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Experimental investigation on 4-strokes biodiesel engine cooling system based on nanofluid

Francesco Micali, Marco Milanese, Gianpiero Colangelo*, Arturo de Risi

Department of Engineering for Innovation, University of Salento, Via per Arnesano, Lecce, Italy

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A B S T R A C T

Global biodiesel production grew by 23% per year between 2005 and 2015, leading to a very strong expansion of the sector in a decade and, at the same time, the interest in the use of liquid biofuels/biodiesel in compression ignition engines has grown quickly.

Taking into account that the use of biodiesel in IC engines directly affects their coolant temperature, with impact on performance, in this study an experimental campaign has been carried out on a 4-strokes single cylinder engine, aimed to assess whether the use of nanofluids, instead of water, could be a valuable solution to reduce peak engine temperature. Such nanofluids were characterized by higher thermal conductivity compared to conventional fluids, due to CuO nanoparticles added at different concentrations within the base fluid.

Measurements of temperature were recorded at steady and unsteady conditions, by proper thermocouples located around the exhaust valve seat in the cylinder head and in the exhaust valve spindle. Particularly, temperatures of the exhaust valve spindle and exhaust valve seat in the cylinder head were measured at part and full engine loads, using water as coolant and then CuO based nanofluids.

Experimental results showed that, at 100% engine load in unsteady conditions, it was possible to achieve a temperature reduction up to 13.6% on the exhaust valve seat and up to 4.1% on the exhaust valve spindle, when nanofluid at 2.5% volume concentration was used.

1. Introduction

Due to their potential role in addressing the challenges of energy and environment, biofuels have been receiving significant attention from scientists in various disciplines and countries [1–3].

Liquid biofuels accounted for about 4% of the total fuel consumption in the EU transport sector in the period 2009–2013 [4]. Biodiesel is the most important biofuel used in the European Union, taking a 75% share [5]. Furthermore, global biodiesel production grew by 23% per year between 2005 and 2015, leading to a sevenfold expansion of the sector in a single decade [6].

In this scenario, the interest in the use of liquid biofuels and/or biodiesel in compression ignition engines has grown quickly in recent years [3].

A lot of studies have been carried out to evaluate the effects of biofuels on the performance and exhaust emissions of IC engines [7–15]. Sivakumar et al. [16] investigated the effect of aluminium oxide nanoparticles as additive to pongamia methyl ester (PME) blends on performance, combustion and emission of a single cylinder direct injection diesel engine. Canakci [17] compared the combustion characteristics and emissions of diesel fuel and biodiesel in a four-cylinder turbocharged DI diesel engine.

As known, a peculiar aspect, which could affect engine operation, is related to the cooling system: actually, it influences the combustion temperature in the engine, directly affecting performance and emissions. In addition, the cooling system also has an influence on the lubricating oil temperature and the exhaust recirculation gas temperature [18]. Moreover, considering that on four-strokes engines the scavenge period is used to cool the components, the amount of air processed during the valve overlap causes fuel consumption increasing, representing a loss: thus, if the valve temperature could be relevantly reduced, thanks to cooling enhancement, scavenge period could be reduced as well and specific fuel consumption improved [19–21].

Several studies have been carried out on the relationship between temperature of the engine coolant and engine performance/emission.

* Corresponding author.
E-mail address: gianpiero.colangelo@unisalento.it (G. Colangelo).

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Since 1988, Finlay [20] demonstrated that increasing and adjusting cylinder block wall temperature, acting on coolant temperature at the engine inlet, it is possible to reduce HC emissions. Ogawa et al. [23] reported that the HC emissions were 25% lower and NOx emissions were 7% higher when the coolant temperature increased. Pang et al. [24] demonstrated that low coolant temperature could reduce NOx emissions by up to 30%, with minor improvements to specific fuel consumption, Carbon monoxide (CO) and HC emissions. Torregrosa et al. [25] investigated the relationship between ignition delay and coolant temperature. Studying in depth these results, Rehman et al. [22] showed that raising the temperature of the coolant in the engine block could yield significant improvements in brake specific fuel consumption, with a corresponding reduction in the HC emissions. Similarly, lowering the coolant temperature in the cylinder head increases the knock limit of the engine, with a corresponding reduction in the levels of NOx in the exhaust emissions.

In another study, Hossain et al. [26] demonstrated how the different physico-chemical properties of biofuels, with respect to fossil diesel and gasoline, alter the effects of coolant temperature on combustion and exhaust emissions: this issue, has been rarely investigated so far.

Therefore, taking into account the role of coolant on engine emission and performance and that these parameters can be also related to the kind of fuel, in the present work an experimental investigation has been carried out, in order to evaluate how the use of nanofluids (*NFs*), as cooling fluid for biodiesel IC engine, could affect the heat transfer rate from the exhaust valve to the cooling bores.

Nanofluids are examples of innovative heat transfer fluids, in which nanometric particles (*NPs*) are used to improve heat transfer performance of traditional coolants like water, water-ethylene glycol blends, diathermic oil [27].

Several authors investigated on nanofluids thermal conductivity and their heat transfer capability as relevant factors in development of high thermal efficiency systems [27–29]. Nanofluids are liquid/solid suspensions, made of traditional heat transfer fluids (i.e. water, oil, glycol etc.) and nanoparticles of metal or metal oxide. The presence of nanoparticles enhances thermal conductivity that depends on volume fraction, particle size, material etc. of solid phase, as Colangelo et al. [30] showed experimentally with diathermic oil based nanofluids. Xie et al. [31], instead, compared experimental results to theoretical models, observing that the experimental results of thermal conductivity of nanofluids were higher than the ones obtained by theoretical correlations. Xue [32] obtained an increase of 20.0% of thermal conductivity with a concentration of 4.0%vol of CuO nanoparticles in ethylene glycol. Li et al. [33] experimentally showed that thermal conductivity of Al_2O_3-water nanofluid, with a concentration of 6.0%vol, increased 1.52 times. Minsta et al. [34] measured thermal conductivity of CuO-water and Al_2O_3-water nanofluids obtaining increase up to 24.0%, with a volume fraction of 14.0% of CuO nanoparticles. Yu et al. [35] obtained an increase of 26.5% measuring thermal conductivity of ZnO-ethylene glycol nanofluid at 5.0%vol concentration of solid phase. Wen et al. [36] carried out experimental investigations on Al_2O_3-water nanofluid flowing in a copper pipe in laminar conditions. They found enhancement of convective heat transfer up to 47.0%, with a volume fraction of 1.6%. Rashidi et al. [37] investigated Multiwall Carbon Nanotubes (MWCNT)-water nanofluid at weight fraction of 2.0% in a copper tube. Hwang et al. [38] found a convective heat transfer coefficient enhancement up to 8.0% with Al_2O_3-water nanofluid at 0.3%vol, measured in a stainless tube. Kim et al. [39] studied Al_2O_3-water nanofluid in a stainless tube with an inner diameter of 4.57 mm as well, obtaining an increase of heat transfer coefficient of 20.0%. Heyhat et al. [40] carried out an experimental investigation on convective heat transfer coefficient in a circular tube at constant wall temperature with Al_2O_3-water nanofluid, obtaining enhancements up to 23.0%.

The results on thermal conductivity and convective heat transfer coefficient lead scientific community to study stability of nanofluids, as Colangelo et al. [41], and their effects on engines cooling. Tzeng et al. [42] studied the effects of CuO and Al_2O_3 nanofluids on engine transmission oil at different engine operation setups. Bai et al. [43] analyzed an engine cooling system with nanofluid as heat transfer fluid with good results using Cu-water nanofluid. With a volume concentration of 5.0%, heat transfer capability increased by 44.1%. Marè et al. [44] obtained an increase of convective heat transfer coefficient of 42.0% and 50.0% with Al_2O_3-water nanofluid and Carbon Nanotubes (CNT)-water nanofluid, while Farajollahi et al. [45] investigated a shell and tube heat exchanger working with Al_2O_3-water and TiO_2-water nanofluids. Yousefi et al. [46] [47], investigated on thermal efficiency of a plate solar collector by using Al_2O_3-water nanofluid and MWCNT nanofluid as working fluids, finding enhancement of thermal efficiency. Colangelo et al. [48] built a modified plate solar collector and investigated on thermal efficiency by using water and Al_2O_3-water at 3.0%vol.

The present experimental campaign aimed at assessing whether the use of nanofluids in a biodiesel four-strokes engine could be a valuable solution to reduce its temperature. Particularly, several experimental tests have been carried out on the CAT-AVL single cylinder engine to compare the temperature achieved with pure water and CuO nanofluid as engine coolant.

2. Testing engine and equipment

The experimental tests were carried out by a CAT-AVL 4-strokes single cylinder engine, able to monitor and record all operating parameters, as engine load, exhaust gas temperature, intake air temperature, pressure and mass flow rate, coolant temperature and mass flow rate, etc. Table 1 summarizes the main characteristics of the CAT-AVL 4-strokes - single cylinder engine.

According to the main objective of this work, measurements of temperature close to the exhaust valve were performed by proper thermocouples (VS1, VS2, VS3), mounted around the exhaust valve seat in the cylinder head, as shown in Fig. 1.

The thermocouples VS1 was mounted in the cylinder head side (flame deck), in between the exhaust gas valves and the injector, the thermocouple VS2 was installed in between the exhaust valve and the inlet valve, while the thermocouple VS3 was placed within the exhaust valve seat, farther from the injector, towards the external side of the head of cylinder.

Additionally, 3 K-thermocouples, indicated as CB1, CB2 and CB3, were installed close to the cooling bore, as shown in Fig. 2, in order to measure the temperature gradient between the exhaust valve seat and the cooling bore surface (see Fig. 3).

Fig. 4 shows three cross sections of the head of cylinder with the positions of the thermocouples in between the exhaust valve seat and the cooling bore.

One thermocouple (VP1) was installed within the exhaust valve spindle in order to measure the temperature in the most critical point in terms of temperature, due to heat flux from combustion (Fig. 4).

Table 1
Main characteristics of the CAT-AVL 4-strokes single cylinder engine.

Nominal power/cylinder [kW]	52
Cylinder bore [mm]	137
Stroke [mm]	168