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Performance of Al_2O_3-SiO_2/PAG employed composite nanolubricant in automotive air conditioning (AAC) system

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Abstract. Automotive Air conditioning (AAC) system is the contributor of harmful gasses emission and global warming. In order to solve the issues, investigation on potential improvement in lubrication used in air conditioning system is done to improve the system performance and efficiency. The performance of AAC system namely cooling capacity, compressor work, coefficient of performance (COP) and power consumption was investigated by comparing pure lubricant and Al_2O_3-SiO_2/PAG nanolubricants. Performance of AAC by using different ranges of refrigerant charges (95 to 155 g) and speeds (1200 and 1800 rpm) was investigated. The result shows that the cooling capacity and COP of pure lubricant were relatively lower than Al_2O_3-SiO_2/PAG nanolubricants. The compressor work and power consumptions of Al_2O_3-SiO_2/PAG nanolubricants were greatly reduced. Cooling capacity and COP are enhanced by 102.99% and 23% respectively. The compressor work and power consumption are reduced by 25.9% and 28.24% respectively. From the results, nanolubricants gives more advantages in AAC performance over pure lubricant. Therefore, Al_2O_3-SiO_2/PAG composite nanolubricants is recommended to be used as the compressor lubrication to enhance AAC performances system.

1. Introduction
Environmental issues around the world are increasing rapidly nowadays and immediate preventive measures and solutions are needed to solve the issues. Air conditioning system is the biggest energy consumptions and major contributor to global warming [1] in the world. Automotive Air Conditioning (AAC) system is one of best application of refrigeration system. AAC system is necessary to provide thermal comfort to the vehicle passengers [2] and remove the unwanted heat. However, to maintain desired level of comfort, more fuel is consumed to cool down the vehicle which causing harmful gasses emission into the atmosphere, eventually raising the average temperature on earth.

AAC system consists of the compressor, condenser, expansion valve and the evaporator. A working fluid is needed to be present to ensure the systems work efficiently. 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. In an ideal working environment, the working fluid involves in the AAC system is the combination of both refrigerant and the lubricant simultaneously flowing and transferring heat throughout the system. Thus, the combination of the lubricant and refrigerant is needed to be utilized and considered in an ACC system [3]. Hydrofluorocarbons (HFCs) refrigerant (R134a) is currently used as common refrigerant worldwide [4]. Lubricant is need for lubrication of the condensers in the air conditioning system in preventing excessive friction in the bearings [5], time reducing the refrigerant temperature during compressing process and in the same time sealing the refrigeration leakage path [6]. Moreover, lubricants are able to enhance the efficiency of the compressor by reducing the compressor friction loss [7]. Choosing the right lubricant is important to provide maximum coefficient of performance (COP) value thus reducing power consumption [8].

Therefore, studies are need to be done to investigate potential improvement in lubrication to increase the efficiency of the refrigeration system. The use of nanoparticles in refrigeration systems is considered by many scientists for its contribution in enhancement of thermo-physical properties and heat transfer capabilities [9-11]. Nanolubricants have the higher advantages over pure lubricant in terms of heat transfer, efficient in dispersion stability, clogging particle and pumping force reduction [1, 12]. Besides, nanolubricants also decrease the amount of energy needed to operate the systems. This helps in reducing energy consumption, emissions, global warming potential and greenhouse gas effects [13]. Studies have been done to prove the potential of nanolubricants in enhancing the thermodynamic and mechanical performance of the refrigeration system [14] and also in its capability to increase the performance of the refrigeration system [1] and systems efficiency. The study on addition of nanoparticle in refrigerant or lubricant mixture in improving performance for refrigeration system are done by few researchers [10, 15-20].

Researches on different metal oxides nanolubricants combinations in refrigeration systems [21, 22] and on the utilization of nanolubricants; mainly focusing on single-component based nanolubricant for AAC system performance[23, 24] are considered very limited even though extensive nanoparticles research in refrigeration system has been done. Zawawi et al. [14] studies on AAC performance of Al_2O_3-SiO_2/PAG nanolubricants with 50:50 composition ratios for refrigerant charges (95 to 155g) at compressor speed of 900, 1500 and 2100 rpm. So, as the continuation for the study reported by Zawawi et al. [14], study on AAC performance of Al_2O_3-SiO_2/PAG nanolubricants with 60:40 composition ratios is done. In the present study, the AAC system setup is developed for performance analysis of Al_2O_3-SiO_2/PAG nanolubricants. The performance (cooling capacity, compressor work, COP and power consumption) of the Al_2O_3-SiO_2/PAG nanolubricants for 0.06% volume concentrations has been investigated with a refrigerant charges range of 95 to 155 g and at compressor speed of 1200 and 1800 rpm. The performance investigation is conducted to compare the performance of the employment of pure lubricant and Al_2O_3-SiO_2/PAG in AAC system.

2. Methodology

2.1. Al_2O_3-SiO_2/PAG nanolubricants preparations

From previous study [22], Al_2O_3-SiO_2/PAG nanolubricants is selected as the best metal oxide combination for applications in refrigeration compressors. Thus, in this study, Al_2O_3-SiO_2/PAG nanolubricants is utilized in the AAC system study as the main lubricant. Table 1 shows the properties of the Al_2O_3 and SiO_2 nanoparticles and PAG 46 lubricant properties at the atmospheric pressure are given in table 2. Two-step method was used in the preparation of Al_2O_3-SiO_2/PAG nanolubricant for 0.06% volume concentration. Researchers widely used this method in nanofluids preparation [25-28]. Al_2O_3/PAG nanolubricant and SiO_2/PAG nanolubricants were separately prepared. These two single nanolubricants were then mixed and homogenized together by 60:40 composition ratio for 2 hours to maintain the stability of the nanolubricants. Dispersion and stability of the Al_2O_3-SiO_2/PAG is done with accordingly to previous researches [22] with method suggested by Sharif et. al. [29]. The volume concentrations of the nanolubricant were calculated using equation (1) [27, 29-31].

$$\phi = \frac{m_p/\rho_p}{m_p/\rho_p + m_l/\rho_l} \times 100 \tag{1}$$

Table 1. Properties of nanoparticles [32].

Properties	**Al_2O_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) [32].

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

2.2. AAC test setup

The AAC system setup in this study is utilized from SD Speciation of Perodua Kancil as one of representative compact car in Malaysia [30]. Development and specification of the setup was referred with Redhwan et. al [30]. 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

As stated in previous study [14], the experimental procedure of AAC performance investigation is conducted by following regulation and recommendation from SAEJ2765 standard. A 105 ml of Al_2O_3-SiO_2/PAG nanolubricants was prepared to replace the previous lubricant in the compressor. 95g refrigerant mass was weighed using weight balanced and is charged into the system. Water heater was then used to heat water in water tank until the inlet and outlet achieve equilibrium temperature. The controlled room ambient temperature and humidity are between 24.5 to 25.5°C and 50 to 60% respectively. Induction motor was started at 1200 rpm speed and the experiment was run for a 20 minutes time interval. The temperatures and water flow rate measurement were monitored and recorded through a data logger module. Next, the cycle of experiment was repeated for different refrigerant chargers and compressor speed of 1800 rpm. The schematic diagram of the AAC system test rig is shown in figure 1.

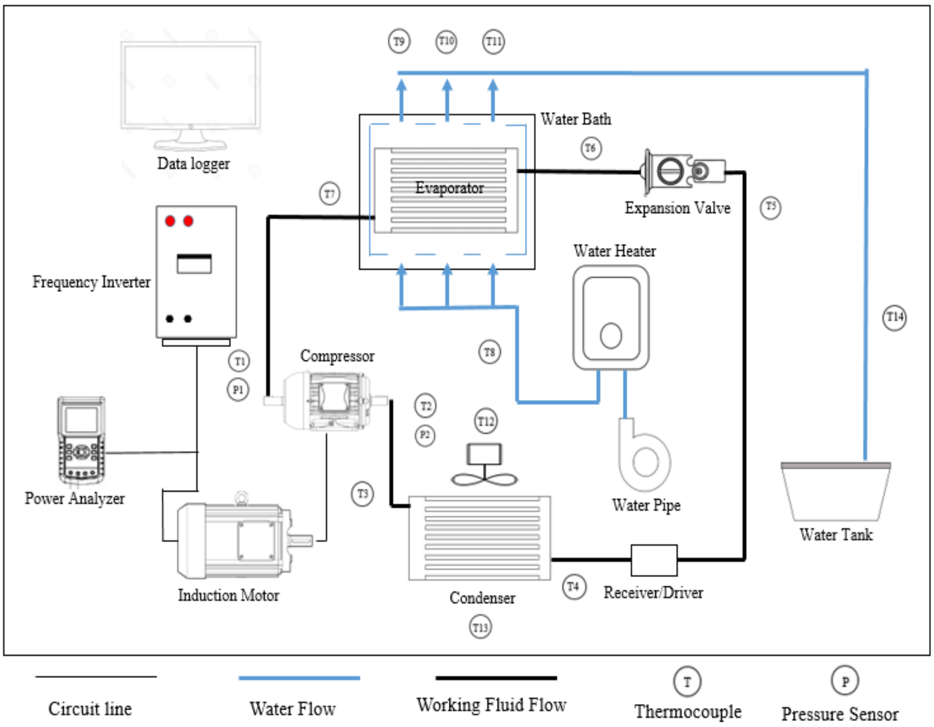

Figure 1. Schematic diagram of AAC test rig.

3. Results and discussion

AAC system performance namely cooling capacity, compressor work, COP and power consumption is investigated for various compressor speed at constant volume concentration of 0.06%. Figure 2 depicts the cooling capacity for Al_2O_3-SiO_2/PAG nanolubricant as a function of refrigerant charges. The cooling capacity of Al_2O_3-SiO_2/PAG nanolubricants increases along with increment of refrigerant. The trend is observed to agree well with the reported findings [1, 33]. It can be observed that the cooling capacity of the Al_2O_3-SiO_2/PAG nanolubricants at different compressor speed are higher than pure PAG lubricants. This is due to the nanoparticles in the nanolubricant contributes in the enhancement in thermal conductivity of nanolubricant to [34] and also enhancement of the heat transmission and causes the heat transfer to rise in the evaporator [31]. A high cooling capacity indicates that the system has an overall higher heat transfer and the system is able to cool down more efficiently. With the increasing of compressor speed, the mass flow rate tends to rise higher causing the heat transfer to rise in the evaporator [35] hence eventually improves the cooling capacity. Thus, the conservation of mass equation is proven. The highest cooling capacity is found to be 1.17 kW or 102.99% for compressor speed of 1800 rpm at 155 g refrigerant charge.

The compressor work of PAG and nanolubricants against refrigerant charges is shown in figure 3. It is clearly observed in the figure that the compressor work increases with compressor speeds but decreases as the refrigerant charges increases. Compressor at high speed tends to work much harder compare to lower speed [36]. This can also be deduced that the low compressor speed produces lower load on the compressor thus having a lower compressor work compare to a higher compressor speed. Besides, the compressor works for Al_2O_3-SiO_2/PAG nanolubricants are relatively lower compared to the PAG lubricants. The compressor work for AAC system utilized by Al_2O_3-SiO_2/PAG nanolubricants is maximumly reduced by 25.90% at 1800 rpm for 155g refrigerant charge meanwhile the minimum reduction is 8.11% also at 1800 rpm. Nanolubricants contributes in reducing pumping force of the compressor to achieve comparable heat transfer [37] and this helps in reducing the work required by the compressor to run the system [1].

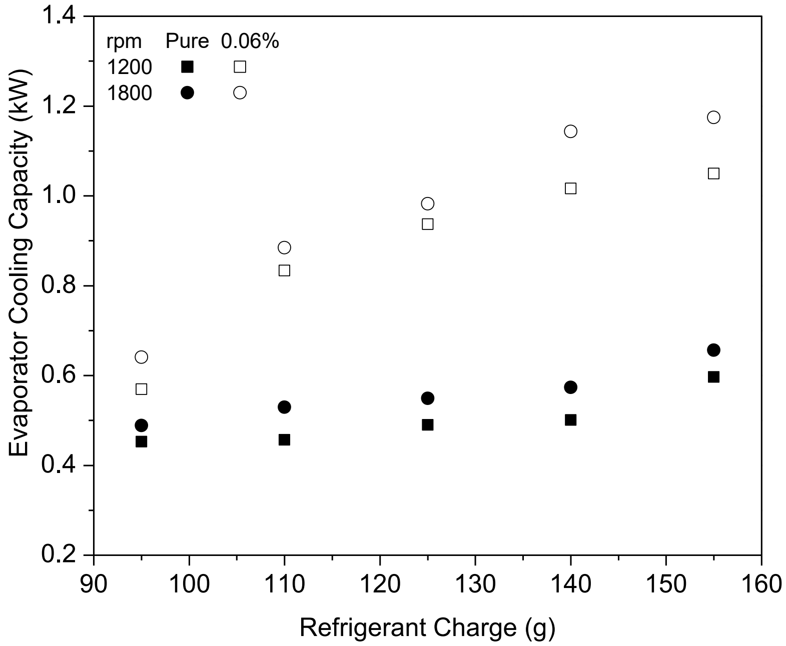

Figure 2. Evaporator cooling capacity against refrigerant charges.

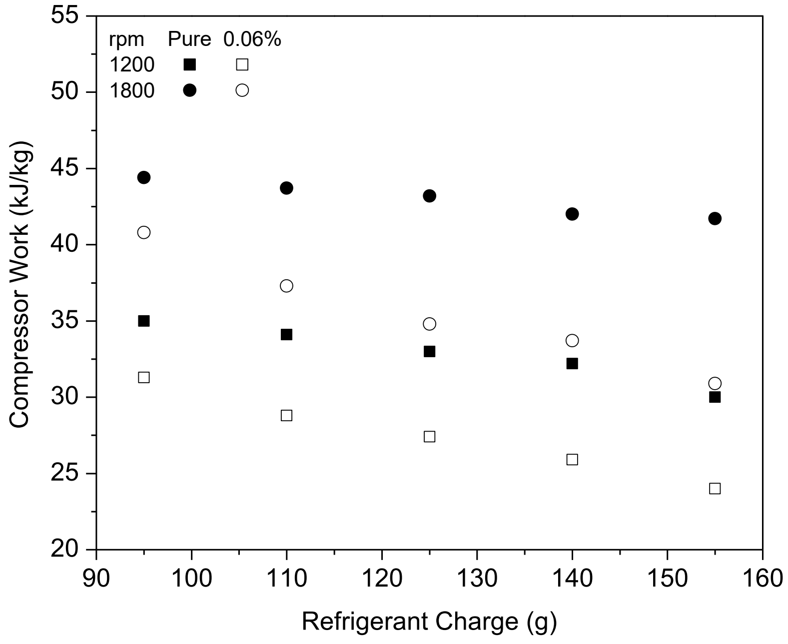

Figure 3. Compressor work against refrigerant charge.

Figure 4 depicts COP against the refrigerant charge of the system. COP of Al_2O_3-SiO_2/PAG nanolubricants is higher compared to pure lubricant. This is due to pure lubricant has low cooling capacity and high compressor work. However, Al_2O_3-SiO_2/PAG nanolubricants has higher increment of the cooling capacity reducing compressor work and eventually increases the COP of the system. Similar trend is also observed in previous researches reported in the literature [23, 24]. Al_2O_3-SiO_2/PAG nanolubricants gives the maximum COP of 7.16 for 1200 rpm compressor speed. For the same compressor speed, COP value is recorded at 5.82 for pure lubricant. COP value for Al_2O_3-SiO_2/PAG nanolubricants is increased by 23% compared to pure lubricant.

Power consumption of Al_2O_3-SiO_2/PAG against refrigerant charge is illustrated in figure 5. The power consumption of 0.06% volume concentration is lower compared to pure lubricant. The maximum reduction was recorded as 28.24% at 1200 rpm for 155g refrigerant charge. Meanwhile, the minimum reduction of 13.09% at 1800 rpm compressor speed for 95g refrigerant charge was obtained. The power consumption of Al_2O_3-SiO_2/PAG was compared with the results from previous study by Redhwan et. al [24]. Al_2O_3-SiO_2/PAG nanolubricant has a lower dynamic viscosity compared to Al_2O_3/PAG thus lower the power consumption of the system and promotes energy saving. At higher viscosity, the compressor tends to work harder to overcome the viscosity resistance and more pumping force is needed to pump the refrigerant at the suction side. Hence, Al_2O_3-SiO_2/PAG is recommended to be used in AAC system as nanolubricants gives more advantages in AAC performance over pure lubricant.

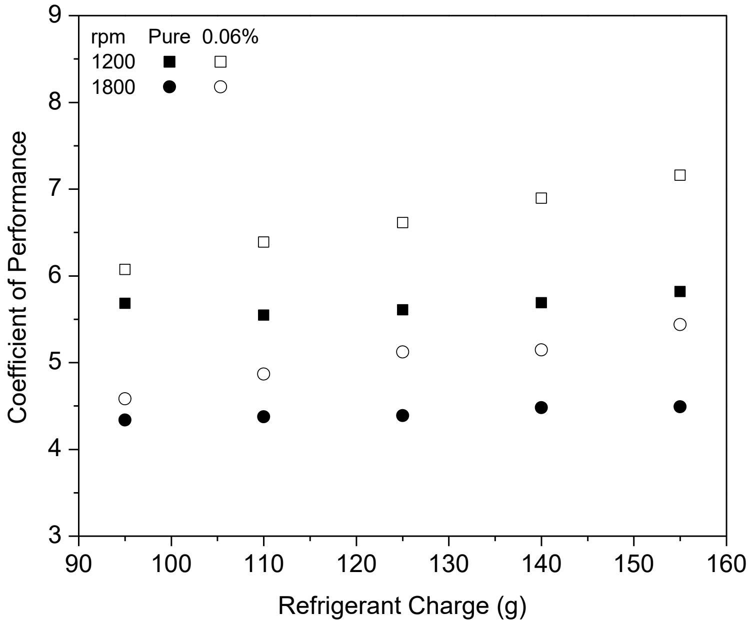

Figure 4. Coefficient of performance against refrigerant charges.

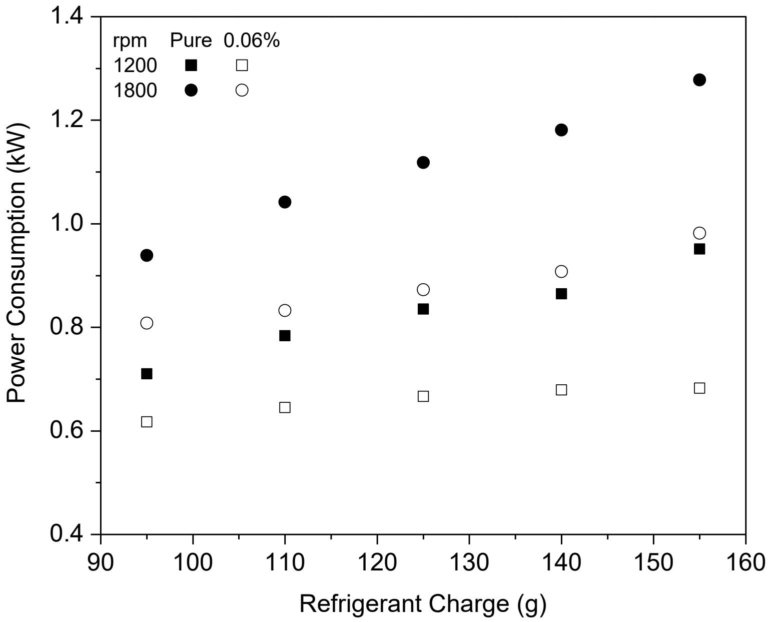

Figure 5. Power consumptions against refrigerant charges.

4. Conclusion

The performance of automotive air conditioning system operating with Al_2O_3-SiO_2/PAG nanolubricant was determined through the evaluation of cooling, compressor work, COP and power consumption. The highest cooling capacity and COP enhancement of 102.99% and 23% were recorded for AAC system utilized with 0.06% Al_2O_3-SiO_2/PAG nanolubricant. Meanwhile the compressor work and power consumptions were greatly reduced at maximum reduction of 25.9% and 28.24% respectively. Based on the findings, the author highly recommends the Al_2O_3-SiO_2/PAG 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 Al_2O_3-SiO_2/PAG nanolubricants are required to extend the present work.

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