajuan pemampat dalam julat 1200 – 3840 rpm, caj awal refrigerant antara 120 hingga 160g. *Response surface methodology* (RSM) dan *analysis of variance* (ANOVA) digunakan dalam pengoptimuman kajian pengaruh parameter kelajuan pemampat EDC, caj refrigerant, dan kepekatan isipadu pada prestasi AAC-EDC yang dijalankan menggunakan nano pelincir. Semua nano pelincir didapati mempunyai kestabilan yang sangat baik, dengan hanya pemendapan kecil dilihat selepas sebulan. Keputusan pemerhatian secara visual disokong pula oleh ukuran ultra-violet visible spectroscopy, yang menunjukkan bahawa kesemua nano pelincir menunjukkan nisbah kepekatan kekal pada 90% sehingga 30 hari. Zeta potential yang melebihi 60 mV juga mengesahkan kadar kestabilan nano pelincir adalah sangat baik. Nano pelincir mono dan hibrid bagi kelikatan dinamik meningkat dengan kepekatan isipadu tetapi berkurangan dengan suhu. Menariknya, penurunan kelikatan dinamik berlaku pada kepekatan isipadu di bawah 0.05% berbanding dengan pelincir POE tulen. Keputusan tribologikal memberikan prestasi tribologi yang luar biasa dari segi COF dan WSD untuk semua nano pelincir berbanding pelincir POE tulen dengan kepekatan isipadu kurang daripada 0.05% adalah disyorkan. Nano pelincir mono SiO_2/POE menjadi nano pelincir terbaik berbanding pelincir POE tulen, mono TiO_2/POE dan hibrid TiO_2-SiO_2/POE dengan pengurangan kerja pemampat sehingga 22.3%, peningkatan dalam penyerapan haba dan prestasi COP sehingga 110% dan 53.8% masing-masing pada kepekatan isipadu 0.01%. Daripada pengoptimuman RSM, parameter optimum iaitu halaju pemampat, caj refrigerant awal dan kepekatan isipadu bagi nano pelincir SiO_2/POE pada 1808 rpm, 160 g dan 0.013% masing-masing menghasilkan tindak balas optimum penyerapan haba, kerja pemampat, suhu keluar injap pengembangan, dan penggunaan kuasa EDC iaitu 19.91 kJ/kg, 5.34 kJ/kg, 10.28 °C dan 116.66 W dengan nilai *desirability* tertinggi sebanyak 0.941. Oleh itu, boleh disimpulkan bahawa kepekatan isipadu 0.013% nano pelincir SiO_2/POE adalah disyorkan untuk penghasilan prestasi optimum dalam sistem AAC-EDC. Oleh itu, ia dicadangkan untuk diguna pakai di kenderaan sebenar dan juga boleh menggunakan bahan penyejuk yang lebih mesra alam serta lebih baik sifat-sifatnya seperti R1234yf.

ABSTRACT

The automotive air-conditioning (AAC) system consumes the most energy among the auxiliary components in vehicles to achieve thermal comfort inside the vehicle's cabin. Nanolubricant was used to improve the performance of the AAC system. Few studies investigated the AAC system performance with nanolubricant but were mainly concerned with belting-driven compressor (BDC) and polyalkylene-glycol (PAG) nanolubricant. However, a limited study was undertaken for AAC with an electrically-driven compressor (AAC-EDC) with polyol-ester (POE) lubricant and none with nanolubricant. Therefore, using nanolubricant in AAC-EDC system is expected to increase the performance and minimize the size of the battery and AAC components. This study aims to evaluate the rheological and tribological properties of the POE nanolubricants and evaluate the performance and optimize the operating parameters of the AAC-EDC system. The POE nanolubricant was formulated and stabilized using a two-step method of preparation. Mono TiO_2/POE, mono SiO_2/POE and hybrid TiO_2-SiO_2/POE nanolubricants were prepared at different volume concentrations of 0.01 to 0.1%. Quantitative and qualitative methods were used to assess the stability of nanolubricants. The rheological properties were measured at a temperature of 30 to 100 °C. Meanwhile, the four-ball tester was used to evaluate the tribological properties of nanolubricants according to ASTM D4172-18 standard. Further, the AAC-EDC experiment was performed in the range of 1200 to 3840 rpm compressor speed and 120 to 160 g for the initial refrigerant charge. Response surface methodology (RSM) and analysis of variance (ANOVA) were used in the optimization to investigate the influence of compressor speed, initial refrigerant charge, and volume concentration as input parameters on the AAC-EDC performance with nanolubricants. All nanolubricants were found to have excellent stability, with minor sedimentation for up to 30 days of observation. The visual observation results were supported by ultra-violet visible (UV-Vis) spectroscopy evaluation. The mono and hybrid nanolubricants were sustained for over 90% of the UV-Vis concentration ratio for up to 30 days. The zeta potential at more than 60 mV for all nanolubricants further confirmed the excellent stability condition. The dynamic viscosity of the mono and hybrid nanolubricants was increased with volume concentration while decreasing with temperature. Interestingly, the dynamic viscosity decrement occurred for nanolubricants at less than 0.05% volume concentration compared to pure POE lubricant. The tribological evaluation was performed with a better coefficient of friction (COF) and wear scar diameter (WSD) compared to pure POE lubricant at less than 0.05% volume concentrations for all nanolubricants. The mono SiO_2/POE nanolubricant in the AAC-EDC system performed better than pure POE lubricant, mono TiO_2/POE and hybrid TiO_2-SiO_2/POE nanolubricant with a reduction in compressor work of 22.3%, heat absorption increment up to 110% and COP enhancement up to 53.8% at 0.01% volume concentration. From RSM optimization, the optimum parameter, namely compressor speed, initial refrigerant charge and volume concentrations of 1808 rpm, 160 g and 0.013%, respectively, yield the optimum responses of heat absorption, compressor work, expansion valve discharge temperature, and EDC power consumption for SiO_2/POE nanolubricant were attained at 19.91 kJ/kg, 5.34 kJ/kg, 10.28 °C and 116.66 W respectively with highest desirability of 0.941. It can be concluded that a 0.013% volume concentration of SiO_2/POE nanolubricant was highly recommended for optimum performance in the AAC-EDC system. Therefore, it is recommended to employ these nanolubricants in the actual vehicle conditions and can also be applied in better environment refrigerants such as R1234yf.

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