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The utilization of Al_2O_3 nanoparticles in combustion engines

JEL: L62 DOI: 10.24136/atest.2018.469
Data zgłoszenia: 19.11.2018 Data akceptacji: 15.12.2018

The methods used for obtaining Al_2O_3 nanoparticles were discussed in the paper. The utilization of Al_2O_3 nanoparticles to improve thermal conduction and tribological properties in different media including engine oil was presented therein.

Keywords: Al_2O_3 nanoparticles, thermal conductivity, tribological properties, engine oil.

Introduction

The main aim of the automobile industry is to obtain the best automobile design in terms of performance, fuel consumption among others. Due to these challenges, an optimisation process is mandatory to obtain the best design to compromise between performance, size and shape. In an attempt to arrest that situation different researches and experiments were carried out to investigate heat transfer characteristics for automotive radiators using, inter alia, ethylene glycol and water dispersed with Al_2O_3 nanoparticles among others.

The other important problem in automobile industry is to provide the best tribological properties of media used. The primary function of a lubricant used in engines, gearboxes is to keep two mating metal surfaces apart, what allows reduction of friction and wear intensity.

Modern engines operate under high speed and loading and therefore put demands upon lubricants which cannot be met by non-formulated petroleum products [1]. To provide proper operational conditions, base fluids need the help of chemical additives. The latter improve the lubricating ability of the base oils by either enhancing the desirable properties already present or adding new properties. Therefore, additives are the most integral part of the modern formulated lubricants.

Many studies pointed that nanoparticle dispersed lubricants allowed decreasing the levels of wear and friction.

Various types of nanoparticles were used to prepare nano lubricants, including polymers, metals, organic and inorganic materials [2].

The review [3] presented the development of nanoparticles (CuO, TiO_2, SiO_2, ZnO, Diamond, Al, etc.,) mixed with different lubricating oils, preparation and evaluation methods of nanolubricant for the machine components. The recent researches in the nanolubricant were mainly focusing on improving the machine life and tribological properties.

Maxwell [4] developed a classical theory of thermal conductivity of spherical particles and Hamilton and Crosser [5] modified that theory for non-spherical particles suspended in fluids.

Lee et al. [6] later confirmed that the Hamilton and Crosser models agree with Al_2O_3/water or ethylene glycol nanofluids but fails with CuO nanofluids.

According to the review [7], alumina is the most cost effective and widely used material in the family of engineering ceramics.

The aim of the paper was to give actual state of investigations on the use of Al_2O_3 nanoparticles in combustion engines.

1.Method for obtaining of Al_2O_3 nanoparticles and nanofluids containing them

Suresh et al. [8] synthesized Al_2O_3 nanoparticles by using a chemical precipitation method. They prepared nanofluids by dispersing a specified amount of Al_2O_3 nanoparticles in water using an ultrasonic vibrator generating ultrasonic pulses of 100 Wand 36 ± 3 kHz. The nanofluids were kept in the ultrasonic vibrator continuously for 6 h. The pH of the prepared nanofluid was found to be 4.8,which is far from the isoelectric point. In addition, the zeta potential was expected to be around 45 mV which is indicative of good colloidal stability. They found that the Al_2O_3/water nanofluid was very stable for several weeks without visually observable sedimentation.

Beck et al. [9] subjected a mixture of Al_2O_3 nanoparticles and ethylene glycol to ultrasonic mixing for several minutes to obtain uniform dispersion. They reported that the resulting dispersions remained uniform for the duration of the experiments because of surface charges on the particles.

In the other paper, Beck et al. [10] presented data for the thermal conductivity enhancement in seven nanofluids containing 8–282 nm diameter alumina nanoparticles in water or ethylene glycol. It was found, that the thermal conductivity enhancement in such nanofluids decreased with the particle size decrease below about 50 nm. Such observation was in agreement with a decrease in the thermal conductivity of alumina nanoparticles with decreasing particle size, which is due to phonon scattering at the solid–liquid interface. The limiting value of the enhancement for nanofluids containing large particles was higher than that obtained by the Maxwell equation, but was predicted well by the volume fraction weighted geometric mean of the bulk thermal conductivities of the solid and liquid. This observation allowed development of a simple relationship for the thermal conductivity of alumina nanofluids in both water and ethylene glycol

Gharagozloo and Goodson [11] diluted 20% weight concentration Al_2O_3–water nanofluid with less than 1% nitric acid with deionized water to the desired volume concentrations. The measured pH for each of the nanofluid concentrations was 5.5. The nanofluid was sonicated continuously for 4 h at 60 Hz and 130 W. They observed that the nanofluid was stable with only minor settling after a week.

Soltani et al. [12] first prepared the base liquid by mixing Carboxymethyl cellulose aqueous solutions with a concentration of 0.5 wt.% with distilled water, using a mechanical mixer. Then, the nanoparticles were added and thoroughly mixed for 6 h. The prepared nanofluids were sonicated for 1 h just before the experiment to increase the stability of solutions.

Hung et al. [13] produced Al_2O_3/water nanofluid using a homogenizer operating at 8000 rpm for 30 min, an electromagnetic agitator running at 600 rpm for 90min, and an ultrasonic vibrator operating at 400W for 60 min. The base liquid was prepared by adding 0.2 wt.% of water soluble chitosan as a cationic dispersant to distilled water. They confirmed that the difference between initial and final concentrations (after 2 weeks) of Al_2O_3/water nanofluid was less than 5%, indicating the stability of the prepared nanofluids.

Chandrasekar et al. [14] synthesized Al_2O_3 nanoparticles using a microwave assisted chemical precipitation method. The nanofluids were kept under ultrasonic vibration for 6 h at 36±3 kHz and 100W.

Jian et al. [15] regulated the pH value of the base water by adding a small amount of HCl solution, and then the nanoparticles were added. The dispersion was vibrated continuously for 4 h in an ultrasonic bath. It was observed that nanoparticles could be stably suspended in water at least for 3 days when the pH value is 4.9.

Anoop et al. [16] used two Al_2O_3 nanoparticle sizes obtained by laser evaporated physical methods to make alumina nanofluids. The particles were dispersed using ultrasonication and by keeping the pH value away from the iso-electric point. The pH values used for 1 wt.%, 2 wt.%, 4 wt.% and 6 wt.% were 6.5, 6, 5.5 and 5, respectively. The obtained suspensions were stable for several weeks.

Regardless of the base fluid, a stability of several weeks was obtained using only sonication [17] or sonication with adjustment of the pH value [16], while a stability of a month was found using sonication [18]. In addition, methanol nanofluids were very stable (zeta potential over 60 mV) even though the mixture was sonicated only for 2h [19]. It should be mentioned that some researchers didn't show details about how the Al_2O_3 nanofluids were prepared for their experiments.

Abdullah et al. [20] obtained an optimal composition (0.5 vol.%) of 70nm hBN and Al_2O_3 nanoparticles separately dispersed in SAE 15W40 diesel engine oil by sonication technique. The oil properties were studied by measuring the Viscosity Index (VI), Total Acid Number (TAN), Total Base Number (TBN) and flash point temperature. In addition, the stability of nanoparticles in oil was also observed by measuring the absorption value over time using ultraviolet (UV) spectrometer.

2. An improvement of thermal properties in different media using Al_2O_3 nanoparticles

Al_2O_3 nanoparticles showed excellent dispersion quality and increased thermal conductivity when suspended in heat transfer fluids like water, oils and glycols mixtures. Brownian motion of the particles and large surface area probably enhanced thermal conductivity of nanofluids. A detailed measurement of thermal conductivity of Al_2O_3 nanoparticles dispersed in ethylene glycol and water base fluids was done up by Lee et al. [21]. Thermal conductivities of nanofluids were measured using transient hot wire method. A considerable improvement in thermal conductivities of the nanofluids was noticed and these techniques created an interest in heat transfer studies using nanofluids.

Vajjha et al. [22] studied a three - dimensional laminar flow and heat transfer with Al_2O_3 and CuO in ethylene glycol/water mixture circulating through the flat tubes of an automobile radiator to evaluate their superiority over the base fluid. Convective heat transfer coefficient along the flat tubes with the Nano fluid flow was improved over the base fluid. The local and the average friction factor and convective heat transfer coefficient increased with increasing particle volumetric concentration of the nanofluids at various Reynolds numbers. The pressure loss increased with increasing particle volumetric concentrations of nanofluids. However, due to the reduced volumetric flow needed for the same amount of heat transfer, the required pumping power diminished.

Eastman et al. [23] pointed out, that nanofluid consisting of Cu nanometer-sized particles dispersed in EG had a much higher effective thermal conductivity than pure EG. The effective thermal conductivity of EG increased by up to 40% for a nanofluid consisting of EG containing approximately 0.3% of Cu nanoparticles compared to EG-base nanofluids containing either CuO or Al_2O_3 nanoparticles with the same particle volume fractions. They concluded that nanofluids consisting of Cu nanoparticles directly dispersed in EG exhibited improved thermal conductivity enhancements compared to nanofluids containing oxide particles.

Wang et al. [24] showed a 12 % increase in thermal conductivity for 28 nm diameter Al_2O_3 – water and 23 nm CuO – water Nano fluids with 3% volume fraction. For the case of 8 vol % Al_2O_3 – water Nano fluid, thermal conductivity enhancement as high as 40% was achieved.

In the studies of Lee et al. [21] based on CuO- water/ Ethylene glycol Nano fluids with particle diameters 18.6 and 23.6 nm as well as Al_2O_3– water/ Ethylene glycol Nano fluids with particle diameters 24.4 and 38.4 nm, they discovered a 20% thermal conductivity increase at a volume fraction of 4%. In both cases it was found that thermal conductivity increased linearly with particle volume fraction.

From their results Murshed et al. [25] showed a 20% increase in thermal conductivity for Al_2O_3 – water Nano fluids.

In their study, Das et al. [26] used Al_2O_3 (38.4 nm) water and CuO (28.6 nm) water Nano fluids at different temperatures ranging from 210 °C to 510 °C. The study aim was to investigating the increase of thermal conductivity with temperature for nano fluids with water as base fluid and particles of Al_2O_3 or CuO as suspension material. A temperature oscillation technique was utilized,for the measurement of thermal diffusivity and thermal conductivity is calculated from it. It was observed that for 1 vol % Al_2O_3/ water Nano fluid, thermal conductivity enhancement increased from 2% at 210 °C to 10.8% at 510 °C, and for 4 vol % thermal conductivity enhancement increased from 9.4% at 210°C to 24.4% at 510 °C. This was expected theoretically since, with the increment of the Nano fluids bulk temperature T, molecules and nanoparticles were more active due to enhanced Brownian motion and could transfer more energy from one location to another per unit time.

The ANOVA technique and Taguchi robust design method were used to investigate the effect of parameters, such as the nanoparticle additive concentration, the applied load, temperature, and speed to the tribology behavior of lubricant [27].

Peng et al. [28] used the Taguchi technique to determine the optimal aluminum nanoparticles size in oleic acid and ethanol. Their results revealed that the optimal nanoparticles size is 65 nm.

Thakre et al. [29, 30] added three kinds of Al_2O_3 nanoparticle sizes with different concentrations to regular engine oil to evaluate their tribological properties. L18 orthogonal array and ANOVA analysis were used to determine the optimum COF. The analysis results showed that the minimum coefficient of friction was obtained with 0.8 wt % of medium nanoparticles size (60 nm) and 160 N apply force at 1200 rpm rotational speed.

3.An improvement of tribological properties in different media using Al_2O_3 nanoparticles

Abdullah et al. [20] studied properties of conventional diesel engine oil enriched with hBN/Al_2O_3 nanoparticles. It was found, that the nano-oil with hBN nanoparticles could improve or at least maintain the key lubrication properties, though the TAN value slightly increased. In addition, the dispersion of nano-oil was stable up to 168 hours before the sedimentation occurred. The dispersion of nano-oil with hBN nanoparticles was better than that of nano-oil with Al_2O_3 nanoparticles.

Le and Lin [31] investigated the tribological properties of glycerol lubricant with aluminum nanoparticles as an additive and sodium dodecyl sulfate (SDS) as the dispersive medium for iron to iron friction using a thrust collar tribotester. The effects of different concentrations of aluminum nanoparticles, SDS, and deionized water in glycerol on tribology properties of iron to iron friction were studied. The experimental parameters were set up according to the Taguchi technique, their influence on the coefficient of friction (COF) and wear rate were examined by response surface methodology (RSM) and analysis of variance (ANOVA) methods. The analysis results were used during optimization the parameters allowing obtaining the best lubricant effects. The optimal combination of the parameters for both minimum COF and wear rate was 0.6667 weight percent (wt %) of aluminum nanoparticles, 2 wt % of SDS, and 10 wt % of deionized water content of glycerol, respectively. The wear surface topography and the average roughness of the surface were examined via a scanning electron microscope (SEM) and a Mitutoyo Surftest SJ-400 instrument. It was found, that aluminum nanoparticles used as an additive in lubricant reduced the surface roughness of a collar remarkably. The energy dispersive spectrometer (EDS) was used during confirmation the deposition of aluminum nanoparticles on the collar surface leading to decreased friction and wear.

During studies carried out by Yesaswi et al. [32], the Al_2O_3 nanoparticles were prepared and mixed with 10W30 engine oil. By various techniques thermal characteristics of fluid were identified with different parameters.

Mohan et al. [33] investigated the influence of Al_2O_3 nanoparticles as lubricant additive on the relative motion of a plane surface over the other having circular surface in contact. A pin-on-disk setup as per ASTM G99 was for the experiments in starved and fully flooded conditions at various loads and relative speeds at the pin and disc contact. The lubricant SAE 20W-40 with nano-additives was used to study the influence on friction and specific wear rate at the interface. Based on the experiments, tribological behavior of lubricant with Al_2O_3 nanoparticles was compared with the lubricant without NPs. The coefficient of friction and specific wear rate were found to be decreased in lubricant containing Al_2O_3 nanoparticles.

Summary

The researches and experiments carried out by the several scientists, showed that addition of nanoparticles to the base fluids like water and Ethylene glycol improved thermal conductivity of Nano fluids compared to the conventional base fluids. Many scientists preferred use of water as base fluid with addition of Al_2O_3 nanoparticles. Their experiments showed, that there are some factors affecting the rate of enhancement of thermal conductivity of the base fluid with addition of nanoparticles. Such factors are: volume fraction of particles, thermal conductivity of the base fluid, particle size, temperature and particle shape. All these factors affect the thermal conductivity of the base fluids differently in the positive manner. Furthermore, with the addition of nanoparticles the heat transfer coefficient is improved for the Nano fluids. However, Ethylene glycol as a base fluid was not widely discussed and how its thermal properties and capabilities varied with addition of Al_2O_3 nanoparticles, though some researchers reported, that some nanoparticles affected the thermal conductivity. Moreover, Ethylene glycol and water were not compared as base fluids.

You can also note a few mentions about utilizing of Al_2O_3 particles as additives in glycerol lubricant or in engine oils to improve tribological properties.

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Wykorzystanie nanocząstek Al_2O_3 w silnikach spalinowych

W pracy omówiono metody stosowane do otrzymywania nanocząstek Al_2O_3. Przedstawiono wykorzystanie nanocząstek Al_2O_3 w celu poprawy przewodnictwa cieplnego i właściwości tribologicznych w różnych mediach, w tym oleju silnikowym.

Słowa kluczowe: nanocząstki Al_2O_3, przewodnictwo cieplne, własności tribologiczne, olej silnikowy.

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