Assessment of Oxygenated and Nanofluid Fuels as Alternative/Green Aviation Fuels

Selçuk Sarıkoç

Nomenclature

Al_2O_3	Aluminum oxide
CNT	Carbon nanotube
CO	Carbon monoxide
LHV	Lower heating value (MJ/kg)
Mn_2O_3	Manganese oxide
SI	Spark-ignition
ZnO	Zinc oxide

1 Introduction

High-octane fuel, which is obtained by formulating gasoline and called aviation gasoline, is used in aircraft piston engines (Çetinerler, 2021). The effective oxygen concentration at sea level is 20.9%. This value is 10.5% at 18000 ft. and 6.3% at 30000 ft. (Hypoxico, 2021). At high altitudes, low oxygen density negatively affects combustion efficiency, causing incomplete combustion, thus reducing engine performance and limiting the maximum altitude.

Oxygen additives reduce the pollution of the atmosphere to a minimum by enabling the fuel to burn more efficiently. Because oxygenated fuels ensure complete combustion of the fuel in the combustion chamber they lead to reducing the amount of harmful emissions chemicals released into the atmosphere (Rashedul et al., 2014).

S. Sarıkoç (✉)
Department of Motor Vehicles and Transportation Technologies, Amasya University, Tasova Yuksel Akin Vocational School, Amasya, Türkiye

T. H. Karakoc et al. (eds.), *Research Developments in Sustainable Aviation*, Sustainable Aviation, https://doi.org/10.1007/978-3-031-37943-7_8

Nanomaterials have many advantages such as high energy density, ability to mix with liquid fuels, heterogeneous combustion kinetics, ignition acceleration reaction, and cost. The higher surface area-to-volume ratio and more reactive surface of the nanoparticles cause the nanofluid fuel mixture to oxidize faster. Thus, they provide higher combustion enthalpy and energy density. Nanofluids provide high evaporation rate, better atomization, more homogeneous air-fuel mixture, and better flame sustainability in fuels. This results in a shortening of the premixing and diffusion phases and a significant reduction in the ignition delay. This short ignition delay, better atomization of the fuel, and the highly reactive surface allow the combustion reaction to start faster and earlier. Thus, a higher amount of heat release rate and cylinder internal pressure are created (Saxena et al., 2017).

In the literature, many nanomaterials such as Al_2O_3, ZnO, TiO_2, CeO_2, SiO_2, and CNT (carbon nanotube) are used as fuel additives because they increase the heat transfer by radiation and enable the air-fuel mixture to oxidize faster with its high surface area-to-volume ratio (Ağbulut et al., 2020; Zhang et al., 2019; Nanthagopal et al., 2020).

There are many studies in the literature on the use of nanomaterials in the internal combustion engines. For example, there are studies in which CNT of different sizes is used as a fuel additive in diesel engines under various engine conditions (Zhang et al., 2019; Najafi, 2018). Sivakumar et al. (2018) researched on the effects of mixing Al_2O_3 nanoparticles with biodiesel in a diesel engine on engine performance, combustion, and emission characteristics, Ağbulut et al. (2020) investigated the effects of mixtures of various metal oxide nanomaterials, including Al_2O_3, with biodiesel in a diesel engine, on engine performance, combustion, emission, vibration, and noise characteristics; Manigandan et al. (2020) compared the effects on emissions in diesel engines by giving hydrogen to fuel mixtures consisting of different kinds of nanoparticles, including CNT and Al_2O_3 additives; and Chen et al. (2018) used CNT and Al_2O_3 additives as fuel additives in diesel engines and examined the effects of nanoparticles on engine performance, combustion, and emission characteristics.

In the literature, on the use of nanomaterials in spark-ignition engines, Amirabedi et al. (2019) investigated the effects of mixtures of manganese oxide (Mn_2O_3) nanoparticles with ethanol on engine performance and emissions. As a result of the study, it was calculated that the gasoline-10% ethanol-20 ppm Mn_2O_3 fuel mixture increased the engine power by 19.56% and the specific fuel consumption decreased by 36.72% compared to gasoline.

2 Effect of Oxygenated and Nanofluid Fuels on Combustion Process

In the literature, it has been stated that the lack of enough oxygen in the environment during combustion causes incomplete combustion, thus reducing the performance and efficiency of the engine (Pulkrabek, 2016). In addition, alcohols with high oxygen content improve combustion, provide complete combustion, reduce CO formation, and prevent energy loss from the exhaust (Yesilyurt et al., 2020). High oxygen content of alcohols (Canakci et al., 2013) and higher laminar flame velocity than gasoline (gasoline, 33–44 cm/s; methanol, 52 cm/s; ethanol, 48 cm/s; butanol, 48 cm/s) improve the combustion process (Li et al., 2017) and increase engine torque, specific fuel consumption, thermal efficiency, and combustion efficiency (Balki et al., 2014). The high heat of evaporation caused due to the cooling effect on the combustion chamber and the higher octane number properties of alcohols considerably reduce knocking, making the combustion more uniform and thus improving the combustion process (Zhang et al., 2014). Furthermore, oxygen-rich alcohols affect the combustion process positively by improving the premix and diffusion combustion phases (Emiroğlu & Şen, 2018). However, the lower calorific value of alcohols compared to gasoline increases somewhat of the specific fuel consumption. More fuel is consumed to achieve the same engine power output due to the lower calorific value of alcohols (Li et al., 2017).

Alcohols (methanol and ethanol) have higher features than gasoline, such as oxygen content, octane number, evaporation heat, and laminar flame propagation speed, improve combustion, and provide more stable operation of the engine (Pulkrabek, 1997; Li et al., 2017; Yilmaz & Atmanli, 2017). Important properties of gasoline, methanol, and ethanol are presented in Table 1.

In spark-ignition engines, combustion starts with the ignition of the spark plug, and the flame front spreads rapidly. The temperature and pressure of the burnt gases increase as a result of compressing the unburned mixture in front of the flame front. In this compression, it increases the temperature and pressure of the unburned mixture. During the combustion process in the engines, the heat transfer by conduction and convection during combustion is not significant compared to radiation due to combustion actually occurring in a very short time per cycle. Therefore, heat

Table 1 Important properties of gasoline, methanol, and ethanol (Pulkrabek, 1997; Li et al., 2017; Yilmaz & Atmanli, 2017)

Fuel type	Gasoline	Methanol	Ethanol
Formula	C_8H_{15}	CH_3OH	C_2H_5OH
Density (kg/m^3)	715–765	792	0.803
LHV (MJ/kg)	43	20.05	26.9
Octane number	92	111	129
Oxygen content (%)	–	50	34.73
Latent heat (kJ/kg)	307	1147	918.42
Laminar flame speed (cm/s)	33–44	52	48

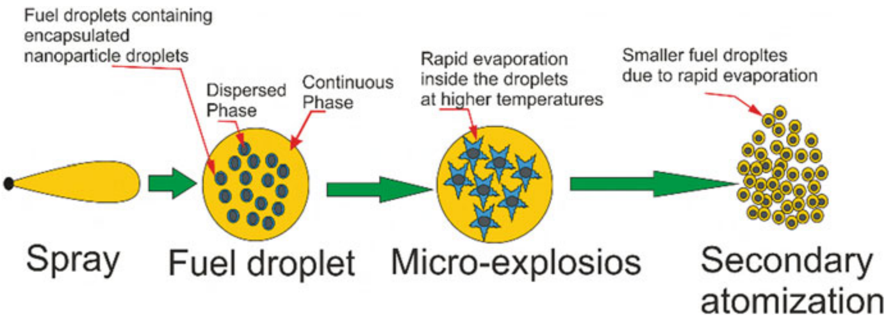

Fig. 1 The effect of nanomaterial on the combustion process with micro-explosions

transfer by radiation is more important in heat transfer in the combustion process (Pulkrabek, 1997).

Aluminum oxide (Al_2O_3) nanoparticles are encapsulated in the fuel mixture, causing a micro-explosion during combustion, thus providing a more homogeneous fuel-air mixture by allowing the fuel mixture to be atomized for the second time. This improves the complete combustion process positively, resulting in better combustion characteristics. With the addition of 50 ppm and 100 pm Al_2O_3 to the fuel, an increase of 28.91% and 29.7% was obtained, respectively (Sivakumar et al., 2018). CNT increased the peak pressure and heat release rate in the engine by 23.33% and 28%, respectively. It also improved the combustion process by reducing the ignition delay time by 8.98% (Najafi, 2018). CNT also caused a 23% rate reduction in specific fuel consumption. It was also stated that it provides better fuel stability (Manigandan et al., 2020). In another study, it was observed that CNT increased the maximum cylinder pressure and heat release rate by 5% and 4%, respectively (El-Seesy et al., 2019). Nanoparticles increase the heat transfer rate with their higher heat conduction properties and improve the combustion process characteristics by making a catalytic effect in the fuel (Sungur et al., 2016). In addition, the nanomaterial additive greatly affects thermal efficiency. The thermal conductivity of nanomaterials increases the heat transfer of the fuel mixture, which reduces the ignition delay, resulting in an increase in pressure rise rate and peak pressure; thus, they lead to better thermal efficiency (Kumar et al., 2017).

However, nanoparticles are likely to clog the injector as they tend to agglomerate due to their large surface area and surface activity (Saxena et al., 2017). In order to prevent the precipitation and agglomeration of nanomaterials in the fuel, they are usually added to the fuel in liquid solution (emulsion) form using a solvent and surfactant (Nanthagopal et al., 2020). Ultrasonic homogenizers are used to mix these surfactants and nanomaterials homogeneously with the fuel and to ensure the stability of the mixture (Soudagar et al., 2018). Thus, these nanomaterials can be used as additives in liquid fuels as nanofluids. The effect of nanomaterial on the combustion process is presented in Fig. 1.

3 Summary and Conclusions

Engine performance and combustion process characteristics can be improved by making improvements in the chemistry and technology of the fuel used in the engine. In this regard, using alcohol and nanomaterials can be improved important fuel properties so that an increase can be obtained in the engine performance and combustion efficiency. Considering the above information, the benefits of oxygenated fuels (alcohols) and nanomaterials for air vehicles can be summarized as follows:

The combustion process at a high altitude for high-flying vehicles can be improved by oxygenated fuels, which is providing extra oxygen content.

Oxygenated fuels can not only increase the fuel oxygen content of unmanned aerial vehicles but also improve cold flow characteristics. Furthermore, nanomaterials increase the fuel oxygen surface area and increase the combustion efficiency by creating a catalytic effect. In this way, engine performance and combustion efficiency increase at high altitudes, and harmful exhaust emissions and fuel consumption can be reduced.

The oxygen content, octane number, combustion surface, and heat transfer rate of the fuel can be increased with nanomaterial additives added to the fuel. Thus, performance parameters such as engine torque, engine power, thermal efficiency, and combustion efficiency can also be improved. As a result of improving the engine performance and combustion process, useful load-carrying capacity, endurance, longer range flight, higher altitude, and fuel economy can be achieved.

Considering all this, the fuel blend consisting of surfactant, nanomaterial, and alcohol can be used in the internal combustion engine. Thus, by using alcohol and nanomaterials for air vehicles, it is possible to improve fuel properties, increase engine performance, and improve phases of combustion characteristics. The author recommends for future studies should have done experimental investigations of the stability of the nanomaterials and the effects of nanomaterials on the engine performance, combustion process, and exhaust emission characteristics.

Acknowledgment The author would like to thank Amasya University for its support.

References

Ağbulut, Ü., Karagöz, M., Sarıdemir, S., & Öztürk, A. (2020). Impact of various metal-oxide based nanoparticles and biodiesel blends on the combustion, performance, emission, vibration and noise characteristics of a CI engine. *Fuel, 270*, 117521. https://doi.org/10.1016/j.fuel.2020.117521

Amirabedi, M., Jafarmadar, S., & Khalilarya, S. (2019). Experimental investigation the effect of Mn2O3 nanoparticle on the performance and emission of SI gasoline fueled with mixture of ethanol and gasoline. *Applied Thermal Engineering, 149*, 512–519. https://doi.org/10.1016/j.applthermaleng.2018.12.058

Balki, M. K., Sayin, C., & Canakci, M. (2014). The effect of different alcohol fuels on the performance, emission and combustion characteristics of a gasoline engine. *Fuel, 115*, 901–906. https://doi.org/10.1016/j.fuel.2012.09.020

Canakci, M., Ozsezen, A. N., Alptekin, E., & Eyidogan, M. (2013). Impact of alcohol–gasoline fuel blends on the exhaust emission of an SI engine. *Renewable Energy, 52*, 111–117. https://doi.org/10.1016/j.renene.2012.09.062

Çetinerler, E.. (2021). Uçak Motorları. http://www.tayyareci.com/akademi/motor.asp. Accessed 29 Oct 2021.

Chen, A. F., Akmal Adzmi, M., Adam, A., Othman, M. F., Kamaruzzaman, M. K., & Mrwan, A. G. (2018). Combustion characteristics, engine performances and emissions of a diesel engine using nanoparticle-diesel fuel blends with aluminium oxide, carbon nanotubes and silicon oxide. *Energy Conversion and Management, 171*, 461–477. https://doi.org/10.1016/j.enconman.2018.06.004

El-Seesy, A. I., Kosaka, H., Hassan, H., & Sato, S. (2019). Combustion and emission characteristics of a common rail diesel engine and RCEM fueled by n-heptanol-diesel blends and carbon nanomaterial additives. *Energy Conversion and Management, 196*, 370–394. https://doi.org/10.1016/j.enconman.2019.05.049

Emiroğlu, A. O., & Şen, M. (2018). Combustion, performance and exhaust emission characterizations of a diesel engine operating with a ternary blend (alcohol-biodiesel-diesel fuel). *Applied Thermal Engineering, 133*, 371–380. https://doi.org/10.1016/j.applthermaleng.2018.01.069

Hypoxico. (2021). *Altitude to oxygen chart*. https://hypoxico.com/altitude-to-oxygen-chart/. Accessed 29 Oct 2021.

Kumar, S., Dinesha, P., & Bran, I. (2017). Experimental investigation of the effects of nanoparticles as an additive in diesel and biodiesel fuelled engines: A review. *Biofuels, 10*(5), 615–622. https://doi.org/10.1080/17597269.2017.1332294

Li, Y., Gong, J., Deng, Y., Yuan, W., Fu, J., & Zhang, B. (2017). Experimental comparative study on combustion, performance and emissions characteristics of methanol, ethanol and butanol in a spark ignition engine. *Applied Thermal Engineering, 115*, 53–63. https://doi.org/10.1016/j.applthermaleng.2016.12.037

Manigandan, S., Sarweswaran, R., Booma Devi, P., Sohret, Y., Kondratiev, A., Venkatesh, S., Rakesh Vimal, M., & Jensin Joshua, J. (2020). Comparative study of nanoadditives TiO2, CNT, Al2O3, CuO and CeO2 on reduction of diesel engine emission operating on hydrogen fuel blends. *Fuel, 262*, 116336. https://doi.org/10.1016/j.fuel.2019.116336

Najafi, G. (2018). Diesel engine combustion characteristics using nano-particles in biodiesel-diesel blends. *Fuel, 212*, 668–678. https://doi.org/10.1016/j.fuel.2017.10.001

Nanthagopal, K., Kishna, R. S., Atabani, A. E., Al-Muhtaseb, A. A. H., Kumar, G., & Ashok, B. (2020). A compressive review on the effects of alcohols and nanoparticles as an oxygenated enhancer in compression ignition engine. *Energy Conversion and Management, 203*, 112244. https://doi.org/10.1016/j.enconman.2019.112244

Pulkrabek, W. W. (1997). *Engineering fundamentals of the internal combustion engine* (Vol. 1). Prenrice Hall.

Pulkrabek, W. W. (2016). *İçten Yanmalı Motorlar Mühendislik Temelleri. 1. Baskı*. İzmir Güven Kitabevi.

Rashedul, H. K., Masjuki, H. H., Kalam, M. A., Ashraful, A. M., Ashrafur Rahman, S. M., & Shahir, S. A. (2014). The effect of additives on properties, performance and emission of biodiesel fuelled compression ignition engine. *Energy Conversion and Management, 88*, 348–364. https://doi.org/10.1016/j.enconman.2014.08.034

Saxena, V., Kumar, N., & Saxena, V. K. (2017). A comprehensive review on combustion and stability aspects of metal nanoparticles and its additive effect on diesel and biodiesel fuelled C.I. engine. *Renewable and Sustainable Energy Reviews, 70*, 563–588. https://doi.org/10.1016/j.rser.2016.11.067

Sivakumar, M., Shanmuga Sundaram, N., Ramesh Kumar, R., & Syed Thasthagir, M. H. (2018). Effect of aluminium oxide nanoparticles blended pongamia methyl ester on performance, combustion and emission characteristics of diesel engine. *Renewable Energy, 116*, 518–526. https://doi.org/10.1016/j.renene.2017.10.002

Soudagar, M. E. M., Nik-Ghazali, N.-N., Abul Kalam, M., Badruddin, I. A., Banapurmath, N. R., & Akram, N. (2018). The effect of nano-additives in diesel-biodiesel fuel blends: A comprehensive review on stability, engine performance and emission characteristics. *Energy Conversion and Management, 178*, 146–177. https://doi.org/10.1016/j.enconman.2018.10.019

Sungur, B., Topaloglu, B., & Ozcan, H. (2016). Effects of nanoparticle additives to diesel on the combustion performance and emissions of a flame tube boiler. *Energy, 113*, 44–51. https://doi.org/10.1016/j.energy.2016.07.040

Yesilyurt, M. K., Aydin, M., Yilbasi, Z., & Arslan, M. (2020). Investigation on the structural effects of the addition of alcohols having various chain lengths into the vegetable oil-biodiesel-diesel fuel blends: An attempt for improving the performance, combustion, and exhaust emission characteristics of a compression ignition engine. *Fuel, 269*, 117455. https://doi.org/10.1016/j.fuel.2020.117455

Yilmaz, N., & Atmanli, A. (2017). Experimental evaluation of a diesel engine running on the blends of diesel and pentanol as a next generation higher alcohol. *Fuel, 210*, 75–82. https://doi.org/10.1016/j.fuel.2017.08.051

Zhang, Z., Wang, T., Jia, M., Wei, Q., Meng, X., & Shu, G. (2014). Combustion and particle number emissions of a direct injection spark ignition engine operating on ethanol/gasoline and n-butanol/gasoline blends with exhaust gas recirculation. *Fuel, 130*, 177–188. https://doi.org/10.1016/j.fuel.2014.04.052

Zhang, Z., Lu, Y., Wang, Y., Yu, X., Smallbone, A., Dong, C., & Roskilly, A. P. (2019). Comparative study of using multi-wall carbon nanotube and two different sizes of cerium oxide nanopowders as fuel additives under various diesel engine conditions. *Fuel, 256*, 115904. https://doi.org/10.1016/j.fuel.2019.115904