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Composite nanolubricants in automotive air conditioning system: An investigation on its performance

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Abstract. AAC system is an important and necessary system in a vehicle in giving thermal comfort to the automotive cars passenger by reducing the surrounding temperature. The experimental investigation on performance of AAC system using composite nanolubricant provides useful data for future development of automotive cars due to its efficiency in improving the system performance. The AAC test bench was developed and utilized from Perodua Kancil. Cooling capacity, compressor work and coefficient of performance (COP) of AAC system using pure lubricant and Al₂O₃-SiO₂/PAG composite nanolubricants had been investigated at different refrigerant charges (95 to 155g) and different speeds (900 to 2100 rpm). The result shows that the cooling capacity and COP of composite nanolubricants increased compared to pure lubricant. Meanwhile, the compressor work was reduced. Cooling capacity and COP are relatively increased by 59.91% and 7.72% respectively compared to based lubricant. The maximum reduction achievement for compressor work is by 9.35% with 155g refrigerant charge and at 2100 rpm. Therefore, Al₂O₃-SiO₂/PAG composite nanolubricants is recommended to be used as the compressor lubrication to enhance AAC performances system.

1. Introduction

Currently the refrigeration system is applied in many applications such as air conditioning for industrial needs, residential areas and especially for the automotive industry. The automotive air conditioning system or also well known as the AAC system; designed to act as a necessity system for providing comfort for passengers in a vehicle by reducing the temperature of surrounding especially in hot and humid environments. The function of AAC is mainly to remove heat formed in the passenger's compartment as quickly as possible to provide comfort in any given condition [1]. Currently all designs of vehicles are pre-installed with an AAC system which works by applying the vapour compression cycles in order to remove the unwanted heat and to reduce the temperature of the compartment. The components involved in the AAC system are similar to a refrigeration system which is the compressor, condenser, expansion valve and the evaporator.

To enable the components of the AAC to operate efficiently, a working fluid is also needed to be present. The working fluid involves in the AAC system is the refrigerant and the lubricant which will flow throughout the system and at the same time transfers heat along the system. Since the depletion



of the ozone layer, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) refrigerant are replaced by hydrofluorocarbons (HFCs) refrigerant (R134a) that is currently used as common refrigerant worldwide [2]. Primary use of lubricant is for lubrication of the condensers in the air conditioning system. Lubricant is also deliberately used for the purpose of lubricating the bearings, to cool refrigerant gas during compression and also to seal the refrigeration leakage path [3]. In a working environment, the lubricant is composed of a mixture of oil and refrigerant. Thus, the utilization combination of the lubricant and refrigerant have to be taken into consideration in an ACC system [4]. Studies have shown that lubricants are able to improve the efficiency of the compressor by reducing the friction loss in the compressor [5]. Therefore, it is important that researches and studies are made in order to produce a lubricant that is able to further increase the efficiency of the refrigeration system.

An experimental study by D.S Kumar [6] has also proven that Al_2O_3 -PAG oil is able to increase the efficiency of the system without causing any choking and the system works normally and safely. There have also been many studies made on nanolubricant to search and discover new type of composition for the nanolubricant because nanolubricants have the potential to improve the efficiency and enhance the thermodynamic and mechanical performance of the refrigeration system. A nanolubricants when compare to a pure lubricant have the advantages of higher heat transfer, more effective dispersion stability, clogging particle reduction and also reduce the pumping force [7]. By introducing nanoparticles into the lubricant, researches are able to further increase the performance of the nanolubricant and these nanolubricants have shown extraordinary potential and capability to increase the performance of the refrigeration system [7].

Researches on composite nanolubricant are limited [8-13]. Even though extensive nanoparticles research in refrigeration system has been done, research on the application of nanoparticles for AAC system performance [7, 14, 15] is consider very limited and mainly focusing on single-component based nanolubricant. However, none effort has been done to investigate the performance of AAC system using composite nanolubricant. Hence in this paper, the AAC system test rig is designed and developed for performance analysis of Al_2O_3 - SiO_2 /PAG nanolubricants in the system. The Al_2O_3 - SiO_2 /PAG nanolubricant is formulated by the two-step method and established the colloidal stability of the suspended nanoparticles. Finally, the coefficient of performance (COP) experiment is conducted to compare the performance of the AAC with and without nanolubricants so as to provide the fundamental data for the application of the nanoparticles in the compressor and AAC system.

2. Methodology

2.1. Composite Nanolubricants Preparations

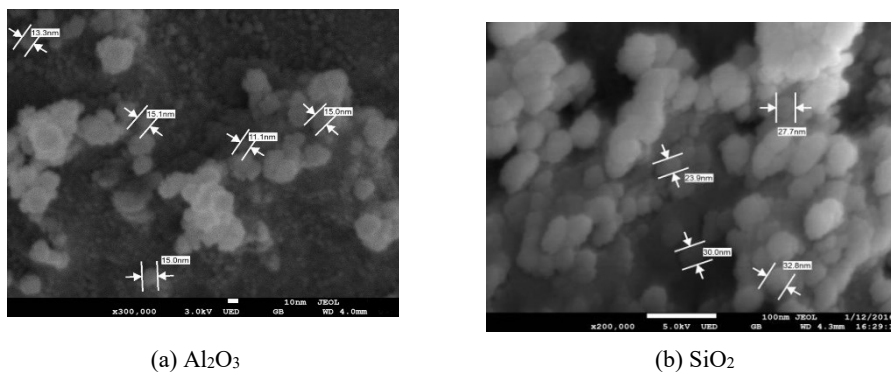
Different metal oxides nanoparticles are used namely; Al_2O_3 (13 nm) and SiO_2 (30 nm) in preparation of nanolubricants. These nanoparticles are procured from Sigma-Aldrich. The properties of the nanoparticles are given in Table 1. PAG 46 lubricant properties at the atmospheric pressure are given in Table 2. The characterizations of these nanoparticles are obtained by the field emission scanning electron microscopy (FESEM) technique. The images of FESEM are shown in Figure 1.

Table 1. Properties of nanoparticles [7, 11, 14, 16-19]

Properties	Al ₂ O ₃	SiO ₂
Molecular mass (g/mol)	101.96	60.08
Average particle diameter (nm)	13	30
Density (kg/m ³)	4000	2220
Thermal Conductivity (W/m.k)	36	1.4
Specific Heat (J/kg.K)	773	745

Table 2. Properties of polyalkylene glycol (PAG 46)

Properties	PAG 46
Density (g/cm ³) @ 20°C	0.9954
Flash Point (°C)	174
Kinematic viscosity (cSt) @ 40°C	41.4-50.6
Pour Point (°C)	-51

(a) Al₂O₃(b) SiO₂**Figure 1.** FESEM Image of Dry Nanoparticles[11]

The two-step method was used in the preparation of the different combination composite nanolubricant for 0.06% volume concentration. At first, all nanolubricants used in the experiment; Al₂O₃/PAG nanolubricant and SiO₂/PAG nanolubricants were separately prepared. Two combinations between these two nanolubricants were homogenized together by a 50:50 mixture ratio. The volume concentrations of the composite nanolubricant were calculated using Eq. (1) [7, 14, 15, 20].

$$\phi = \frac{m_p / \rho_p}{m_p / \rho_p + m_t / \rho_t} \times 100 \quad (1)$$

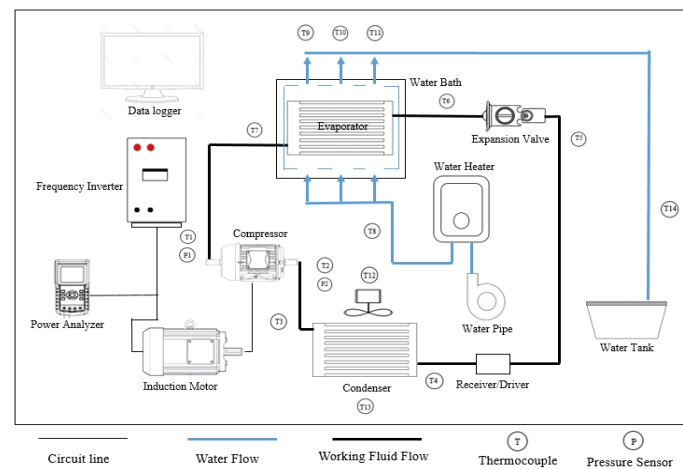
2.2. AAC Test Setup

The AAC system bench setup is utilized from SD Speciation of Perodua Kancil as one of representative compact car in Malaysia [21]. Development and specification of the setup was referred with Redhwan et. al [21]. The bench setup is divided into four main parts i.e. refrigeration system made from AAC system of the car, driver and control system where an electrical motor and an inverter frequency controller are utilized, water bath system for evaporators and piping system and complete instrumentation and data logger of the AAC system. The main setup of the system such as compressor, condenser, evaporator, expansion valve and piping system are included. The components are listed in Table 3.

Table 3. List of components used in experimental setup

No.	Description	No.	Description
1	Compressor	6	Pressure Gauge
2	Three phase induction motor	7	Data Logger Module
3	Evaporator (inside Water bath)	8	Water Heater
4	Frequency Inverter Controller	9	Flow Transducer
5	Power Analyser	10	R134a gas

By following regulation and recommendation from SAEJ2765 standard, the experimental procedure of AAC performance investigation is conducted. The compressor is refilled with a volume of 105ml of composite nanolubricant that is prepared beforehand. Weighing scale is used to weight the desired amount of refrigerant (95 to 155g) to be charged into the system. Water heater is then used to heat water in calorimetric water tank until the inlet and outlet achieve equilibrium temperature. The room ambient temperature and humidity is controlled between 24.5 to 25.5°C and 50 to 60% respectively. Induction motor was started till a speed of 900 rpm achieved which can be adjusted using frequency inverter and the experiment is run in a 20 minutes time interval. The temperatures and water flow rate measurement are monitored and recorded through a data logger module and analysis is then preceded. Next, the experiment is repeated for different motor speed, refrigerant charge and various mixture ratios of composite nanolubricants. The schematic diagram of the AAC system test rig is display in Figure 2.

**Figure 2.** Schematic Diagram of AAC Test Rig

3. Results and discussion

Figure 3 shows the cooling capacity of composite nanolubricants at various refrigerant charges. The cooling capacity increases along with the increasing of initial refrigerant charges and speeds. The trend of cooling capacity with charge amount observed to agree well with the previously reported findings [1, 22, 23]. Composite nanolubricants have a higher cooling capacity compare to pure PAG lubricant. This is because the nanoparticles in the composite nanolubricants contributes in the enhancement of the heat transmission and causes the heat transfer to rise in the evaporator [11]. The maximum cooling capacity is 59.91% for $\text{Al}_2\text{O}_3\text{-SiO}_2/\text{PAG}$ composite nanolubricant at 2100 rpm and 140 g when compared to pure PAG under the same condition. Cooling capacity increases with the mass flow rate thus proved the conservation of mass equation. The increase in mass flow rate of the system causes the heat transfer to rise in the evaporator. [24] The mass flow rate tends to rise higher with the increasing of compressor speed as shown in Figure 4 hence increasing the cooling capacity.

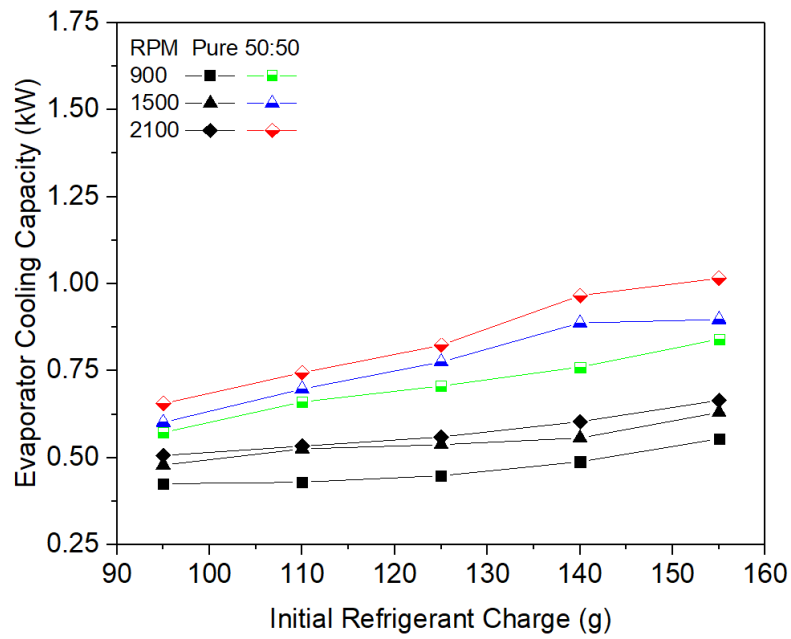


Figure 3. Evaporator cooling capacity variations for different refrigerant charges

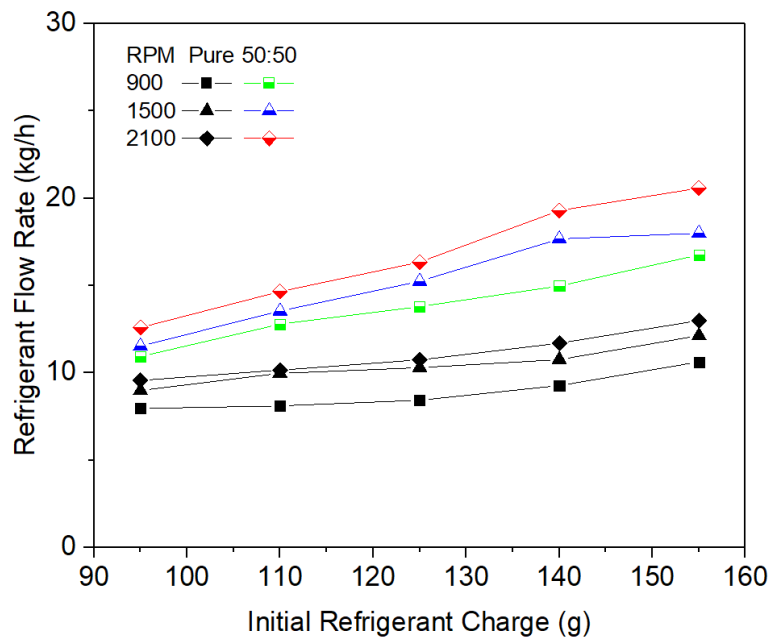


Figure 4. Refrigerant flow rate variations for different refrigerant charges

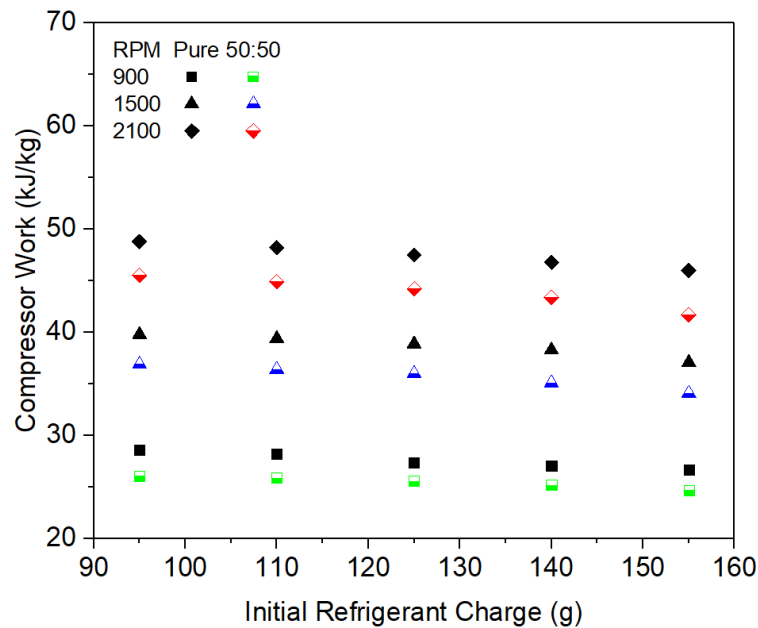


Figure 5. Compressor work variations for different refrigerant charges

The compressor work of PAG and composite nanolubricants for different initial refrigerant charges at three different compressor speeds is shown in Figure 5. From Figure 5, it is clearly observed that the compressor work at same speed increases with refrigerant charge increments. However, the compressor work decreases with increment of its speeds at same refrigerant charge. Compressor works for different initial charge are relatively lower compared to the PAG-based fluids. The highest reduction of compressor work of $\text{Al}_2\text{O}_3\text{-SiO}_2/\text{PAG}$ composite nanolubricants for 50:50 nanoparticle ratios is 9.35% for the 155 g refrigerant charge and speed at 2100 rpm. According to Ahamed et al. [25], to achieve comparable heat transfer, the composite nanolubricants reduced pumping force of the compressor. This behaviour helps in reducing the work required by the compressor to run the system thus improving the COP of the system [7].

From the Figure 6, COP with different compressor speed is plotted against the initial refrigerant mass of the system. The graph depicts a lower COP for the pure PAG lubricant compared to composite nanolubricants. This is due to the low cooling capacity and high compressor work of pure lubricant performance. This trend is agreeable to research reported in the literature [6, 26]. The highest achievable enhancement ratio of composite nanolubricants is for 7.72% $\text{Al}_2\text{O}_3\text{-SiO}_2/\text{PAG}$ composite nanolubricants of 50:50 ratios at 155 g refrigerant charge and speed at 2100 rpm in comparison with pure PAG for the same conditions.

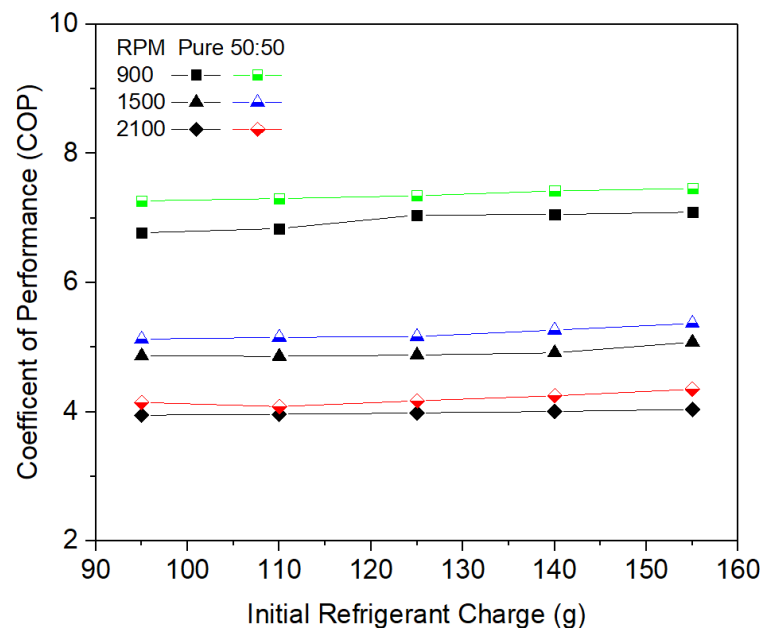


Figure 6. Coefficient of performance variations for different refrigerant charges

4. Conclusions

The performance of automotive air conditioning system operating with $\text{Al}_2\text{O}_3\text{-SiO}_2/\text{PAG}$ nanolubricant was determined through the evaluation of cooling, compressor work and coefficient of performance (COP). Preparation of composite nanolubricants and the development of AAC test bench utilized from a representative compact car were explained thoroughly. The performance of composite nanolubricants was determined at different initial refrigerant charges from 95 to 155g and at different induction motor speed from 900 to 2100 rpm. The highest enhancement of cooling capacity and COP are 59.91% and 7.72% respectively. Meanwhile, the maximum reduction obtained for compressor work is 9.35%. Based on the findings, the author highly recommends the $\text{Al}_2\text{O}_3\text{-SiO}_2/\text{PAG}$ composite nanolubricants for applications in automotive air systems as it yielded significant enhancements in system performance compared to PAG based lubricant. Further investigations on the performance of refrigeration system using the $\text{Al}_2\text{O}_3\text{-SiO}_2/\text{PAG}$ composite nanolubricants are required to extend the present work.

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