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Date Pit Methyl Ester Combustion and Emissions in a Single Cylinder Direct Injection Diesel Engine

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Abstract
Currently available biofuels for diesel engines are mainly generated from food crops, raising concerns that they do not result in net reductions of greenhouse gas emissions throughout the full production to use lifetime. The lipid content of organic waste streams from food crop production may be used to make sustainable diesel fuel. Using a contemporary direct injection diesel engine, this study investigates the combustion and emissions of biodiesel (fatty acid methyl esters) generated from waste date pits. Unblended date pit methyl esters were evaluated against rapeseed and soybean methyl esters as well as a reference fossil diesel, at constant injection and ignition timing at 1200 rpm. Datum pit esters had a considerably shorter mean alkyl moiety chain length and fewer double bonds than rapeseed or soybean biodiesel. Date pit methyl esters had a greater premixed burn percentage and peak heat release rate than rapeseed and soybean methyl esters. The unblended date pit methyl esters had the lowest NOx exhaust emissions, indicating that adiabatic flame temperature influences rates of thermal NOx generation more than global in-cylinder temperatures. All of the methyl esters examined had reduced particle emissions compared to the reference fossil diesel and Oman diesel.
Keywords: Biofuel, Waste date pit, Diesel

Introduction

Understanding the potentially catastrophic consequences of human climate change and the role of fossil fuel use in global warming has fueled the development of new energy sources [1–3]. With the rise of hybrid and electric cars [4–6], liquid fuels will likely remain a significant energy vector in transportation, particularly for heavy duty vehicles [7]. Since the early 1990s, IC engine exhaust pollutants (NOx and PM) have been widely recognised as harmful to human health, especially when produced by diesel engines [8,9]. Thus, sustainable renewable fuels for compression ignition combustion are required, both in terms of production and end-use exhaust emissions.

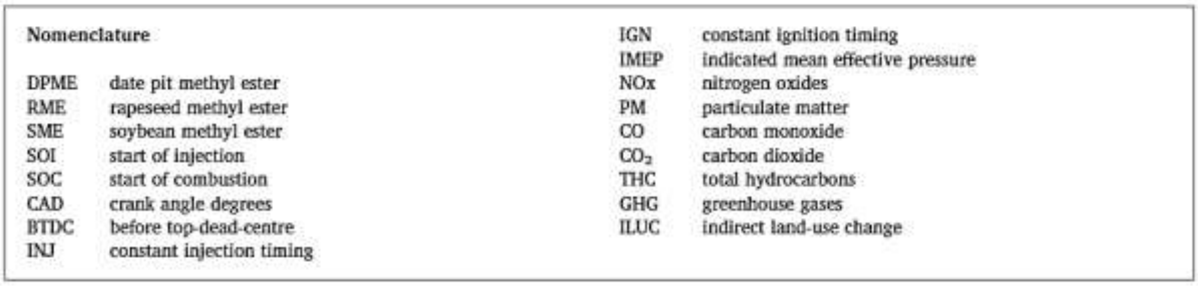
While legal goals for renewable transportation fuels have been in place for some time, such as in the EU [10], the US [11], and China [12], it is increasingly becoming clear that alternative fuel production should not compete with food crop production. In the EU, this has led in a cap on the amount of food crop biofuels allowed in road ILUC [13].

Biodiesel is the most frequently used alternative to fossil diesel for compression ignition combustion, and is produced in the European Union primarily from rapeseed, sunflower, and to a lesser degree soybean oils [14]. While straight vegetable oils like these [15,16] were widely used in the 1980s, problems including fuel injector coking, combustion chamber deposits, piston ring sticking, thickening and dilution of engine lubricating oil were observed. Identifying oils appropriate for biodiesel generation, synthesising and evaluating the resulting fatty acid esters has been the topic of numerous research and reviews [19–26].

Many studies have explored non-edible crops with lipid levels appropriate for biodiesel synthesis [27,28], such as Jatropha curcas L., a poisonous shrub or tree whose seeds contain up to 50% m/m glycerides [29]. On the other hand, Schönborn et al. [30] found that jatropha oil methyl esters (JME) have comparable ignite properties to palm methyl esters, but emit more nucleation mode particles due to the presence of long chain and high boiling temperature lignoceric esters (C24:0). Lifecycle study indicates that the prospective reductions in global warming potential (GWP) with biodiesel production from jatropha are similarly equivalent to those obtained with biodiesel production from food crops such as sunflower, soy, and rapeseed [32,33].

An option to using food crop oils for biodiesel production is using waste edible cooking oils [34,35]. These waste oils contain high amounts of free fatty acids (FFA), requiring a two-step transesterification procedure and resulting in lower ester yields than unused oils [37–39]. Wu et al. [40] showed that waste cooking oil methyl esters had comparable ignition properties to food crop methyl esters, but a lower reduction in particulate matter emissions than fossil diesel. Many culinary wastes and leftovers, such as wasted coffee grounds [41–43] and date pits (or seeds) [44–48], include lipids appropriate for biodiesel production. The date palm is primarily grown in hot, dry areas, with GCC countries producing the most [49,50]. Various solvent extraction methods have reported maximum oil yields of 10.36-16.5 percent from dried and powdered date pits [45,46]. Date pit biodiesel has been shown to have physical characteristics that are substantially within the range needed by law [46]. Chapagain et al. [44] extracted methyl and ethyl fatty acid esters from desert date oil kernels. The resulting biodiesel had a comparable fatty acid profile to soybean oil (mostly C16:0 to C18:2) and was tested in a light-duty diesel engine alongside a reference fossil diesel and a B5 mix of the two fuels. While the engine load was not consistent throughout the testing, overall reductions in NO emissions and increased CO levels at 1200 rpm (but not at 2200 rpm) were seen. Several studies have shown links between fatty acid profiles of esters from different oils and combustion performance and emissions of contemporary diesel engines. Schönborn et al. [30] observed that increasing fatty acid moiety alkyl chain length and degree of saturation decreased the duration of ignition delay, and that this change in ignition delay was the main impact of ester molecular structure on NOx exhaust emissions. Pinzi et al. [51] found an increase in emissions of total hydrocarbons (THC), CO, and PM with increasing ester alkyl chain length. As alkyl chain length increased, so did the boiling point of CO and THC, while decreasing the relative amount of fuel bound oxygen resulted in greater PM emissions. Benjumea et al. [52] tested engines with various ratios of highly saturated palm oil FAME and unsaturated linseed oil FAME. The rise in NOx emissions with decreasing saturation (increase in double bonds) was attributable to an increase in ignition delay time and premixed burn percentage. Zhu et al. [53] evaluated five single component fatty acid esters at various engine speeds and loads as 40% v/v blends with a fossil diesel.

The duration of ignition delay decreased with increasing ester alkyl chain length (and saturation), resulting in increased HC, CO, and smoke emissions while decreasing NOx emissions. This paper reports the first detailed results of combustion experiments using waste date pit methyl esters (DPME) in a single-cylinder direct injection compression ignition engine, to compare the combustion and emissions of biodiesel produced from DPME to other commonly used feedstocks (RME and SME).Each biodiesel evaluated in the study engine was mixed with a reference fossil diesel and compared to a fossil diesel available commercially in Oman.encouraging the use of advanced biofuels and waste feedstocks that minimise negative environmental impacts.



Nomenclature

DPME	date pit methyl ester
RME	rapeseed methyl ester
SME	soybean methyl ester
SOI	start of injection
SOC	start of combustion
CAD	crank angle degrees
BTDC	before top-dead-centre
INJ	constant injection timing
IGN	constant ignition timing
IMEP	indicated mean effective pressure
NOx	nitrogen oxides
PM	particulate matter
CO	carbon monoxide
CO_2	carbon dioxide
THC	total hydrocarbons
GHG	greenhouse gases
ILUC	indirect land-use change

2. Experimentation

2.1 Apparatus for engine and emissions testing

All of the combustion tests detailed here used a modern direct injection diesel engine modified to a single cylinder research engine. We used a new low volume fuel system for high pressure direct injection (100–250 mL sample fuel at 1600 bar) since date pit methyl esters were scarce. The author has previously detailed the engine test facilities and experimental methods [54–56]. Throughout all tests, the low volume fuel system and sample fuel lines were kept at 30°C, and the engine was normally aspirated using air at ambient temperature and pressure. Table 1 details the engine's specs, while Fig. 1 depicts the low volume fuel system's schematic operation.

The exhaust gas composition was measured for all experiments using an automobile gas analyser system (Horiba MEXA9100 HEGR) and a rapid particulate spectrometer (Cambustion DMS 500); the technical and measurement specifications of the exhaust emissions analysers are provided in Tables 2 and 3. It was done 180mm downstream of the exhaust valves, with the sampled gas going via a heated pipe at 190°C to the automotive gas analyser equipment. The heated line also served as a sampling point for particle measurements, with a dilution cyclone placed between the engine exhaust and the heated line. Exhaust gases were diluted 5:1 here, and then 200:1 in the analyzer. The sample line and both dilution cyclones were kept at 75°C.

2.2. Fuels studied

They were evaluated as unblended biodiesel and blended with a 0% FAME reference fossil diesel. Date pit methyl esters (DPME) were produced by Soxhlet extraction of lipids from dried and powdered date pits, followed by base catalysed transesterification with methanol (after rotational evaporation of the recovered lipids from the solvent used) [46]. Its acid value was 3.1 mg KOH/g oil, its Free Fatty Acid content 1.55 percent, its Saponification value 236 mg KOH/g oil, and its density 910 kg/m3 at 25°C. A commercially available diesel fuel from Oman (obtained from Oman Oil) was also evaluated as a reference fuel. To demonstrate the relative performance of a commercially available diesel fuel near a possible source of waste date pits for oil extraction and biodiesel production [50], the Oman diesel was included in the research.

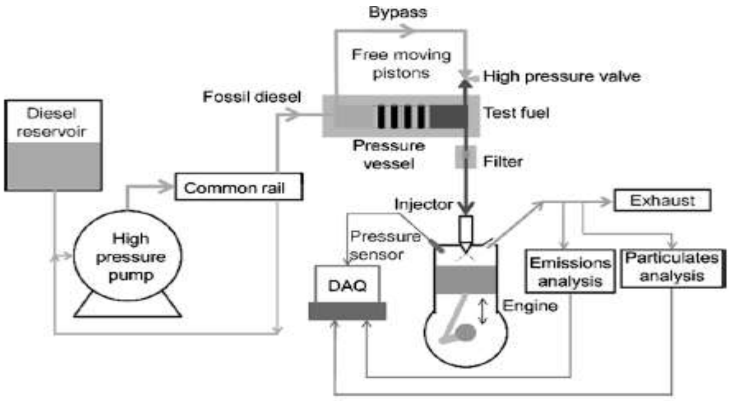


Fig. 1. Schematic showing operation of the low volume fuel system.

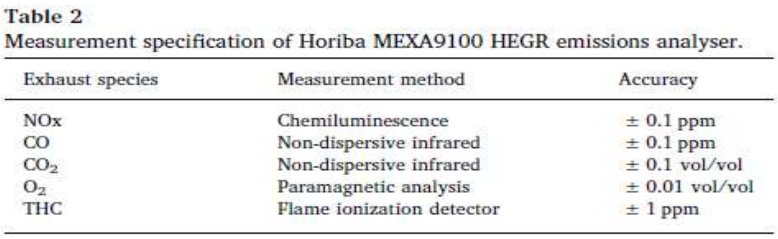


Table 2
Measurement specification of Horiba MEXA9100 HEGR emissions analyser.

Exhaust species	Measurement method	Accuracy
NOx	Chemiluminescence	± 0.1 ppm
CO	Non-dispersive infrared	± 0.1 ppm
CO_2	Non-dispersive infrared	± 0.1 vol/vol
O_2	Paramagnetic analysis	± 0.01 vol/vol
THC	Flame ionization detector	± 1 ppm

3. Result and discussion

Pressure and perceived net heat release rates

A constant injection and ignition timing were used to measure the in-cylinder pressure and apparent net heat release rates of the various methyl esters and reference diesel mixes. The reference fossil diesel generated greater in-cylinder pressures than all other test fuels, but unblended methyl esters consistently released the least peak heat (Fig. 2). Unblended methyl esters also release more heat during diffusion (or mixing rate regulated) combustion, which is consistent with prior research on both single component methyl esters and biodiesels (FAME mixes) [30,55,60]. Also, at constant injection time, DPME heat release rates rise higher than SME or RME after SOC .

4. Conclusion

The following conclusions may be derived from testing of date pit methyl esters in a modern direct injection diesel engine:

1. Despite its greater cetane number, DPME had a comparable ignition delay as RME and SME, both as pure methyl esters and as 20% v/v mixes with a reference fossil diesel.

The reduced mean number of double bonds in the date pit methyl esters offset the shorter mean alkyl moiety of DPME compared to RME and SME.

2. DPME had higher peak heat release rates than RME or SME, with a quicker rise in heat release rates after combustion. With respect to the cetane numbers of the methyl esters, an effect on the length of ignition delay, and thus time available for fuel and air premixing, is not immediately evident.

3. Unblended DPME produced the least NOx at constant injection and ignition time. The DPME's greater peak heat release rates and in-cylinder maximum global temperatures than RME and SME were anticipated to enhance thermal NOx generation rates.

The DPME's shorter alkyl moiety chain length and lower mean number of double bonds than other esters may have resulted in lower adiabatic flame temperature, lower local temperatures, and lower NOx generation rates.

4. Unblended DPME and RME had the greatest CO and THC emissions at constant ignition timing, perhaps due to lower local temperatures indicated by DPME's low NOx emissions and RME's greater viscosity.

5. Unblended methyl esters had lower levels of exhaust particulate matter than either reference fossil diesel or methyl ester/reference diesel blends. The proportional variations in

fatty acid ester composition had no effect on total particle mass emitted, however unblended DMPE had lower particle number emissions (100-200 nm) than all other fuels examined.

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