Iranica Journal of Energy & Environment

Journal Homepage: www.ijee.net

IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Performance and Emission Characteristic of Distilled Technical Cashew Nut Shell Liquid Stabilized Triglyceride Biofuel

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P A P E R I N F O

Paper history:
Received 7 July 2015
Accepted in revised form 15 August 2015

Keywords:
Biodiesel
Cashew nut shell oil
Diesel fuel additive
Jatropha
Diesel engine
Tallow oil
Triglycerides

A B S T R A C T

Crops such as Jatropha and Pongamia are being grown exclusively for biofuel production. An alternative approach is to grow a food crop and use the waste material for biofuel. Distilled technical cashew nut shell liquid (DT-CNSL) can be used as a non-transesterified biofuel and can also act as an additive to enable vegetable oil triglycerides to be used directly with diesel. In this study we evaluate the emission and performance characteristics of blends of vegetable and tallow oils stabilized in diesel with DT-CNSL. It was found, DT-CNSL can be used as an excellent biofuel additive. Triglycerides is directly blended with diesel in the presence of DT-CNSL and then used in conventional diesel engines. DT-CNSL blends of diesel obey emission and performance parameters of diesel. DT-CNSL offers stability to blends of tallow oil in diesel and the saturated nature of triglycerides seems to be not an issue and there is no formation of precipitates or solidification at -10°C. This publication demonstrates the use of both tallow oil and plant oils as direct blends of diesel without transesterification in the presence of DT-CNSL.

***doi**: 10.5829/idosi.ijee.2015.06.04.06*

Abbreviations

Distilled technical cashew nut shell liquid	DT-CNSL
Pure plant oil	PPO
straight vegetable oil	SVO
American Society for Testing and Materials	ASTM
Brake specific fuel consumption	BSFC
Exhaust gas temperature	EGT

INTRODUCTION

Biofuel has the potential eventually to replace conventional petroleum fuels. However, biodiesels from food grains like coconut, soybean, canola and palm have been criticized because food is being diverted for fuel use [1-3]. Use of non-farm land for cultivation of non-edible oils like Jatropha and Pongamia have also been criticized, in this case for diverting agricultural land for fuel applications [4-9]. One approach that overcomes the land utilization issue is to use waste material from the production of a food product as a starting material for biofuel. An additional problem for the production of biofuel from vegetable oil like jatropa is the need to convert triglycerides into methyl esters using methanol and sodium hydroxide, which is costly and generates toxic waste. If the triglyceride can be used directly without conversion to a methyl ester then use of oil derived from a food waste material is more feasible. We have previously shown that distilled technical cashew nut shell liquid (DT-CNSL) can be used directly as a non-transesterified biodiesel and can also act as an additive to convert other vegetable triglycerides to biofuel without the need for methyl ester formation [10-14].

DT-CNSL contains cardanol as its main constituent. This pale yellowish-brown liquid is widely used for polymer applications [15]. We have previously carried out extensive research in the isolation of CNSL

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Please cite this article as: S. K. Sanjeeva, C. B. Nair, G. M. Kini, P. V. Subba Rao, S. Ramamoorthy, C. Barrow, P. K. Pullela, 2015. Performance and Emission Characteristic Studies of Distilled Technical Cashew Nut Shell Liquid Stabilized Triglyceride Biofuel, Iranica Journal of Energy and Environment 6 (4): 282-289.

constituents, including developing a process for the isolation of anacardiac acid from natural CNSL and cardanol from technical CNSL [12, 14]. Anacardic acid derived from CNSL has been used as a precursor to synthesize sildenafil analogues [13], the first T-type channel binding dihydropyridines [10], and some cyclooxygenase 2 (COX-2) inhibitors [11].

Cardanol has a benzene ring, one phenolic group and a linear C15 carbon chain [15]. The presence of 21 carbons means its average molecular weight is close to that of diesel, which contains hydrocarbons having up to 18 carbon atoms. Phenols are considered to be irritants and are rarely used in the fuel industry. However, substituted phenols were recently reported to be excellent fuel additives for stabilizing formulations of biodiesel in diesel [16-18]. The main advantage of these phenolic derivatives of cardanol is they have improved biodiesel thermal stability, primarily because they act as antioxidants [19]. Engine studies on cardanol/diesel blends show comparable performance to diesel alone [20, 21].

CNSL cannot be directly used for fuel applications due to the presence of a large amount of polymeric material [15], which makes it insoluble in diesel. Even a 5-10% polymeric material content for CNSL renders it unsuitable for fuel applications. Moreover, technical CNSL contains about 10% cardol (diphenolic), which is acidic and can cause corrosion in diesel engines. Hence, we have developed a process to obtain distilled technical CNSL (DT-CNSL) from the raw cashew nut, which can produce DT-CNSL containing up to 99% cardanol.

The SVO's tested in this study include pongamia, jatropa, palm, neem, soybean, sunflower, coconut, groundnut, rice brawn, and canola oil. All of these oil blends with diesel formed droplets on the walls of the container indicating the precipitation. Hence, we concluded that SVO is partially insoluble in diesel and these non-uniform fuels are likely to cause problems such as increasing NOx, improper spraying and burning of fuel, and increase in smoke and pollutant production. We also observed that waste vegetable oil and tallow oil separated within a day from the diesel blend. A striking aspect of mixing tallow oil with diesel is the formation of greasy precipitated layer within a day of storage. Therefore, we tested blends of SVO or tallow oil in diesel, with DT-CNSL as a fuel additive, and here report improved performance and emission characteristics. A similar stabilization of SVO in diesel has previously been observed with isobutanol [22]. But isobutanol has a flash point of 28^{o}C; s,o it cannot be used in diesel engines. We recently proposed a mechanism for the stabilization of SVO in diesel using DT-CNSL [7] and report here the emission and performance characteristics of this stabilized biodiesel product.

MATERIALS AND METHODS

Extraction of cardanol from cashew nut shell oil

CNSL was purchased from a cashew processing facility located in Ankola, India, with the specification of a minimum of 90% cardanol. DT-CNSL was obtained as a pale yellow-brownish liquid from the distillation of technical CNSL at 230^{o}C under 0.2 mm vacuum. The extracted CNSL oil mainly contained Anacardic acid and only 5% cardanol. To get a high yield of cardanol second stage distillation was carried out at 210-230^{o}C. At 205-210^{o}C the distilled fraction contains rich anacardic acid was subjected to decarboxylation process at 170-175^{o}C under reduced pressure (30-40mm) resulted in 90% cardanol [23].

Source of triglycerides

Plant oils were obtained from Falcon-India exporters based in Bangalore, India. The plant oils used for our studies were sunflower oil, jatropha, coconut, palm, pongamia and rapeseed oil.

Another main source of triglyceride used in the study was tallow oil obtained from an importer based in India who sourced the material from Australia. Both plant oils and tallow oil have a minimum of 98% triglycerides content and were used after filtration through white cotton cloth. Tallow oil has a minimum of 70% saturated triglycerides and is a solid. Before preparation of tallow oil blends, Tallow oil was filtered through thin cotton cloth to remove fibers and impurities. Diesel fuel was obtained from a Hindustan Petroleum retail outlet located in Bangalore. Trinonyl phenyl phosphite (TNPP) was purchased from Aldrich. We used SVO as a common term to define both vegetable oil and waste vegetable oil. In this paper, the term 'triglycerides' is used when referring to both tallow oil and SVO.

Preliminary engine tests

A test was conducted on a Kirloskar diesel engine TV2, 10 KVA, 1500 rpm. The engine rpm was constant and fuel flow was adjusted. The engine was under no load condition and fuel efficiency was measured by the amount of time that the engine ran. The longer the engine ran the better the fuel performance. 500ml of fuel blend was added to the above engine and the engine was run until it stopped on its own. This setup could measure only fuel consumption over time.

Controlled engine studies

A test was conducted on a Kirloskar oil engine, twin cylinder, 102 mm bore, 116 mm stroke, 1.896 litres displacement, at a compression ratio of 17.5, 20 hp and with an injection pressure of 185 bar. The Loading sequence followed was a) no load (0), b) 3.1 kW, c) 6.1 kW, d) 9.1 kW and d) 11.1 kW. The pressure sensor was from Kistler (maximum pressure: 250 bar), and ASTM standards were followed to measure the airflow using an air drum with a calibrated orifice and a manometer. The room temperature was 30 ± 3^oC, and air density was 1.164 kg/m^3. Test parameters are defined as, mf/min: grams of fuel consumed per minute, load kW: load applied for specific study, rpm: engine rotations per minute, NO_x: nitrogen oxides produced, opacity: opacity is the degree to which smoke blocks light, and the basis for measuring the amount of smoke coming from a diesel-powered vehicle, EGT: exhaust temperature, HC: total hydrocarbons produced in exhaust smoke, CO: total carbon monoxide produced in exhaust smoke, CO_2: total carbon dioxide produced in exhaust smoke.

RESULT AND DISCUSSION

DT-CNSL production

Products obtained during the production of DT-CNSL from raw cashew nut are shown in Figure 1. Cashew cake can be used to fuel a furnace for heat generation for use in the distillation and decarboxylation of CNSL. Residol is a highly sought after material for coating boats and ships, because of its high water repellant properties. Cashew kernel as a food is the most valuable product isolated during the hot CNSL oil bath process and generates the majority of the farmer's income from cashew farming.

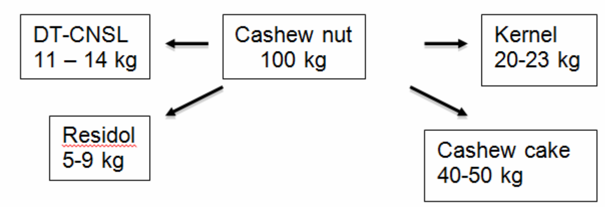

Figure 1. Cashew nut to DT-CNSL: Process typically involves separation of kernels by hot CNSL oil bath, decarboxylation on a hot belt, and vacuum distillation to obtain DT-CNSL in the range of 11-14%. The whole process of cashew raw nut processing is energy neutral except for vacuum generation.

Miscibility and stability of DT-CNSL with diesel

DT-CNSL contains cardanol as the major component and it can range from 97-99% by weight, depending on the temperature of distillation and vacuum system used. Our process typically yields 98-99% cardanol and 1-2% cardol, with minor quantities of other phenolic and non-phenolic components. The solubility of DT-CNSL in hydrocarbon solvents like hexane and toluene is well known [15]. Solubility in high hydrocarbons is unknown and we investigated the solubility in diesel and the stability of these blend over six months. All the blends (5, 10, 20, 40% DT-CNSL) were stable in diesel for up to 180 days and in the case of the 40% blend there was a slight turbidity around 90 days. We also observed that the typical microbial growth observed during long storage of diesel (> six months) was not observed in DT-CNSL blends. This may be due to the partially phenolic nature of cardanol acting as an antimicrobial and preventing microbial growth during storage. Antimicrobial and antibacterial activities of CNSL phenols have been observed previously [15], although DT-CNSL has never been used in practice to improve the shelf life of diesel.

Engine testing: Measurement of fuel efficiency

Considering the high kinematic viscosity of DT-CNSL, the DT-CNSL/diesel blends were initially tested on a Kirloskar diesel engine for their ability to run the engine. Although this experiment is qualitative and only run time could be monitored, it provided an environment similar to field conditions. The engine was idle for three months before use and was a 6 year old engine with minimal maintenance and therefore a close match to what would be encountered in a real situation. The engine was run for a whole day and the given value is an average of three readings. The engine was run under no load condition and the order of samples run on the engine was randomly varied to prevent any pattern or effect due to running one type of blend. The engine was allowed to run on 500 ml fuel and as soon as the engine stopped on its own, the next fuel blend was loaded. Temperature of test site varied during the day from 29 to 37 ^oC. Obtained results from this study are summarize in Table1.

TABLE 1. Preliminary engine testing of DT-CNSL blends of diesel.

Biofuel formulation	Engine start time	Engine stop time	Engine run time (min)
Test 1			
Diesel	12:00	12:25	25
B 20	12:33	1:03	30
B10	1:13	1:45	32
Test 2			
B20	2:32	3:02	30
B10	3:10	3:38	28
diesel	3:45	4:15	30
Test 3			
B10	4:20	4:53	33
Diesel	5:02	5:31	29
B20	5:41	6:10	29

Diesel: 28±2.8 min, B10: 31±2.6 min, B20: 30±0.6 min.

There were two characteristic observations from the study. Firstly, DT-CNSL fuel blends performed better than diesel in the initial runs. Secondly, as the study progressed, there was little difference in performance of DT-CNSL blends and diesel, suggesting improvement in engine performance over time. It is well documented in the literature that fuels with good lubricating properties can improve engine performance and it is hypothesized that in this case the effect is caused by DT-CNSL.

Engine testing: Combustion and emission characteristics

This study of diesel blends using a field engine indicated that controlled engine testing was needed to understand combustion and emission parameters. The chosen engine test bed comprised a Kirloskar twin cylinder in a controlled environment with calibrated instruments, test procedures according to ASTM standards, and test readings were taken in triplicate. Samples were diesel, B5, B10 and B15. All readings are average of three recordings with a minimum of a 2-hours gap between each repetition. The engine was loaded with the fuel of interest and the residual oil was removed by following standard fuel loading procedures and the engine was run for 30 min on the fuel before the readings were recorded. Brake specific fuel consumption was calculated using grams of fuel consumed per minute and load (kW) applied. Maximum cylinder dynamic pressure was recorded to understand the pressure characteristics and fuel burning efficiency as shown in Figure 2.

The BSFC, exhaust gas temperature and cylinder dynamic pressure of DT-CNSL blends were found to be comparable to those for diesel. Surprisingly, the NOx emissions were found to be significantly lower for the DT-CNSL blends as compared to diesel. It is known that the exhaust gas temperature is linearly to NOx and inappropriately burned fuels tend to give rise to increased exhaust temperature and increased NOx levels. We observed that DT-CNSL blends had the same exhaust temperature as diesel, but lower NOx emissions. There was an increased opacity of exhaust gas at lower loads for DT-CNSL blends and at higher loads the opacity was similar to that for diesel. A linear increase in opacity with DT-CNSL concentration indicates that the observed opacity increase was due to DT-CNSL. But the data are inconclusive for higher opacity, as at 0 and 11.1 kW loads, the opacity is almost the same for DT-CNSL blends and reference diesel. In subsequent experiments it is shown that the opacity is almost the same for DT-CNSL blends and diesel. These engine testing results indicate that the DT-CNSL blends perform similarly to diesel.

Engine testing: Combustion and emission characteristics of DT-CNSL blends with diesel and triglycerides

Engine tests were performed for fuel blends of diesel, triglycerides and DT-CNSL at different concentrations to obtain combustion and emission parameters. As some

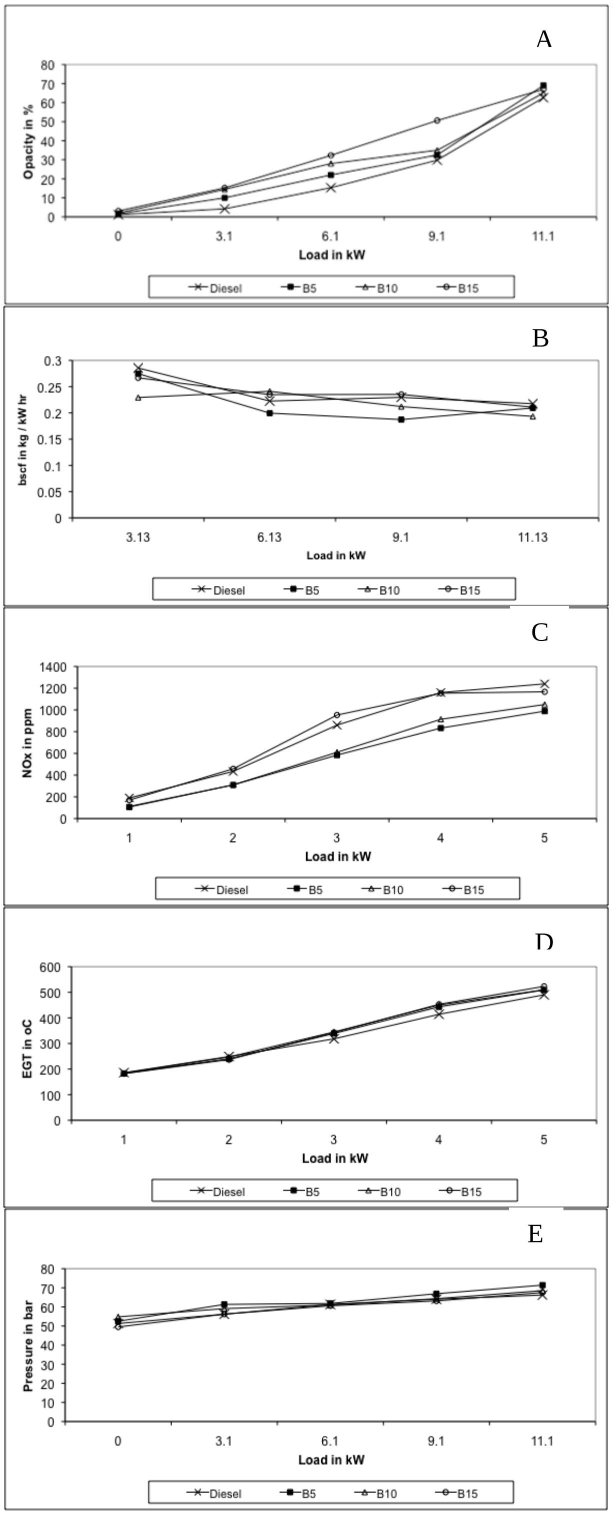

Figure 2. The samples are Diesel: commercial Euro II diesel; B5: 5% DT-CNSL, 95% Euro II Diesel; B10: 10% DT-CNSL, 90% Euro II Diesel; B 15: 15% DT-CNSL, 85% Euro II Diesel. A) Opacity, B) Brake specific fuel consumption, C) Emission of nitrogen oxides (NOx), D) Exhaust gas temperature (EGT), E) Maximum cylinder dynamic pressure.

of the blends of triglycerides in diesel had precipitates, all the blends were prepared 30 min prior to engine testing. The test parameters were found to be similar for all the fuel blends tested, indicating that as long as the fuel is uniform, performance of triglycerides in diesel with or without DT-CNSL is similar to diesel. However, samples 2, 5, 8 and 9 showed precipitate formation within one month of storage, making them unsuitable for fuel applications. Figure 3 shows the engine test results of DT-CNSL/triglyceride blends with diesel.

Increase in fuel efficiency

A non-controlled simple fuel efficiency study of DT-CNSL/diesel blends indicated that DT-CNSL can improve fuel efficiency (Table 1). Chemically this can be anticipated for DT-CNSL because it contains chemicals having higher carbon atoms than diesel. It was observed that SVO mixed directly with diesel did not result in high fuel efficiency. It is also observed that transesterified biodiesel containing almost the same number of carbon atoms as diesel gave low fuel efficiency. Hence, it was concluded that high carbon content alone could not be the sole reason for the observed increase in fuel efficiency.

It has been reported that biodiesel (having a slightly higher viscosity than diesel) removes carbon deposits and can make engines run more efficiently. As we used an old engine in our study (> 5 years old), which was expected to have high carbon deposits, the high fuel efficiency may be attributable partially due to carbon deposit removal by the biodiesel. Surprisingly, when we carried out a similar study in a controlled atmosphere on an engine that was regularly cleaned, had an electronic dynamometer and a computerized data collection system, we still observed an increase in fuel efficiency (Figure 2). This is likely to be due to reasons other than carbon deposit removal.

We tested the calorific value of fuel blends and found that they were significantly higher than for diesel. The actual values obtained were as follows: For diesel 35,449 kJ/kg; for 5% DT-CNSL blend 38,773 kJ/kg; for 10% DT-CNSL blend 42,650 kJ/kg; and for 15% blend 44,312 kJ/kg. The higher calorific value of fuel could contribute to increase in mileage and the fuel efficiency observed. In the case of DT-CNSL/diesel blends the high fuel efficiency is likely to be due to a combination of desired solvent properties, high carbon content and high calorific value. The suitable solvent properties could be concluded from the fact that, when the test was performed on a field engine, the first reading of diesel was significantly lower (>20%) than with the DT-CNSL blends. The second reading of diesel after running DT-CNSL blends showed an improved by 10-15% in mileage for diesel alone, indicating that studied DT-CNSL blends were in fact good for the engine and could improve the performance of the diesel engine. We observed similar effects with the engine that was regularly cleaned, but it was only a 3-5% improvement (Figures 2 and 3). This effect is in agreement with the improved performance of diesel engines used with transesterified biodiesel made from waste vegetable oil [3, 7].

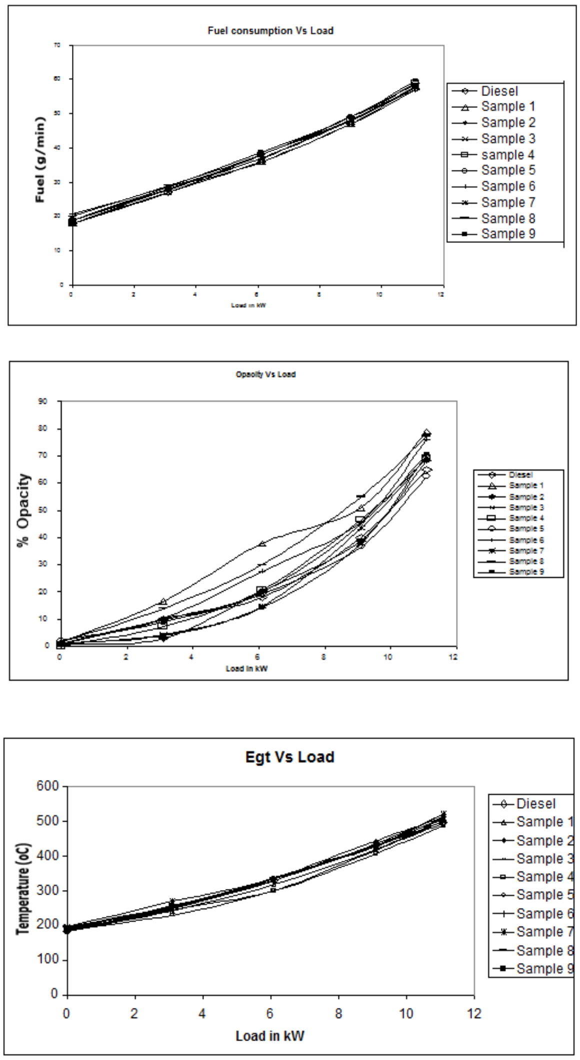

Figure 3. The sample are Diesel: Sample 1: 10% DT-CNSL, 90% diesel, Sample 2: 10% sunflower oil, 90% diesel, Sample 3: 5% DT-CNSL, 5% sunflower oil, 90% diesel, Sample 4: 5% DT-CNSL, 10% sunflower oil, 85% diesel, Sample 5: 5% sunflower oil, 95% diesel, Sample 6: 5% DT-CNSL, 5% tallow oil , 90% diesel, Sample 7: 5% DT-CNSL, 10% tallow oil, 85% diesel, Sample 8: 5% tallow oil, 95% diesel and Sample 9: 10% tallow oil, 90% diesel. a) Brake specific fuel consumption, b) Opacity, c) Exhaust gas temperature (EGT).

Reduction in NO_x

An inherent drawback of biodiesel from plant sources is an observed increase in NOx [24]. A similar NOx increase has been reported for SVO blends with diesel

[22, 25]. Published literature on SVO/diesel blends in diesel engines indicates this NOx increase is primarily due to non-uniform spraying and burning of fuel [3, 22, 25]. We expected DT-CNSL/diesel blends to have a similar effect, considering its similarity in physical properties, like viscosity, with SVO. Surprisingly, we observed significantly low NOx for DT-CNSL/diesel blends as shown in Figure 4 and could not attribute this to any reason known in the art. To determine the reason for this observed lowering of NOx we performed the following study on SVO/diesel and biodiesel/diesel blends. 5, 10 and 20% blends of SVO, biodiesel and DT-CNSL in diesel were made and stored in containers that protected them from light and air. The fouling of fuel blends was monitored for three months. SVO blends of diesel resulted in the separation of two layers within the first week of storage, whereas the clouding and microbial growth was observed in the case of biodiesel containing samples from fifteen days, and after a month all biodiesel blends with diesel showed formation of greasy precipitates. Biodiesel fouling is reported to result in high NOx and it has been hypothesized that fouling contributed to non-uniform spraying of fouled biodiesel [26, 27]. An alternative hypothesis is that long-term storage of biodiesel results in formation of free fatty acids and alcohol, which along with traces of glycerol, could aid in microbial growth, eventually resulting in turbidity of diesel blends [3, 28]. Moreover, we observed that physically fatty acids were insoluble in diesel. Given the information and data available, we hypotheses that biodiesel fouling could be due to fatty acid formation and eventual microbial growth, which results in NOx increase. The antimicrobial properties of CNSL phenolic's including cardanol is probably improving long-term stability of the fuel blends.

It is likely that the ability of DT-CNSL to improve the solubility of small amounts of free fatty acid that are formed from hydrolysis of SVO enables the fuel to have a uniform spraying pattern, and hence is able to run the engine efficiently, resulting in decreased NOx. Whatever the explanation, results show that using DT-CNSL results in a fuel blend that is stable for a longer time than other biodiesel fuel blends and also results in lower, rather than higher, NOx emissions.

Comparison of emission parameters of diesel and DT-CNSL blends

We observed higher opacity for DT-CNSL/diesel blends compared to diesel, as shown in Figure 4. This can be attributed to higher carbon content in DT-CNSL than in diesel. However, a significantly high opacity could be problematic and represent insoluble impurities. Therefore, we investigated individually hydrocarbon, carbon monoxide and carbon dioxide emissions. An analysis of the emission gases indicated that the

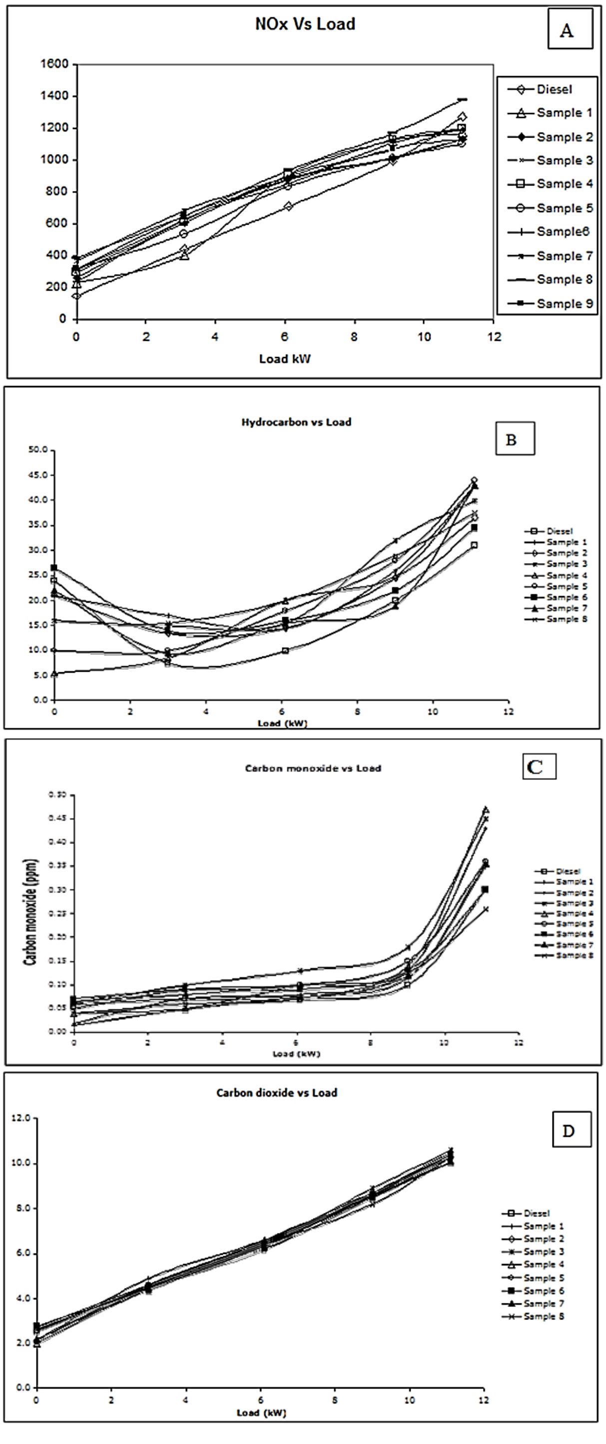

Figure 4. The sample are Diesel: Sample 1: 10% DT-CNSL, 90% diesel, Sample 2: 10% sunflower oil, 90% diesel, Sample 3: 5% DT-CNSL, 5% sunflower oil, 90% diesel, Sample 4: 5% DT-CNSL, 10% sunflower oil, 85% diesel, Sample 5: 5% sunflower oil, 95% diesel, Sample 6: 5% DT-CNSL, 5% tallow oil , 90% diesel, Sample 7: 5% DT-CNSL, 10% tallow oil, 85% diesel, Sample 8: 5% tallow oil, 95% diesel and Sample 9: 10% tallow oil, 90% diesel. a) Emission of nitrogen oxides (NOx), b) Hydrocarbons, c) Carbon monoxide, d) Carbon dioxide.

opacity and individual gases increase with percentage of DT-CNSL in the blends. With low loads the DT-CNSL/diesel blend showed a high HC, CO and CO_2, but as the loads were increased the parameters were similar to those for diesel alone.

Using a more sensitive opacity meter, which could analyze the individual gas components, we found that increases in HC, CO and CO_2 were co-relate with increases in DT-CNSL in the blends, and at higher loads there was no significant difference between diesel and DT-CNSL blends. This clearly indicates that at higher loads, DT-CNSL blends can withstand load and are more suitable fuels compared to diesel. The initial burst of high opacity could also be attributed to the engine getting accustomed to the DT-CNSL/diesel/triglyceride blend.

Tallow oil as biodiesel: Stabilization with DT-CNSL

Tallow is a waste fat that currently has limited used including soap production. Due to a shift in the soap industry towards vegetable produced triglycerides tallow is becoming a waste material that needs to be disposed of by rendering plants. Attempts to use tallow as biodiesel require conversion to methyl esters and even then the high-saturated fatty ester content make these oils perform poorly. We report here that tallow oil can be blended directly with diesel in the presence of DT-CNSL, without the need for conversion to methyl esters. We observe that even at – 10^oC, the saturated fat does not precipitate out of diesel [7]. A detailed study on the mechanism of stability of tallow oil and SVO blends in DT-CNSL/diesel has been submitted for publication [7].

Tallow and DT-CNSL blends in diesel: A practical use for tallow?

Tallow has high saturated fat content and even after transesterification blending with diesel is problematic. Over 90% of tallow oil is discarded as waste and so finding a use for this waste from rendering is a significant commercial opportunity. Increasing demand for meat, particularly in developing countries, means that the generation of tallow waste is increasing. We showed that tallow can be blended directly with diesel in the presence of DT-CNSL, and therefore, can be used in a diesel engine as biodiesel. Even though the tallow is in the native tryacylglyceride form and is not transesterified, blending with diesel and DT-CNSL obeys emission and combustion parameters, as shown in Figure 4. Tallow behaves similarly to SVO or PPO, and CO, HC and NO_X emission are similar, as shown in Figures 3 and 4. Therefore, the use of DT-CNSL as an additive enables either tallow or SVO to be used directly in diesel blends, without the needs for conversion to methyl esters.

CONCLUSION

Engine studies show that DT-CNSL can be used as an additive to stabilize SVO and tallow in diesel, eliminating the need transesterification to methyl esters. Performance and emission studies indicate that these new fuel blends can be effective biofuels. A reduction in NOx emission and an increase in fuel efficiency occurred for some blends and further study of the mechanisms is warranted. Stabilization and use of tallow in diesel blends, using DT-CNSL as an additive, could result in an alternate use for this waste product. In addition, our results showed that cashew waste (specifically DT-CNSL) could also be a viable as a biofuel.

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Persian Abstract

DOI: 10.5829/idosi.ijee.2015.06.04.06

چکیده

محصولاتی همچون جاتروفا (Jatropha)و پانگامیا (Pongamia) تنها برای تولید سوخت های زیستی کشت می شوند . کشت محصولات خوراکی و استفاده از ضایعات آنها برای تولید سوخت های زیستی یک روش جایگزین می باشد مایع مقطر گرفته شده از پوسته بادام زمینی (DT-CNSL)همچنین می تواند به عنوان یک سوخت زیستی غیر استری استفاده شود و هم می تواند به عنوان یک ماده افزودنی ، تری گلیسریدهای روغن گیاهی را قادر سازد تا مستقیما با دیزل استفاده شود. در این تحقیق ما مشخصات عملکردی و خروجی مخلوط روغن های گیاهی و حیوانی (پی) تثبیت شده در دیزل با DT-CNSL را ارزیابی می کنیم .دریافتیم که DT-CNSL می تواند به عنوان یک ماده افزودنی عالی برای سوخت های زیستی استفاده شود .تری گلیسریدها مستقیما با دیزل در حضور CNSL مخلوط می شوند و سپس از آن در موتور های دیزلی معمولی استفاده می شود . مخلوط های DT-CNSL و دیزل از پارامترهای عملکردی و خروجی دیزل پیروی می کند DT-CNSL . همین طور برای پایدارسازی مخلوط روغن بادام زمینی و دیزل پیشنهاد می شود که به نظر می رسد تری گلیسریدهای اشباع شده طبیعی مشکلی به وجود نمی آورند و هیچ رسوبی و یا انجمادی در دمای ۱۰ -cرخ نمی دهد. این مقاله استفاده مستقیم روغن های گیاهی و بادام زمینی را با دیزل بدون فرآیند ترانس استری فیکاسیون در حضور DT-CNSL را نشان می دهد.