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Experimental investigation of utilization of Soya soap stock based acid oil biodiesel in an automotive compression ignition engine

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HIGHLIGHTS

- Acid oil biodiesel (B100) contains 72.3% of unsaturated fatty acids (oleic and linoleic).
- Power drop with B100 is in the range from 1.3% to 15.9%.
- NOx emission with B100 is higher than base diesel.
- NOx emission is higher with maximum torque than maximum speed.
- CO, HC, CO_2 and smoke emission are less with B100.

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ABSTRACT

An experimental investigation was carried out in an automotive diesel engine with 5.59 kW rated power in order to analyse the effect of soya soap stock based acid oil biodiesel on engine's performance, combustion, and emissions characteristics at maximum torque and power conditions. The measured physico-chemical properties show the acid oil biodiesel is mainly composed of 72.3% unsaturated fatty acids and it meets the desired fuel quality for automotive diesel engine. Carbon mono oxide, unburnt hydrocarbon and Smoke emissions with acid oil biodiesel decreased significantly however oxides of nitrogen emission increased in the range from 12% to 38%. In addition to this, power output also dropped marginally and thermal efficiency decreased. The peak in-line fuel pressure and in-cylinder temperature are higher with acid oil biodiesel than base diesel. The results emerged from this study indicate the acid oil biodiesel can be a potential fuel for automotive compression ignition engines.

1. Introduction

Biodiesel is mainly produced from the feedstocks including vegetable oils, animal fats and algae. Utilization of biodiesel in diesel engines is not getting momentum due to its higher cost. The price of the feedstock typically accounts for 75% of the cost of production of biodiesel [1]. Biodiesel is produced from variety of feed stocks including non-edible and edible oils, animal fat, and algae biomass. The main challenge is what type of feedstock to be used for biodiesel production to make it sustainable energy system. For example, use of edible oil as a feedstock for biodiesel production may lead to food scarcity; the production of non-edible oil is expensive and not sufficient to meet the demand of biodiesel; the lower-cost feed stocks such as used cooking oil and waste (soap stock) from the refining of vegetable oil (Acid oil) are lucrative alternatives but their availability are less. In this background, soap stock is an alternative feedstock as it is a by-product generated during refining of vegetable oil. So far, soap stock is used as a raw material for low quality soap production. Instead of its application for producing low quality product, it will be better to utilize it for production of biodiesel which is a valuable and costlier product. The comparison of cost for different edible oils (groundnut, peanut etc.), karanja oil (non-edible oil) and soya based acid oil is given in Table 1 [2–4]. The transesterification cost for all the biodiesel will be almost same. The energy input is needed for extracting oil from the seed and converting oil into biodiesel through transesterification process. It may be noted that the more energy input is required to extract oil from seed biomass than acidification of soap stock into oil. The energy required for transestrification process for acid oil biodiesel and other oil based biodiesel is same. Therefore, the cost of soap stock based acid oil biodiesel is relatively less than other biodiesel.

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Nomenclature

B	isentropic bulk modulus of fuel
BMEP	brake mean effective pressure of engine
BTE	brake thermal efficiency
B100	100% biodiesel
B 5	blend of 5% biodiesel and 95% diesel
°CA	degree crank angle
CO	carbon mono oxide
CO_2	carbon di oxide
HC	hydrocarbon
ITE	indicated thermal efficiency
NOx	Oxides of Nitrogen
CV	calorific value of fuel
P	indicated power
η	thermal efficiency
m_f	mass flow rate of fuel
N	speed of engine
T	torque produced by engine
L	piston stroke
A	area of cylinder
K	Kelvin

Table 1
Price of domestic and imported oils available according to local market [1,2.3].

Sno.	Oil	Price per kg (2015) in rupees	Price per kg (2017) in rupees
1	Groundnut	100	98
2	Rapseed	83.5	79
3	Sunflower	60.5	66
4	Linseed	78	90
5	Washed cottonseed oil	59	68.5
6	Castor oil	82.5	83.5
7	Karanja oil	60	65
8	Palm fatty acid distillate	–	46.5
9	Soya acid oil	–	36.5

It is reported in literature that saponification with soap stock is the major problem which leads to a lower conversion rate and poor fuel quality. High moisture content and free fatty acid content are the main reasons for saponification. But, this problem could be resolved by pre-treatment of the feedstock to achieve moisture level and free fatty acid component which are less than 0.06% and 0.5 by weight respectively [5]. Yan et al. proposed a method including pre-treatment using molecular distillation to separate fatty acids and glycerides. This process was followed by esterification (with the help of reusable and recyclable solid super acid catalyst which has increased the conversion efficiency up to 98.2%) and transesterification (with conversion efficiency of 97.25%) [6]. Erzheng et al. proposed one stage lipase catalysed methanolysis to improve the yield of production of soap stock based biodiesel. This process for the production of biodiesel is green, simple and efficient [7]. Haas reported that methyl ester prepared from soy soap stock consist of predominantly oleic, palmetic, stearic, linoleic and linolenic acids [8].

Usta et al. reported the effect of different biodiesel-diesel blends (B5, B10, B15, B17.5 and B25) produced from the feed stock of Hazelnut soap stock/waste sunflower oil on performance of a multi-cylinder turbocharged indirect injection diesel engine. They concluded that the engine with B17.5 produces the maximum power and thermal efficiency [9]. Keskin et al. studied the effects of different biodiesel (feed stock: Cottonseed soap stock)-diesel blends (B20, B40 and B60) on performance of single cylinder direct injection diesel engine and concluded that power output and torque decreased by 6.2% and 5.8% respectively [10]. Ozturk reported the effects of B5 and B10 (Canola oil and Hazelnut soap stock (80/20 v/v) on injection, combustion, performance and emissions of an automotive single cylinder direct injection diesel engine (5.4 kW) and concluded that there is a marginal change in brake specific energy consumption whereas injection delay, ignition delay and the maximum heat release rate are less. Longer injection and combustion duration is also reported. The combustion with B5 is better due to fuel embedded oxygen resulting in increase in Oxides of Nitrogen (NOx) emission and decrease in unburnt hydrocarbon (HC), carbon mono oxide (CO) and smoke emissions. However, the trend is different with B10 as they reported that HC and smoke emissions increased while NOx emission decreased with this blend [11]. Roy et al. studied the effect of B5 and B20 (canola biodiesel) on performance and emissions of 12.2 kW diesel engine and reported that the results are similar to diesel [12].

HC, CO and CO_2 emissions with B100 decreased whereas NOx emission increased by 10% [8]. CO and CO_2 emissions except NOx with different biodiesel-diesel blends (B5, B10, B15, B17.5 and B25) produced from feedstock of Hazelnut soap stock/waste sunflower oil were reported similar to base diesel and a slight decrease in noise (less than 1 db at a distance of 1 m) was also observed [9]. The particulate matter emission with Cotton seed soap stock biodiesel decreased about 46% at higher torque [10]. It is reported that the B5 and B10 of biodiesel prepared from the feedstock of mixture of soap stock and Canola (20/80 v/v%), emissions including NOx reduced for B10 [11]. The similar results were also reported by Roy et al. for B20 of canola biodiesel [12]. It seems that the biodiesel prepared by Ozturk may have the dominance of canola oil biodiesel because the biodiesel contains only 20% of soap stock.

Literature information indicates that biodiesel fuelled engine would run with less particulate matter, CO and HC emissions. However, NOx emission would increase significantly. The main reasons for increase in NOx emission reported in literature are due to advancement of the combustion phasing [13], higher combustion temperatures, oxygen content of biodiesel and different chemical composition of diesel and biodiesel as compared to base petro-diesel [14]. Reduction in particulate matter emission with biodiesel fuelled engine operation is attributed due to higher oxygen content of biodiesel [13–15]. Thangraja et al. reviewed control strategy for NOx emission for the engines operating with alternative fuels. They concluded that even the well-established technology "EGR" is not sufficient for the NOx reduction because it increases smoke, HC and CO emissions along with reduction in power output and deterioration of lubricating oil. They concluded that the combined technologies such as retarding of injection timing and EGR could give the desired results [16]. It is also reported that the reasons for all the regulated and unregulated emissions for biodiesel mainly depend on the combustion of the fuel [17]. Therefore, it is very important to analyse the effect of an alternative fuel on combustion characteristic of the engine, so that the possible modification in the engine could be suggested.

Few studies in literature are available on soap stock based Acid Biodiesel (B100) produced from the waste feedstock of refined vegetable oil and its utilization in diesel engines. No studies on