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Puffing and micro-explosion of diesel–biodiesel–ethanol blends

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HIGHLIGHTS

- Ternary blends of diesel–biodiesel–ethanol droplet resulted in smooth burning puffing and micro-emulsion.
- Identified favourable composition of the blend that leads to micro-explosion of the droplet.
- Observed micro-explosion of secondary droplets resulted from puffing and explosion.

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ABSTRACT

The puffing and micro-explosion of a single burning droplet comprised of neat diesel, rapeseed methyl ester (RME); binary fuel mixtures of diesel–ethanol, diesel–RME, RME–ethanol; and ternary microemulsion of these fuel blends at various compositions have been studied using high speed backlight imaging method. Fuel droplet was suspended on the tip of a 130 μm gauge thermocouple and it was ignited using a glow plug heater. Based on the temporal variation of droplet projected area, the characteristics of fuel droplets studied were classified into smooth burning, puffing and explosion. A ternary plot has been proposed to identify the mixture composition of the blends that can result in smooth burning, puffing and explosion. Micro-explosion phenomenon was observed in the ternary blends with ethanol percentages between 10% and 40%. Secondary droplets resulted from the puffing and explosion of suspended parent droplet were observed to undergo further explosion. The time scales associated with complete disintegration of secondary droplets are found to be comparable to the mixing and the chemical reaction time scales of sprays in diesel engines.

1. Introduction

In recent times, search for alternative fuels has been intensified due to depleting fossil fuel reserves and environmental impacts. With the increasing concern of the environment and more stringent regulations on exhaust emissions, the reduction in engine emissions is a major research objective for engine development. Ethanol is an attractive alternative fuel because it can be a renewable bio-based resource and it has hydroxyl group, thereby providing the potential to reduce particulate emissions in compression ignition (CI) engines. Complete replacement of diesel with ethanol for CI engines is not a feasible solution due to differences in physical and chemical properties, which affects injection and combustion processes. Blending ethanol with diesel not only eliminates the modifications to the engine fuelling and combustion systems but also the reduction of carbon atoms in the fuel molecule helps in reducing soot emissions. However, due to poor miscibility of ethanol in diesel, only small amounts of ethanol (less than 5 vol.%) will form stable solution [1]. To prevent separation and to increase the ethanol content in diesel, a surfactant or an emulsifier should be used [2–5]. Fatty Acid Methyl Esters (FAME) could also be used as an amphiphile (a surface-active agent) to stabilize ethanol and diesel blends [2,6–11]. Oxygenated biofuels are also considered as one of the alternatives for CI engines [12–14]. Biodiesels are derived from biodegradable materials that can significantly reduce toxic emissions and the overall life cycle emission of carbon dioxide when burned as a fuel. Biodiesel contains FAME which could play emulsifier role when mixed with diesel–ethanol blends. Renewable nature of both ethanol and biodiesel makes diesel–bio diesel–ethanol blends a promising alternative fuel for diesel engines. Presence of biodiesel compensates the effect of ethanol on viscosity, density and lubricity of the ternary blended fuel [15]. In a detailed study on solubility of the diesel–biodiesel–ethanol blends, Kwanchareon et al. [7] concluded that water content

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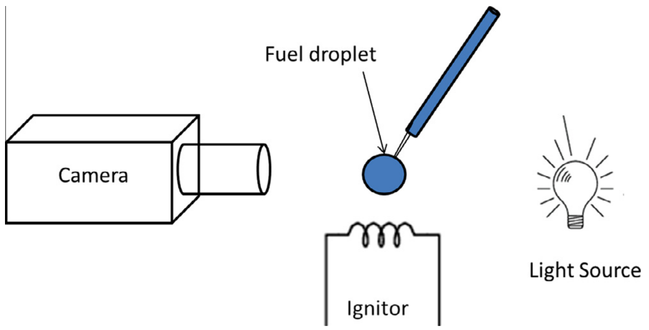

Fig. 1. Schematic of the experimental setup where droplet suspended on the thermocouple junction was ignited and back illuminated images of burning droplet were captured using high speed camera.

Table 1
Composition of binary fuels blends used in the study.

	Diesel (%)	RME (%)	Ethanol (%)
D90E10	90	0	10
D75E25	75	0	25
D50E50	50	0	50
BD90E10	0	90	10
BD75E25	0	75	25
BD50E50	0	50	50
BD25E75	0	25	75

in the ethanol triggers phase separation in blends. Hence, anhydrous ethanol should be used for better stability.

Studies have established that multicomponent fuel droplets with vastly different volatile components can explode violently during combustion [16,17]. During vaporisation or combustion of multicomponent fuel droplet, higher volatile fractions can reach thermodynamically metastable superheat temperatures and leads to bubble nucleation. Rapid expansion of the vapour inside the droplet results in either total or partial disintegration of the parent droplet. If the whole droplets disintegrate into smaller droplets this phenomenon is termed as 'micro-explosion' and it is termed 'puffing' in the event of vapour blowing out of the droplet surface along with fine stream of droplets [18]. Micro-explosion and puffing are beneficial in fuel sprays as it aids secondary atomization and there by enhances mixing of dispersed fuel spray [18]. Micro-explosion phenomenon has been observed in the water–diesel micro-emulsion fuels [19–25]. These studies show that the size and distribution of emulsion water droplets inside the parent diesel droplet affects micro-explosion significantly. Very limited studies in the literature are focused on studying micro-explosion in fuel droplets of diesel–biodiesel–ethanol blends [16].

This study focuses on exploring puffing and micro-explosion phenomenon using suspended droplets of diesel–biodiesel–ethanol blends. Various compositions of three fuels were studied to identify the composition that favours puffing and micro-explosion.

Table 2
Composition of ternary fuels blends used in the study.

	Diesel (%)	RME (%)	Ethanol (%)		Diesel (%)	RME (%)	Ethanol (%)
D80BD10E10	80	10	10	D70BD5E25	70	5	25
D70BD20E10	70	20	10	D50BD25E25	50	25	25
D60BD30E10	60	30	10	D60BD10E30	60	10	30
D50BD40E10	50	40	10	D35BD35E30	35	35	30
D80BD15E5	80	15	5	D50BD10E40	50	10	40
D90BD5E5	90	5	5	D55BD5E40	55	5	40
D70BD10E20	70	10	20	D40BD20E40	40	20	40
D60BD20E20	60	20	20	D40BD10E50	40	10	50
D50BD30E20	50	30	20	D30BD10E60	30	10	60

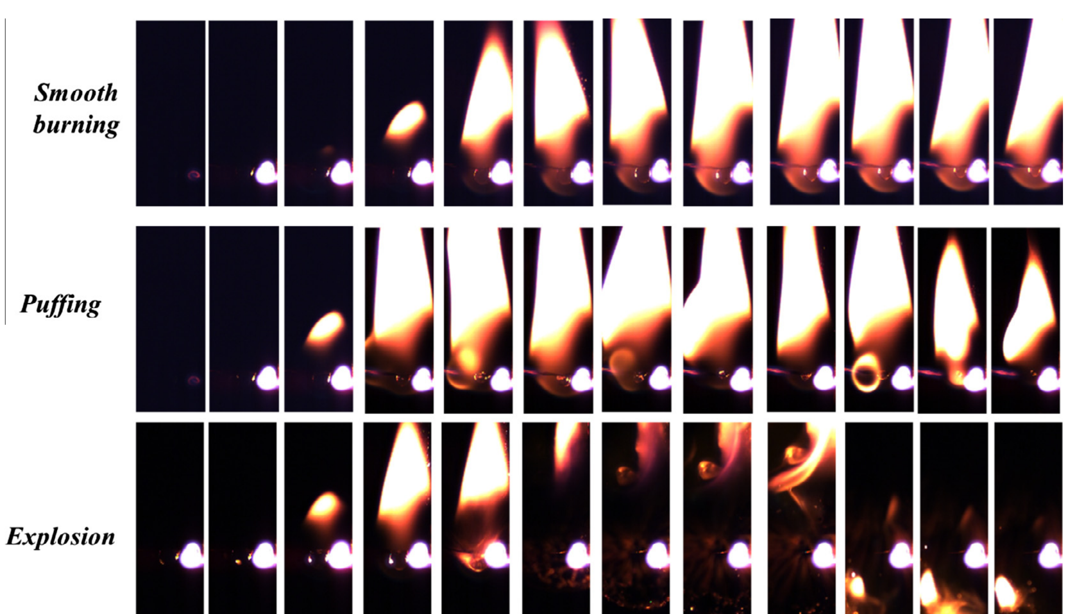

Fig. 2. Image sequence at random intervals, showing various phenomenon in combustion of micro emulsion droplets. No oscillations to the flame or droplet in case of smooth burning while flame and droplet oscillate in case of puffing. Droplet disintegrates and lifts the flame in case of explosion.