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Nanofuels: Combustion, engine performance and emissions

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HIGHLIGHTS

- Stable suspensions of nano-particles of Al, Fe and B in diesel were used as fuels.
- These fuels showed reduced ignition delay, and longer flame sustenance.
- Specific fuel consumption reduced by 7% with nanoparticle modified fuels.
- Emissions of CO and hydrocarbons reduced, however NO_x marginally increased.

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ABSTRACT

Experimental investigation was carried out to study the burning characteristics, engine performance and emission parameters of a single-cylinder Compression Ignition (CI) engine using nanofuels which were formulated by sonicating nanoparticles of aluminum (A_1), iron (F_1) and boron (B_1) in base diesel. These fuels showed reduced ignition delay, longer flame sustenance and agglomerate ignition. Study of engine performance at higher loads revealed drop in peak cylinder pressures and reduction of 7% in specific fuel consumption for A_1 as compared to diesel. Improved combustion rates raised exhaust gas temperatures by 8%, 7% and 5% leading to increased brake thermal efficiencies by 9%, 4%, and 2% for A_1, F_1, and B_1 respectively, as compared to diesel at maximum loading conditions. Volumetric reduction of 25–40% in CO emission, 8% and 4% in hydrocarbon emission was measured when the engine was fueled with A_1 and F_1 respectively as compared to emissions from diesel. However, elevated temperatures resulted into marginal rise in NO_x 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 aluminum, 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/microexplosion behavior of the fuel droplets and was first discovered by Takahashi et al. [9] for slurries of boron/JP-10. This behavior was also evidenced by a few other studies involving aluminum, 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 NO_x formation with combustion of Al-nanofluid in Compression Ignition (CI) engine [14,15]. Aluminum 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 aluminum, iron and boron in petro-diesel 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) determine the evaporation rates and ignition probability of the formulated and stabilized nanofuels (ii) study different combustion stages to explore the burning mechanism of the nanofuel droplets, (iii) study performance characteristics of single-cylinder four-strokes Compression Ignition

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engine with nanofuels and compare them with diesel and (iv) examine emissions and soot produced to investigate their environmental impact.

2. Experimental methods

2.1. Fuel formulation

Stable and homogeneous suspension of iron, aluminum and boron (Nanoshel LLC, USA) in base diesel was made using ultrasonication (Sonics Vibra cell-USA, 750 W, 20 kHz) for 15 min, and addition of the surfactant Span80™ (Qualigen Chemicals, Mumbai, India). The most stable nanofuels with maximum particle loading were selected on the basis of backscattering profiles (Turbiscan classic MA 2000 (Formulaction, France). Compositions of the fuels was nanoparticles (*n*-Fe, *n*-Al or *n*-B) 0.5 wt%, Span80 (0.1 wt%) and rest diesel. Physical properties of nanoparticles (Nanoshel LLC, USA) and nomenclature of selected stable nanofuels are given in Table 1.

2.2. Droplet combustion experiment setup

Fig. 1 shows a schematic diagram of the droplet combustion experiment. Experiments were performed in a Zahabi make muffle furnace (microprocessor based temperature indicator cum controller) with heating range up to 1000 °C. Droplet of formulated fuels was made to fall with micropipette (dropper) on a small stainless steel plate placed inside the furnace where droplets ignited in air at atmospheric pressure. Sequence of droplet formation and its burning process was captured with a high-speed digital camera (NIKON D3X with a speed of ISO-600 at a resolution of 164–164 dpi). The camera was kept just in front for imaging the flame and droplet disruption. Front and side light arrangements were made using halogen lamps. A computer was synchronized with the high-speed digital camera to ensure the recording of droplet disruption photographs.

2.3. 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 $P–\theta$ 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

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

Metal	Particle size (nm)[a]	Atomic mass (g/mol)	Bulk density (g/cm^3)	Metal melting point (K)	Oxide formed	Oxide melting point (K)	Nomenclature of nanofuels
Fe	30–60	55.845	7.87	1811	Fe_2O_3	1839	F_1
Al	5–150	26.981	2.7	933	Al_2O_3	2345	A_1
B	80–100	10.811	2.34	2349	B_2O_3	723	B_1

[a] Data provided by the supplier.

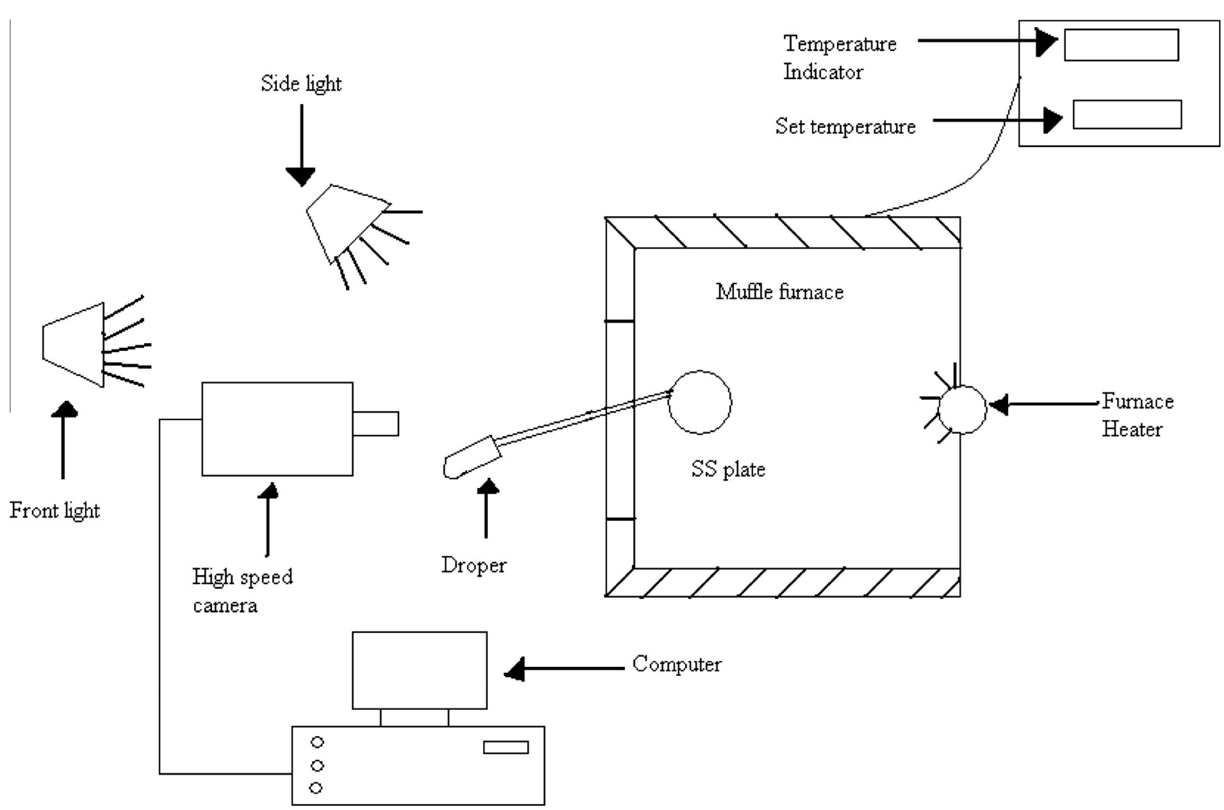

Fig. 1. Schematic diagram of the droplet combustion experiment setup.