Comparative study of engine performance and emission test of Custard Apple seed oil Bio-lubricant dispersed with micro walled carbon nano tube with synthetic lubricants

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Abstract:
Finiteness of global crude oil reserve, increasing crude oil prices and problems related to environment seems to be a reality check for the issues of emerging generation. Vegetable oil based lubricants are an attractive alternate to conventional petro based lubricants due to number of its physical properties like renewability, biodegradability, high lubricity and high flashpoint. Direct application of vegetable oil as vehicle lubricants is less favourable due to its poor thermo oxidative stability, cold flow behaviour and poor anti-ware characteristic. Present research detailed in this document refers to chemical modification of custard apple seed oil through epoxidation, hydroxylation and trans esterification process to improve its thermo-oxidative stability and cold flow behaviour. The micro walled carbon nanotube(MWCNT) of size 30-50nm of .5 wt % concentration was dispersed in this chemically modified custard apple seed oil to improve antiwear properties using ultrasonicator. Then the engine performance and emission test were conducted on a four stroke engine fuelled with diesel using different combination of synthetic lubricant(SAE20W40) and formulated bio-lubricant and the result is compared with synthetic lubricant.The findings show that the partly replaced bio lubricant with synthetic lubricant reduces the emission of CO,HC and CO_2,when compared with synthetic lubricant. The brake thermal, mechanical efficiencies, brake power and specific fuel consumption is superior for biolubricant/ synthetic lubricant combination than synthetic lubricant.

Keywords: Custard apple seed oil, bio lubricant, nano additives, Engine performance

Introduction

The greater attention to environmental resources, limited oil resources, the scarcity, the high cost of synthetic products and the high carcinogenic content in petroleum products make it necessary to study the possibilities of producing fuels and lubricants for alternative feeding. Interest in the use of automotive fuel and lubricants from plants has increased considerably in many countries and in India. Although India is agriculture-oriented, there is little information and development of automotive lubricants from agricultural feed stock. (Horner, 2002) reported that over half of the lubricants sold worldwide pollute the environment due to the complete spill of lubrication and evaporation [1]. The most desirable components for lubricants are oils with a high percentage of monounsaturated fatty acids, a moderate amount of poly saturated fatty acids and a low amount of saturated fatty acids. Vegetable oil and in particular custard apple seed oil is an alternative raw material for the production of automotive lubricant, as well as alternative fuel for the next generation. (Erhan and Sharma, 2006) reported that a high content of unsaturated bonds indicated by the high iodine value of rapeseed oil-based bio-lubricant allows higher performance, a key factor for the economic production of rapeseed oil base bio lubricant [2]. When using vegetable oil as a base for lubricants, they have good lubrication, higher viscosity, a low pour point, a high flash point and a high degree of biodegradability. On the other hand, vegetable oils have poor oxidative stability at high temperatures and suffer from opacity, precipitation, poor flow and solidification after long-term exposure to cold winter temperatures. Wang and Erhan (2001) reported that the poor oxidative stability of vegetable oil is typically attributed to the rapid reaction occurring at C=C double functional group in molecule[3] .

In previous years, Sharma and et al. (2007) attempted to improve oxidative stability by adding commercially available antioxidants to the oil, preparing new antioxidants or genetically modifying the plants from which the vegetable oils are derived[4]. Ajithkumar and Jayadas (2009) have made efforts to improve low temperature properties by mixing vegetable oil with diluents such as poly-α-olefin and diisodecilladipate[5]. Uosukainen E, Linko and Lamasa (1998) conducted research to improve the oxidative stability of rapeseed oil by transesterifying trimethylolpropane (TMP) and methyl ester from rapeseed oil[6]. (Fang et al, 2011) prepared modified rapeseed oil (SRO) by chemical modification with Sulphur compounds [7].

The unsaturation present in the fatty acid molecule of the vegetable oil can be used to introduce various functional groups by carrying out chemical modifications. Among these, epoxidation, hydroxylation and esterification are the most used chemical modifications. In the epoxidation phase, the unsaturated double bond in the vegetable oil is converted to produce an epoxy group indicated by the percentage of oxirane content. (Holser, 2008) predicted that a high percentage of oxygen content in epoxidized oil has a greater number of epoxy groups[8]. Adhvarayu and Erhan (2002) explored the effectiveness of the use of epoxidized soybean oil in some high temperature applications[9]. Salimon and Slih (2009) have extensively documented a three-step synthesis of oleochemical diesters, including epoxidation, opening the epoxidized oleic acid ring to produce monoesters for the production of diesters[10]. Such types of vegetable oils can overcome these shortcomings. The piston ring cylinder liner is the most complex tribological component in an internal combustion engine which contributes significantly to the engine's total friction loss. Arumugam and Sriram (2009) reported the effect of rapeseed oil esterified with a package of biodegradable additives, i.e. 10% castor oil and 5% palm oil methyl ester used as a bio-lubricant to influence tribological characteristics [11]. The formulation has been found to have poor thermo-oxidative stability. Abdullah and Salimon (2010) have extensively documented epoxidation with organic and inorganic oxidants such as potassium peroxomonosulfate and metachloroperoxybenzoic acid [12]. Kim and Sharma (2012) also discussed the possibilities of using epoxidized vegetable oil-based products in PVC and bi-hardening plastic formulations [13]. (Quincha et al 2009) have developed new ecological lubricants using sunflower oil with a high oleic content mixed with polymeric additives to improve the kinematic viscosity values and the thermal sensitivity of the viscosity [14]. Furthermore, the researchers Arumugam s,and Sriram G(2013) reported the tribo-logical behaviour of chemically modified rapeseed oil and synthetic lubricant SAE20W40.However the chemically modified rapeseed oil did not show any improvement in reducing the wear under tested conditions[15] .Various publications have revealed that the tribological improvement of vegetable oil based lubricants was due to the addition of nanoparticles as antiwear additive. Wu et.al(2007) studied the effect of using nano-TiO_2,nano diamond and copper oxide(CuO) nanoparticles as antiwear additives in API-SF engine oil and base oil[16].The results showed that CuO nanoparticles were more effective in reducing friction and wear than nano diamond and nano TiO_2.Demas NG et. al (2012) have done research hon the tribo-logical behaviour with polyalphaolefinbase oil with BN and MoS_2

nanoparticle additives using HFRR. The friction and wear were reduced effectively to MoS_2 nanoparticles with base oil when compared with BN nano additives [17]. Thottackkad et. al (2012) employed the various concentration of CuO nanoparticles with coconut oil. Result showed that the optimum concentration of 0.34 wt% of CuO reduces the coefficient of friction and wear.[18] Leelamani Pillai et. al (2020) have done research on tribological properties of custard apple seed oil bio lubricants with and without addition of CuO nano particle and comment that there is an enhancement of tribological properties by addition of CuO nano particle[19]. There is evidently no research on the literature on wear and the friction effect of the typical engine material contact when lubricated by chemically modified custard apple seed oil bio degradable automotive lubricant dispersed with nano additive. In this context the present research investigates the impact of chemically modified custard apple seed oil, partly replaced with synthetic lubricant (SAE20W40) with nano additive (Microwalled Carbon Nano Tube MWCNT) as automotive lubricant for the diesel engine to investigate engine performance and emission characteristics. Also made comparison with commercial synthetic lubricant (SAE20W40) of equivalent viscosity grade.

Experimental

Formulation of custard apple seed oil based bio-lubricant

To formulate custard apple seed oil based bio-lubricant, custard apple seed oil was chemically modified through epoxidation, hydroxylation and trans esterification process in order to improve its thermo oxidative stability and lower the pour point. The detailed procedure for chemical modification process for custard apple seed oil and its mechanism were adapted from our earlier investigation [19].

Dispersion of chemically modified custard apple seed oil bio-lubricant with micro walled carbon nanotube (MWCNT)

In this study , dispersion of MWCNT particle with chemically modified custard apple seed oil is done with a concentration 0.5 wt%, as an antiwear additive. Commercial grade MWCNT particles in the size range of 30-50 nm was supplied by M/S US nano research materials INC. For dispersion, an ultrasonicator model No: 1.5L501t was used to ensure homogeneous dispersion of MWCNT particle. The chemically modified custard apple seed oil and MWCNT particle of 0.5 wt% were initially taken in a beaker and kept in a ultrasonic bath sonicator. It is then allowed to vibrate for 2 hours and then the blends were shaken for 5 hours in a rotary shaker to ensure the chemically modified custard apple seed oil and MWCNT particles are in a homogeneous phase without agglomeration.

Experimental work

- After the completion of forming emulsions, three samples were prepared as
- 90% SAE20W40 + 10 % CMCASO + 0.5 wt % MWCNT
- 85 % SAE20W40 + 15 % CMCASO + 0.5 wt % MWCNT
- SAE20W40

Emulsions are tested in the Kirloskar TAF 1 single cylinder, air cooled, 4 stroke, direct injection diesel engine .The engine set up consists of a single cylinder 4 stroke disel engine (1), connected to eddy current dynamometer for loading. It is provided with necessary instruments for combustion pressure and crank angle measurement. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurements. The load is controlled by the load cell which in turn activates the alternator for applying load on the engine. Air is taken by the air box and flows through an air flow sensor which measures the amount of air taken. Fuel readings are measured with the help of a fuel sensor. These measurements are provided as inputs to the data acquisition system.

AVL 444 gas analyzer is used to measure the emissions from exhaust pipe.

The set up enables study of engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Lab view based engine performance analysis software package Enginesoft is provided for online performance evaluation.

Fig 1 Testing machine

Fig 2 Smoke meter

Fig 3 Gas Analyser

Fig 4 Dynamometer

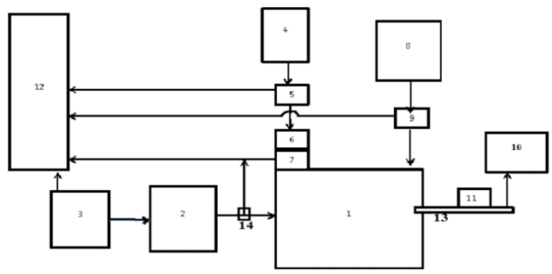

Fig .5 Schematic Diagram of engine Setup

Table 1: Comparison of Results - Engine Emissions

Blend	CO	HC	NOX	CO_2
Details	%	PPM	PPM	%
Conventional Oil 20/40	0.239	45	2023	9.96
10%Custered Seed Oil With Mwcnt	0.075	15	2328	9.4
15%Custered Seed Oil With Mwcnt	0.078	19	2316	9.55

Results and Discussion:

Specific Fuel Consumption

Table 2: Specific Fuel Consumption

Blend Details	Brake power (BP)kw	Specific fuel consumption (SFC) kg/kwh
Conventional Oil 20/40	5.06	0.26
10%Custered Seed	5.1	0.24

Oil With Mwcnt		
15%Custered Seed Oil With Mwcnt	5.1	0.25

Specific Fuel consumption is the amount of fuel required to produce unit kW of power for an hour. The figure represents the specific fuel consumption and Brake power values for the conventional oil 20/40, 10% Custard apple seed oil with MWCNT and 15% Custard apple seed oil with MWCNT. The figure shows a slight increase in the higher brake power level. Addition of the bio-lubricant to the conventional oil helped the engine to produce 0.8% higher brake power than the conventional oil. Though this was a very marginal increase, the corresponding improvement attained in the SFC is significant. Compared with the conventional lubricating oil 20/40, 10% custard apple seed oil with MWCNT reduced the fuel consumption by 7.69% and 15% Custard apple seed oil with MWCNT showed a reduction of 3.85% for the maximum Brake power of 5.1 kW. This might be due to the reason that the improved oil mixture helped in reducing the friction acquiring between the moving parts in the engine. Thereby helped to improve the higher limit of BP and reduce the Specific Fuel Consumption at full load condition.

Mechanical Efficiency

Table 3: Mechanical Efficiency

Blend Details	Brake power (BP)kw	Mechanical efficiency (η_M)
Conventional Oil 20/40	5.06	75.22
10%Custered Seed Oil With Mwcnt	5.1	84.69
15%Custered Seed Oil With Mwcnt	5.1	86.49

Mechanical Efficiency is the ratio between the amounts of useful work produced by the engine to the total work power delivered to it. The figure shows the increase in mechanical efficiency of the engine at full load condition value. The addition of 10% Custard apple seed oil with MWCNT and 15% Custard apple seed oil with MWCNT helped to attain an efficiency value of 84.69% and 86.49% respectively. An increase of 12.59% and 14.98% in mechanical efficiency by using 10% and 15% custard apple seed oil with MWCNT compared to the mechanical efficiency inquired while using the conventional oil 20/40 in the engine is mainly due to the reduced frictional losses provided by the modified oil.

Brake thermal efficiency

Table 4: Brake thermal efficiency

Blend Details	Brake power (BP)kw	Brake thermal efficiency (η_{IT})
Conventional Oil 20/40	5.06	32.72
10%Custered Seed Oil With Mwcnt	5.1	35.45
15%Custered Seed Oil With Mwcnt	5.1	33.89

Brake thermal efficiency is one of the main performance parameters of the engine. It is generally defined as the percentage of heat produced by the fuel is converted into useful work by the engine. The figure shows the BTE values of conventional oil 20/40, 10% Custard apple seed oil with MWCNT and 15% Custard apple seed oil with MWCNT at the full loading capacity of the engine. It can be seen that the engine produces 32.72% BTE at full BP while using conventional oil, which is further improved by modifying the lubricant oil. With the usage of 10% Custard apple seed oil with MWCNT, BTE reached a maximum of 35.45% (8.34% higher than the conventional oil). The reduction in friction, aided the engine to work smoother and convert more useful work. But with the usage of 15% Custard apple seed oil with MWCNT, BTE value reduced to 33.89% (still 3.57% higher than conventional oil).

Emission :

Table 6: Emission

Blend	CO	HC	NOX	CO_2
Details	%	PPM	PPM	%
Conventional Oil	0.239	45	2023	9.96

20/40				
10%Custered Seed Oil With Mwcnt	0.075	15	2328	9.4
15%Custered Seed Oil With Mwcnt	0.078	19	2316	9.55

Emissions are the main outcome to be considered in the selection of any modification to be done to an existing engine. The graph shows a comparison between the conventional oil 20/40, 10% Custard seed oil with MWCNT and 15% Custard apple seed oil with MWCNT in terms of the amount of carbon monoxide (CO), hydrocarbon (HC), Oxides of nitrogen (NOx) and Carbon dioxide (CO_2) emissions produced.

The main reason for the production of CO emission is the incomplete combustion. The usage of custard apple seed oil with MWCNT helped to improve the combustion and thereby reduce the CO emission. At full load condition, CO reduced by 68.61% for 10% Custard apple seed oil with MWNT and 67.36% for 15% Custard seed oil with MWNT compared with conventional 20/40 oil. Also, HC emission reduced by 66.67% and 57.78% for 10%, 15% custard apple seed oil with MWNT at full load condition compared with conventional oil 20/40. The modified oil helped in reducing the frictional loss and led to better utilisation of the fuel molecules, thereby reducing Hydrocarbon and Carbon-monoxide emissions in the exhaust stream. For the same reasons stated above, CO_2 emission also reduced by 5.62% and 4.11% for 10%, 15% custard seed oil with MWNT at full load condition compared with conventional oil 20/40.

The major concern considering the emissions is the increase in the level of oxides of nitrogen in the exhaust stream. The improvements in combustion lead to increase in the in-cylinder peak temperature, this provides a much-needed atmosphere for the generation of NOx emissions. Thus, at full load condition, NOx emission is increased by 15.07% for 10% Custard seed oil with MWNT and 14.48% for 15% Custard seed oil with MWNT compared with conventional 20/40 oil.

Conclusion

- The above synthesis process is an efficient method without any side reactions and provides a greener alternative to the production of petroleum-based lubricant. Further the basic structure of it is retained even after chemical modification of custard apple seed oil, thus maintaining excellent bio degradability.
- The chemically modified custard apple seed oil bio lubricant formulated using above napproach will have better cold flow behaviour of -15°C of oxirane content of 7.04 % and improved oxidation stability.
- The addition of MWCNT nanoparticles as an antiwear additive was effective in enhancing the tribological behaviour of CMCASO
- The engine can be safely operated with custard apple seed oil based bio lubricant with partial replacement of synthetic lubricant(SAE20W40) without any modification of engine and significant changes in engine power and fuel economy
- A marginal improvement in brake power, brake thermal efficiency, mechanical efficiency was observed with the use of custard apple based bio lubricant. The improvement in theefficiancies can be attributed to the higher lubricity of custard apple based biolubricant. Emission (CO, HC, CO_2) is also less compared to Synthetic lubricant

On the whole, this investigation can promote the establishment of chemically modified custard apple seed oil based bio-lubricant for automotive applications. With additional research, genetic modification of custard apple seed and improved oil processing technologies, it has a good potential for commercialization

Acknowledgment

The authors would like to thank M/S Sri Venkateshwara Engineering Consultancy

Services, Kancheepuram for granting permission to carry out Engine performance and Emission test.

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