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Performance Study of Diesel Engine Using Nanofuel

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Abstract

Experimental investigation was carried out to study the engine performance and emission parameters of a single-cylinder Compression Ignition (CI) engine using nanofuels which were formulated by sonicating nanoparticles of aluminium in base diesel. Study of engine performance at higher loads revealed drop in peak cylinder pressures and reduction of 7% in specific fuel consumption for aluminium as compared to diesel. Improved combustion rates raised exhaust gas temperatures by 8% leading to increased brake thermal efficiency by 9%, as compared to diesel at maximum loading conditions. Volumetric reduction of 25–40% in CO emission, 8% in hydrocarbon emission was measured when the engine was fuelled with aluminium as compared to emissions from diesel. However, elevated temperatures resulted into marginal rise in NOx emission.

1. Introduction

Application of nanoscale energetic metal particle additives in liquid fuel is an interesting concept yet unexplored to its full potential. Such formulated nanofuels offer shortened ignition delay, decreased burn times and rapid oxidation which leads to complete combustion [1–3]. Overall calorific value of the liquid fuel increases due to higher energy density of metal particles, eventually improving the performance of engine by boosting power output. The study of evaporation rate and ignition probability plays an important role in determining two critical properties: ignition delay and ignition temperature which characterizes the performance of a diesel engine and are also instrumental in curtailing emissions [4]. Reports have shown that fuels blended with nanoparticles of aluminium, boron or carbon particles enhance ignition probability at lower temperatures as compared to diesel and initiate combustion thereby reducing ignition delay [5–8]. A crucial phenomenon involved in improving the combustion rate of the nanoparticle blended fuels is the disruption/micro-explosion behaviour of the fuel droplets and was first discovered by Takahashi et al. [9] for slurries of boron/JP-10. This behaviour was also evidenced by a few other studies involving aluminium, boron, iron and carbon slurries [10–13]. In order to ensure the feasibility of these derived fuels as commercial substitutes of conventional fuels, they were tested in diesel engine. Cited studies have shown reduced brake specific fuel consumption, smoke and NOx formation with combustion of Al nano-fluid in Compression Ignition (CI) engine [14, 15]. Aluminium nanopowder when blended with water/diesel emulsion fuel reacts with water at higher temperatures and generates hydrogen which promotes combustion in engine chamber [16].

Present investigation is focused on incorporating energetic metal nanoparticles of aluminium in petrodiesel as additives to accelerate combustion rates, reduce ignition delay, and boost calorific values. Engine performance, emissions and combustion attributes of CI engine also have been studied. The ensuing section aims to:

(i) Study performance characteristics of single-cylinder four-strokes Compression Ignition engine with nanofuels and compare them with diesel
(ii) Examine emissions and soot produced to investigate their environmental impact.

2. Experimental Procedure

2.1 Fuel formulation

Stable and homogeneous suspension of aluminium in base diesel was made using ultrasonication for 15 minutes, and addition of the surfactant. Composition of the fuel was nanoparticles 0.5 wt%, surfactant (0.1 wt%) and rest diesel. Physical properties of the nanofuel are given in Table 1.

Table: 1. Physical properties of nano-particles and nomenclature of selected nanofuels

Metal	Al
Particle size (nm)	5–150
Atomic mass (g/mol)	26.981
Bulk density (g/cm3)	2.7
Metal melting point (K)	933
Oxide formed	Al_2O_3
Oxide melting point (K)	2345

2.2 Compression Ignition Engine Test Setup

Engine performance was studied on a single-cylinder, four-stroke, constant speed (1500 rpm) direct injection diesel engine (Table 2). In order to determine the engine torque, test engine was coupled to eddy current type dynamometer. Setup also comprised of necessary instruments for combustion pressure and crank-angle measurements which were interpreted to generate P–θ diagrams. The stand-alone panel box of test setup consisted of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. The engine tests were performed initially with pure diesel at fully throttled and no-load conditions and then nanofuel was fed through a separate fuel feed line. Before running the engine to a new fuel, it was allowed to run for sufficient time to consume remaining fuel from the previous experiment. All the experiments were carried out by varying the loads at a constant speed of 1500 rpm to evaluate the performance

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characteristics such as specific fuel consumption (SFC), brake power (BP), exhaust gas temperature, Air/Fuel ratios, brake thermal efficiency (BTE), brake mean effective pressure (BMEP) and volumetric efficiency. Engine performance analysis software was used for online performance evaluation. More than three runs of tests were performed under the identical conditions, and the repeatability of all result parameters was found to be within 3%. Emissions of CO, NOx and HC were measured using an Exhaust Gas Analyzer (Table 2).

Table: 2. Specifications of Engine and Exhaust Gas Analyzer

Engine	**Kirloskar TV1**	
General details	Four-stroke, CI, vertical, water cooled, single-cylinder	
Bore x stroke	87.5 mm x 110 mm	
Compression ratio	17.5:1	
Capacity	661 cc	
Rated output	5.2 kW at 1500 rpm	
Dynamo meter	Eddy current, water cooled with loading unit	
Piezo sensor	Range 5000 PSI, with low noise cable	
Crank angle sensor	Resolution 1, speed 5500 RPM with TDC pulse.	
Temperature sensor	Type RTD, PT100 and thermocouple, Type K	
Load indicator Software	Digital, range 0–50 kg, supply 230 V AC	
Exhaust gas analyzer		
Parameters	Range	Accuracy
Oxygen (O2)	0–25 vol.%	0.1–0.2%
Carbonmonoxide (CO)	0–9.99 vol.%	±5% of reading
Hydrocarbon (HC)	0–10,000 ppm	±20 ppm
Carbondioxide (CO2)	0–19.9 vol.%	±0.3%

3. Results and Discussions

3.1 Combustion Characteristics

Fig. 1 elucidates variation in cylinder pressure with change in crank angle for nanofuel and diesel. The peak cylinder pressures at full load condition for the nanofuel and diesel were around 55 and 62 bars, respectively. Reduction in peak cylinder pressures was observed with nanofuel as compared to diesel. Nanofuel reduces the chemical delay period that exerts a great influence on the combustion phenomena of Compression Ignition engine as well as on the rate of pressure rise, because the longer the delay, more rapid and higher pressure rise occur [18]. Decline in the peak pressure is attributed to the fact that both physical and chemical delays decrease with addition of nanoparticles. Thus the improved ignition properties of energetic Al nanoparticles initiate early combustion and thereby reduce peak pressures.

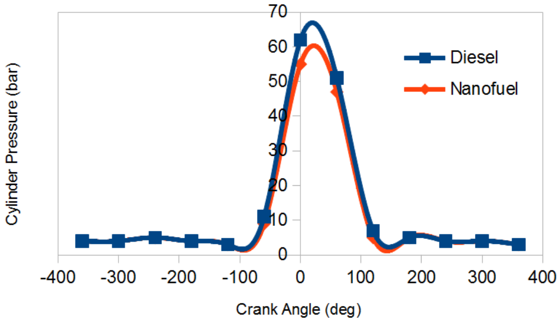

Figure 1: Variation of cylinder peak pressure for nanofuel.

3.2 Engine Performance Characteristics

The nanofuel showed marginal increase (fig 2) in fuel consumption as compared to diesel at lower loads due to preheating and ignition stages. A drop of 7% in specific fuel consumption was registered at higher loads when the engine was fuelled with nanofuel as compared to diesel. Reduced ignition delay and high calorific values of nanofuels further generate same intensity of work with low consumption of fuel than diesel.

Fig. 3 shows the increase in exhaust gas temperatures (EGT) of engine with load. It could be inferred from the figure that EGT increases with load for both diesel as well as nanofuel, obviously due to increase in the combustion temperature. The fragments of nanofuel droplets which are formed due to microexplosion of primary droplet generate secondary local flames which further increase chamber temperature. Rise in EGT at full load conditions has been observed as 9% for nanofuel as compared to diesel. Variation of brake thermal efficiency with load is shown in Fig. 4. The nanofuel exhibits better thermal efficiency mainly at higher load. These results could be explained with the assistance of the burning characteristics and increase in combustion temperature of the nanofuel. Addition of nanoparticles not only enhances the calorific values but also promotes complete combustion due to higher evaporation rates, reduced ignition delay, higher flame temperatures and prolonged flame sustenance. All these factors support the full release of thermal energy thereby leading to higher brake thermal efficiency. This phenomenon could have led to catalytic combustion, and in turn enhanced the thermal efficiency of the diesel engine [19, 20]. Enhancement of 9% in BTE has been observed at higher loads as compared to diesel.

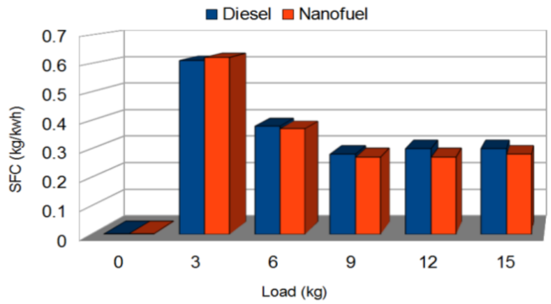

Figure 2: Specific fuel consumption of nanofuel with respect to diesel.

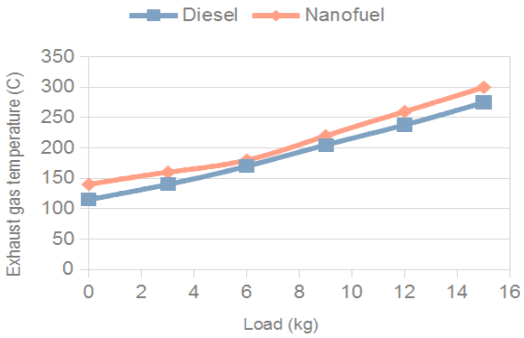

Figure 3: Exhaust gas temperature vs. load

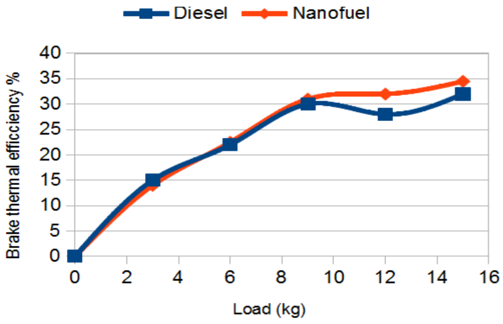

Figure 4: Brake thermal efficiency vs. load

Combustion promotes microexplosion of nanofuels droplets and leads to rise in cylinder pressure and temperature. Such conditions accelerate oxidation reactions leading to controlled combustion when two third of fuel burns followed by complete consumption during effective burning stage leaving behind 2–3% of unburnt HC [21]. Fuel-lean combustion at maximum loads leads to a drop of 8% in hydrocarbon emission with nanofuel as compared to diesel. Fig. 7 depicts NOx concentration as a function of load. NOx emission increased at higher loads when engine was fuelled with nanofuels. It could be argued that at the higher loads, burning temperatures in the combustion chamber increases with load and facilitates NOx emissions according to Zeldovich thermal mechanism [22]. An increase of 5% was observed in NOx emission with nanofuel as compared to diesel.

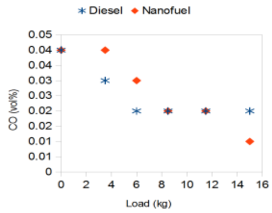

Figure 5: Carbon monoxide emission vs. load

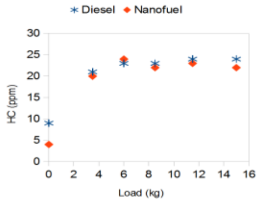

Figure 6: Hydrocarbon emissions vs. load

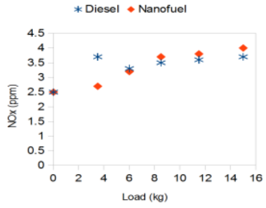

Figure 7: NOx emissions vs. load

4. Conclusions

Peak cylinder pressure decreased at full load conditions and was registered as 55 and 62 for nanofuel and diesel respectively. Engine performance parameter study revealed a noticeable reduction of 7% in specific fuel consumption with nanofuel in comparison to diesel for generating equivalent brake power. Exhaust gas temperatures rose by 9%, resulting into increase in brake thermal efficiencies by 9% compared to diesel at higher loads. At same loads, the emission study showed a decline of 25–40% in CO (vol.%), along with a drop of 8% in hydrocarbon emissions. Due to elevated temperatures a hike of 5% and 3% was observed in NOx emission.

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