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Nanofluid Applications in Future Automobiles: Comprehensive Review of Existing Data

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In recent years fluids containing suspension of nanometer sized particles have been an active area of research due to their enhanced thermo physical properties over the base fluids like water, oil etc. Nanofluids possess immense potential applications to improve heat transfer and energy efficient in several areas including automobile, micro electronics, nuclear, space and power generation. Nowadays most of the researchers are trying to use the nanofluids in automobile for various applications such as coolant, fuel additives, lubricant, shock absorber and refrigerant. The goal of this paper is to create the awareness on the promise of nanofluids and the impact it will have on the future automotive industry. This paper also presents a comprehensive data of nanofluids application in automobile for various aspects.

Keywords: Nanotechnology; Nanofluid; Thermo physical properties; Thermal conductivity

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Introduction

A huge amount of researches and development activities have been devoted to nano scale related technologies in recent years. The NSF (Nano Science and Foundation) predicts the market for nanotech products and services will exceed $1 trillion in the US alone by 2015 [1]. Figure 1 shows the summary of R&D funding for Nano technology from 2007 to 2011. Nano technology is defined as a technology that deals with structures in nanometer range. Due to the small dimension of nano material, their physical, chemical properties can be manipulated to over all properties. About a decade ago, USA based research laboratory started to prepare a special kind of fluid by suspending particles with diameters of 1~100 nm in base fluid such as water, oil, Ethylene Glycol etc. This fluid is named as "Nanofluid" by Choi in 1995 [2].

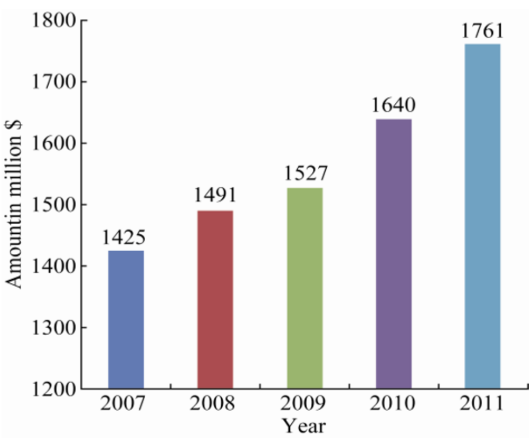

FIG. 1. Summary of R&D funding for Nano technology from 2007 to 2011.

From previous investigations nanofluids have been found to possess enhanced thermo physical properties, such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer co-efficient compared to those of base fluids like water, oil, Ethylene Glycol etc. In recent years the use of colloids which are nanofluids in automobile industries for various applications such as heat transfer, lubrication, additives for fuel, shock absorber has increased. This is directly related to the ability to design the compact vehicles with high efficiency.

Review of recent research

Nanofluid as coolant

Internal combustion spark and diesel engines are used

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worldwide to meet social need for transportation and mobile power generation. In I.C. Engine the cooling system is responsible for thermal management of the engine block and passenger compartments. Operations of majority of the vehicle components depend on coolant temperature. Fig.2 presents the thermal conductivity of different metal, non metal and liquids. The traditional heat transfer fluids (coolants) such as oil, Ethylene Glycol, Fluro carbons have poor heat transfer performance due to their low thermal conductivities. Since the thermal conductivity of solids is greater than liquids, dispersion of solid particles in a given fluid is bound to increase thermal conductivity. However, dispersion of millimeter or micrometer sized particles is prone to sedimentation, clogging and erosion of pipes and channels. In contrast, nanofluid is a stable colloidal suspension of solid particles dispersed in conventional heat transfer fluids to offer a dramatic enhancement in thermo physical properties of the fluids.

Choi & Eastman have tried to suspend various metal and metal oxide nanoparticles in different fluids [2-5]. Putnam et al. has observed that the effective static thermal conductivities of Au based nanofluids were independent of part loading [6, 7]. Experiments on convection heat transfer of nanofluids were conducted by several research groups [8-13]. The experimental results show significant improvements in heat transfer rates of nanofluids. Table 1 summarizes the nanofluid information which was used by each of these groups in their experimental investigations.

Roubert et al. started a project in 2008 that employed nanofluids for industrial cooling that could results in energy savings & resulting emission reductions [14]. Singh et al. have investigated that the use of high thermal conductivity nanofluids in radiators can lead to reduction in the frontal area of the radiator by up to 10%. The fuel efficiency and also vehicle performance will increase by reducing the size of the components [15]. Vasu et al. have used aqueous alumina as a coolant on automobile flat tube plain fin compact heat exchanger. This project concluded that the heat transfer rate will decrease by increasing the air inlet temperature [16]. Tzeng et al. investigated the temperature distribution of rotary blade coupling transmission used in four wheel drive vehicles. They concluded that use of nanofluids in the transmission has a clear advantage from the thermal performance view point [17]. Ravikanth et al. used the nanofluids in radiator to study the heat transfer performance. They used the CuO and Al_2O_3 for their study [34].

Ravikanth et al. concluded that the average heat transfer co-efficient increases with the Reynolds number and the particle volumetric concentration. The Reynolds number and the pumping power requirements for various concentration of Al2O3 & CuO nanofluids were measured and are as shown in Fig.3 and Fig.4. The X-axis labels indicate the percent concentration of nanofluids. The results shows that with increasing percent concentration, the required pumping power is reduced upto 80% for both Al2O3 & CuO. The 82% pumping power reduction attained in 10% concentration of Al2O3 nanofluid & 77% pumping power reduction attained in 6% concentration of CuO nanofluids. The Reynolds number data shows in decreasing trend with increasing percent concentration for both Al2O3 & CuO nanofluids. Kulkarni et al. studied the performance of diesel electrical generator with aluminum oxide nanofluid coolant. They dispersed the aluminum oxide in 50:50 inhibited Ethylene glycol and water mixture. They concluded

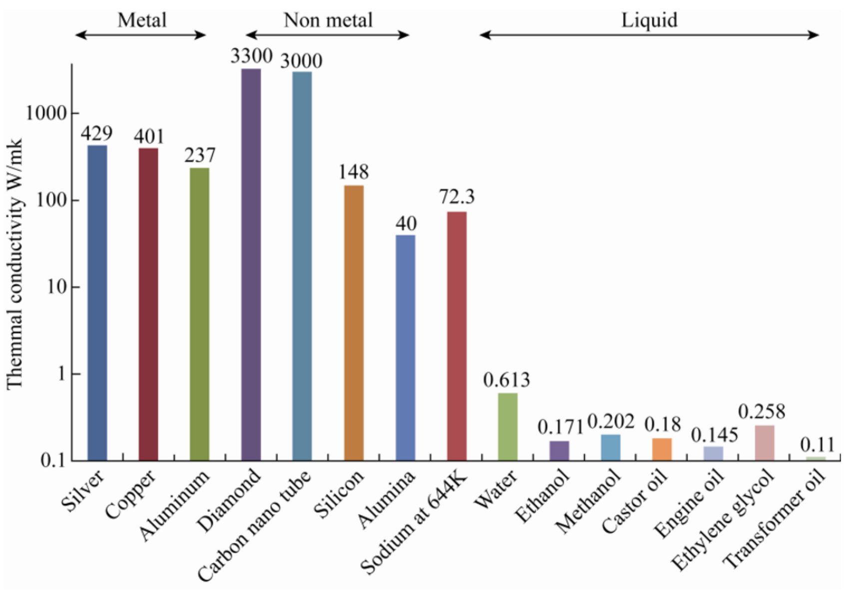

FIG. 2. Comparison of thermal conductivity for different materials.

Table 1 Summery of measured thermal conductivity enhancement for nanofluids containing metal oxide nano particles

Ref.No	Reference	Base fluid	Nano particle& Diameter	Max. Concentration (Vol %)	Maximum Enhancement in thermal conductivity (k) (%)
22	Masuda et al (1993)	Water	Al_2O_3, 13 nm	4.3	30
23	Eastman et al (1996)	Water	Al_2O_3, 33 nm	5	30
24	Pak and Cho (1998)	Water	Al_2O_3, 13 nm	4.3	32
25	Wang et al (1999)	Water	Al_2O_3, 28 nm	4.5	14
25	Wang et al (1999)	Ethylene Glycol	Al_2O_3, 28 nm	8	40
25	Wang et al (1999)	Pump oil	Al_2O_3, 28 nm	7	20
25	Wang et al (1999)	Engine oil	Al_2O_3, 28 nm	7.5	30
26	Lee et al (1999)	Water	Al_2O_3, 24.4 nm	4.3	10
26	Lee et al (1999)	Ethylene Glycol	Al_2O_3, 24.4 nm	5	20
27	Das et al (2003)	Water	Al_2O_3, 38 nm	4	25
28	Xie (2002)	Water	Al_2O_3, 60 nm	5	20
28	Xie (2002)	Ethylene Glycol	Al_2O_3, 60 nm	5	30
28	Xie (2002)	Pump oil	Al_2O_3, 60 nm	5	40
29	Prashar et al (2005)	Water	Al_2O_3, 10 nm	0.5	100
30	Krishnamurthy et al (2006)	Water	Al_2O_3, 20 nm	1	16
26	Lee et al (1999)	Water	CuO, 18.6 nm	4.3	10
26	Lee et al (1999)	Ethylene Glycol	CuO, 18.6 nm	4	20
25	Wang et al (1999)	Water	CuO, 23 nm	10	35
25	Wang et al (1999)	Ethylene Glycol	CuO, 23 nm	15	55
31	Liu et al (2006)	Ethylene Glycol	CuO, 25 nm	5	22.4
27	Das et al (2003)	Water	CuO, 28.6 nm	4	36
24	Pak and Cho (1998)	Water	TiO_2, 27 nm	4.35	10.7
32	Murshad et al (2005)	Water	TiO_2, 15 nm	5	33
33	Li et al (2010)	Water	Al_2O_3, 33 nm	2	25
36	Paul et al (2010)	water	Au, 20 nm	2.6	48

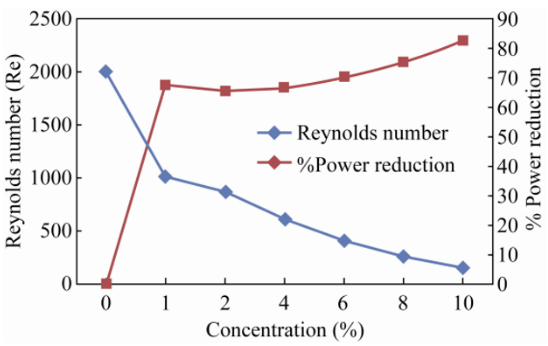

FIG. 3. Comparison of Reynolds number and percent power reduction for different concentration of Al_2O_3 nanofluid.

that the heat exchanger efficiency increases with increasing particle concentration because of the higher heat transfer coefficients of nanofluids [35].

Nanofluid as Lubricant

In automobile lubrication applications surface modified nanoparticles dispersed in mineral oils were reported to be effective in reducing wear & enhancing load carrying capacity [18]. Recently lots of researchers show their interest to enhance the tribological properties (such as load carrying capacity, wear resistance and friction reduction between the moving components) of nanoparticle suspended lubricants. The vehicle life time as well as the performance will be increased by using the nanoparticle suspended lubricants. Osorio et al. investigated the tribological properties of CuO suspended lubricant. They suspended 30~50 nm sized CuO nanoparticles in polyalphaolefin (PAO6). They concluded that the addition of CuO nanoparticles to the polyalphaolefin (PAO6) reduced friction with respect to base oil and also the nanoparticles could react with the surfaces forming antifriction compounds and deposit on the wear surfaces by tribosinterization [37]. The Mu-Jung Kao et al. have used the TiO_2 nanoparticles as additives to reduce the friction between the two pieces of cast iron. They suspended the TiO_2 nano particles in paraffin oil, studied the characteristics of nanofluids and also the studied the tribological properties such as friction, surface roughness etc. They concluded that the nanoparticles could fill rough cracks in a metal wall surface to reduce the coefficient of friction [38].

Nanofluid as fuel additives

The present fuel resources are not going to be around forever with the increase of consumptions, and also the combustion of fossil fuels emits harmful gases like CO, NO_x, etc. So most of the scientists and engineers are trying to improve the performance of automobile by using different methods, for example reducing the vehicle weight, improving the engine performance, reducing the vehicle vibration, and using precision electronics control system. After the invention of nanotechnology the nanoparticles are used as fuel additives to improve the fuel economy as well as to reduce the exhaust emissions. The combustion efficiency and the combustion stability will be increased by adding metallic nanoparticles to our commercial fossil fuels. The scientists in nano science and technology council in USA have achieved to increase 10~25% combustion efficiency by adding 0.5% of aluminum nano-particles to a rocket's solid fuel [19]. Also the combustion speed has been increased because of nanoparticle additives.

Jung Kao et al. investigated the effect of aqueous

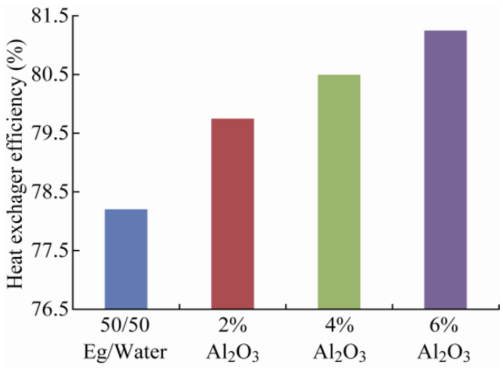

FIG. 5. Comparison of heat exchanger efficiency for different concentration of nanofluids.

aluminum nanoparticles in compression ignition engine. The aluminum nanoparticles have very high activity and can react with water at temperatures from 4000°C to 6600°C to generate hydrogen. Aluminum nanoparticles serve as a catalyst to decompose the water. They also observed that the fuel consumption will reduce by using aluminum nanofluid and diesel mixture [20]. The experimental investigation was carried out to improve the performance and emission characteristics of C.I engine using cerium oxide nanoparticles with diesel and biodiesel mixture fuel by Arul Mozhi Selven et al. [21]. The cerium oxide acted as an oxygen donating catalyst and provides oxygen for the oxidation of CO or absorbs oxygen for the reduction of NO_x. They observed that combustion of the fuel will improve and reduce the exhaust emission by using a cerium oxide nano particle catalyst. The burning characteristics of ethanol droplets containing nano- and micron-sized aluminum particles were investigated by Yanan Gan et al. [39]. In this research aluminum nanoparticles acted as a catalyst. They observed that the fuel burnt completely by suspending the aluminum nanoparticles with the fuel.

Nanofluid in shock absorber

Shock absorbers provided the comfortable ride in vehicles ranging from sports car to pick up trucks. The hydraulic shock absorbers were used in modern automobiles to reduce the space and to improve the performance of shock absorber by absorbing more vibrations. The researchers prepared special kind of fluid by suspending a magnetic nanoparticle with the base fluid. The above prepared fluid is known as Magneto Rheological nano fluid or Electro Rheological nanofluid. Depending on the size of the nanoparticles, the magnetic fluid may be able to change its viscosity proportion to the strength of magnetic field applied to it. Shock absorbers based on magnetic fluids are used in the modern automobiles like "Audi Le mans Quattro". Energy is derived from the electronic control system and the on board computer adjusts the shock absorber based on the information provided by the sensors.

Conclusion

Nano fluids are important because they can be used in numerous applications involving heat transfer and other applications in automobile. Nano fluids have also been used as smart materials to absorb vibrations in automobiles. The main findings in this paper are summarized as follows.

1. The internal combustion engine performance will improve by 5~10% by using Nano particle suspended commercial engine coolant.
2. The vehicle life as well as the performance can be increased by enhancing the tribological properties (such as load carrying capacity, wear resistance and friction reduction between the moving components) of nano-particle suspended lubricants.
3. The combustion of the fuel can improve and reduce the exhaust emission by using a nanoparticle catalyst in commercial fossil fuel.

Further research still has to be on the synthesis and application of nanofluids so that the developing systems will be more efficient, smaller, healthier and environmental friendly.

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