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Comparative properties and utilization of un-preheated degummed/esterified mixed crude palm oil-diesel blends in an agricultural engine

Theerayut Leevijit [a, *], Gumpon Prateepchaikul [a], Kittinan Maliwan [a], Parinya Mompiboon [b], Suppakit Eiadtrong [a]

[a] Department of Mechanical Engineering, Prince of Songkla University, Hat Yai, Songkhla, 90112, Thailand
[b] Faculty of Industrial Technology, Nakhon Si Thammarat Rajabhat University, Mueang, Nakhon Si Thammarat, 80280, Thailand

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ABSTRACT

The production, property, and utilization of un-preheated degummed/esterified mixed crude palm oil (D_gMCPO/EMCPO)-diesel blends in an agricultural engine were studied. The results reveal that D_gMCPO and EMCPO can be produced easily with costs comparable to diesel. They had a poor liquid phase and high viscosity. Through blending with diesel at maximum portions of 20 vol% (D_gMCPO20) and 30 vol% (EMCPO30), clear liquid blends were produced. Almost important fuel properties of these blends met Thailand agricultural engine diesel standard with slightly higher densities and viscosities than diesel, significantly higher oxygen content than diesel, good cetane numbers, and slightly lower heating values than diesel. At 2200 rpm under loads in the range of 1.28–5.6 kW, un-preheated blends were able to well operate the engine as same as diesel. Comparing this with diesel; the blends resulted in slightly higher brake specific fuel consumptions (+4.5% and +5.0%), slightly lower brake thermal efficiencies (−0.9% and −1.2%), significantly lower levels of carbon monoxide (−33.7% and −33.2%), slightly lower exhaust gas temperatures (−5.1% and −5.5%), and significantly higher levels of nitrogen oxides (+8.9% and +15.9%); (all paired values, D_gMCPO20 and EMCPO30 respectively). In conclusion, these blends are recommended as effective diesel substitutes for use in agricultural engines.

1. Introduction

Presently, due to the fast depletion of fossil fuels and worsening environmental problems related to fossil fuel use, many research programs attempting to utilize various grades of diesel substitute made from vegetable oils (VOs) are being intensively conducted around the world [1–14]. Thailand has a largely agriculture based economy and has to import diesel. The highest potential feedstock for the production of diesel substitute in Thailand is oil from palm fruits. Among various types of palm oil, because mixed crude palm oil (MCPO) can be easily produced with a screw-press of whole dried palm fruits, it has become of interest as another form of feedstock for diesel substitute production, especially for farmers living in or near sufficient economic communities. Thus, development of an easily produced, cheap, and easily used diesel substitute from MCPO is much valuable for farmers in Thailand.

Although the cost of MCPO is low, its use in engines with and without blending with diesel may be unsatisfactory because, like other VOs, MCPO is a viscous liquid containing grease, gum, and free fatty acids (FFAs). Its combustion property is not a main problem because a cetane number of palm oil (≈42) [11,14,15] falls within the suitable range of 40–65 for diesel engines [16]. But, the main drawback of MCPO is its flow properties since high viscosity leads to problems such as poor atomization, incomplete combustion, injector choking, ring carbonization, and accumulation of fuel in lubricating oil. The grease and gum content of MCPO cause an increase in viscosity and cause filter and injector nozzle plugging, and high FFAs also increase viscosity and may result in excessive corrosion.

Nevertheless, the flow properties of MCPO can be improved by at least four methods of degumming, degumming and deacidifying, esterification, and esterification and transesterification. In degumming, the gum is eliminated while its oil composition is unchanged to produce degummed MCPO (D_gMCPO). In degumming and deacidifying, both the gum and the FFAs are eliminated producing a diesel substitute mainly consisting of triglycerides (TG)

* Corresponding author.
E-mail address: leetheerayut@yahoo.com (T. Leevijit).

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called degummed-deacidified MCPO (D_{g-a}MCPO) [17]. In esterification of MCPO with methanol, the FFAs and a part of the TG are changed into methyl esters (MEs) while the gum is simultaneously eliminated producing esterified MCPO (EMCPO). In esterification and transesterification of MCPO with a large amount of methanol, the gum is eliminated and the oil composition is changed into MEs [18], in which the properties of MEs are quite similar to diesel [11,12,14,18]. However, the production costs of D_{g-a}MCPO and MEs are higher than the commercial diesel price by 52% and 27%, respectively. Thus, the processes of degumming in which no FFAs are lost and esterification with a small amount of methanol are of interest as more better methods for producing cheap diesel substitutes from MCPO.

In addition, Sanjid et al. [3] reviewed the findings of researches in the recent past which has attempted to utilize various diesel substitutes made from palm oil in diesel engines with or without blending them with diesel and with or without preheating as summarized in Table 1. The different results relating to engine performance and emissions have been found due mainly to variations in the raw materials, production processes, physicochemical properties, operation conditions, and engine features. Thus, to ensure that a particular diesel substitute can be utilized in any engine type, its production, fuel properties, and engine performance should be investigated.

Up to date, however, there have been no studies of the utilization of D_gMCPO and EMCPO in either agricultural or automotive engines. Therefore, the research presented in this paper aimed to investigate the utilization of D_gMCPO-diesel and EMCPO-diesel blends in an agricultural diesel engine without preheating or engine modification. In this work, the production and cost of D_gMCPO and EMCPO were studied, their blending potentials in diesel for unpreheated use were evaluated, compositions and important fuel properties of the blends of interest were determined, and a comparative engine performance test of an indirect injection (IDI) agricultural engine operated with the blends of interest and diesel was examined.

2. Materials and methods

The MCPO used in this research was purchased from Rung-Ruang-Kij Oil Incs., Songkhla, Thailand. Commercial grades (purities of 97–98 wt%) of phosphoric acid (H_3PO_4), sulfuric acid (H_2SO_4), and methanol (CH_3OH) were used for producing D_gMCPO and EMCPO. High speed diesel (HSD) was used for preparing the blends. Containing molecules of TG, diglycerides (DG), monoglycerides (MG), FFA, and ME in MCPO derived fuels were analyzed by Thin Layer Chromatography/Flame Ionization Detector (TLC/FID). Fatty acid compositions of MCPO were analyzed by Gas Chromatography/Flame Ionization Detector (GC/FID).

The cetane number of the blend of interest according to ASTM D613 was tested at the PTT Research & Technology Institute, Thailand. Other important fuel properties of the blends of interest and diesel including density, kinematic viscosity, higher heating value, flash point, cloud point, pour point, carbon residual, sulfate ash, acid value, and copper strip corrosion according to ASTM D1298, ASTM D445, ASTM D240, ASTM D93, ASTM D2500, ASTM D97, ASTM D189, ASTM D482, ASTM D664, and ASTM D130, respectively, were tested at the Scientific Equipment Center and the Chemical Engineering Laboratories, Prince of Songkla University, Thailand.

A second-hand agricultural engine (Kubota RT80) was used in this research. Its specifications are listed in Table 2. The engine was tested on a 12 hp PLINT & PARTNER dynamometer using a constant speed test at an engine speed of 2200 rpm under loads in the range of 1.28–5.60 kW (0.15–0.66 MPa in term of brake mean effective pressure: BMEP). For each test, the engine was well warmed up before starting the test. The experiments were repeated 3 times and the averaged results are reported herein. Based on available

Table 2
Test engine specifications.

Engine type	4-stroke compression ignition
Compression ratio	23: 1
Number of cylinder	1
Cylinder arrangement	Horizontal
Bore/stroke	84 mm/84 mm
Displacement volume	465 cm^3
Method of charging	Naturally aspirated
Maximum power (new engine)	5.9 kW at 2400 rpm
Maximum torque (new engine)	2.8 kg m at 1600 rpm
Injection type	IDI-mechanically controlled
Injection pressure	13.7 MPa
Cooling type	Water

Table 1
Research findings of different performance and emission for palm biofuels; this table was modified from the work of Sanjid et al. [3].

Part A: Performance parameter	
BSFC increase	Blended [19–21], Preheated [15], Degummed deacidified crude blended [17], Methyl and ethyl ester of palm oil [21], Biodiesel [22]
BSFC decrease	–
BTE increase	Preheated [15], Blended [21], Biodiesel [23]
BTE decrease	Degummed deacidified crude blended [17], Methyl and ethyl ester of palm oil [21], Biodiesel [22]
Brake power increase	Blended with additive [24]
Brake power decrease	Blended [20]
Part B: Emission	
EGT increase	Preheated [15], Preheated [21], Blended [20], Methyl and ethyl ester of palm oil [21]
EGT decrease	Degummed deacidified crude blended [17], Blended [21]
Smoke increase	–
Smoke decrease	Degummed deacidified crude blended [17], Biodiesel [22,25]
Carbon monoxide increase	Preheated [15,21], Blended [20,21], Methyl and ethyl ester of palm oil [21]
Carbon monoxide decrease	Degummed deacidified crude blended [17], Blended with additive [24], Preheated crude [26], Biodiesel [23]
Hydrocarbon increase	Preheated [15], Blended [21]
Hydrocarbon decrease	Methyl and ethyl ester of palm oil [21], Preheated [21], Blended with additive [24], Preheated crude [26], Biodiesel [23]
Oxides of nitrogen increase	Degummed deacidified crude blended [17], Preheated crude [26,27], Blended [21], Biodiesel [22,23,25]
Oxides of nitrogen decrease	Blended [20], Preheated [15], Blended with additive [24], Methyl and ethyl ester of palm oil [21], Emulsified [24]
Carbon dioxide increase	Preheated [15]
Carbon dioxide decrease	–
Particulate matter increase	Emulsified [24]
Particulate matter decrease	Preheated crude [26], Blended [19], Degummed deacidified crude blended [28]

BSFC: brake specific fuel consumption; BTE: brake thermal efficiency; EGT: exhaust gas temperature.