# PRODUCTION OF GASEOUS FUEL FROM JATROPHA OIL BY CERIUM OXIDE BASED CATALYTIC FUEL REACTOR AND ITS UTILISATION ON DIESEL ENGINE

by

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*In this study, an attempt is made to produce a hydrocarbon fuel from jatropha vegetable oil for Diesel engine applications. The "catalytic cracking" a process recently introduced by the researchers is chosen as an alternative method to trans-esterification process to match the fuel properties to diesel. Jatropha vegetable oil was cracked into a gas using the cerium oxide catalyst in a fixed bed catalytic reactor. The produced gas is introduced at constant rate into the inlet manifold of the Diesel engine. The experimental work was carried out in single cylinder water cooled direct injection Diesel engine coupled with eddy current dynamometer. The combustion parameters are measured by AVL combustion analyser. From the experimental results, the increase in brake thermal efficiency of the engine for full load was observed to be 10% (relative) compared with diesel. Notably, emissions such as HC, CO, and smoke are reduced by 18%, 61%, and 18%, respectively, when compared with diesel.*

Key words:  *vegetable oil, catalytic cracking, cerium oxide*

## Introduction

The increasing vehicles demand to cope up the industrialization of the world lead to a steep rise in the demand of petroleum fuels. At present, 58% of total fossil fuels consumed in the world by the transport sector [1]. The petroleum reserves are depleting very fast due to the very high consumption of transportation fuels [2]. Thus, a situation has arisen where alternate sources of fuels such as biofuels, hydrogen fuels, *etc*. need to be discovered. It is explicit that the production of biofuels may have to be increased to match the scale of use of fossil fuels. The main issues associated with the use of these vegetable oils as liquid fuels directly are their poor storage stability, high viscosity, poor cold flow properties, and formation of carbon deposits in parts of automobile engines (*i. e*. in Diesel engines) [3]. Hence researchers have developed strategies to improve the fuel properties of vegetable oils by the most recognized method called trans-esterification pro-

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**S1128**

Mylswamy, T., *et al.*: Production of Gaseous Fuel from Jatropha Oil by Cerium ...
THERMAL SCIENCE: Year 2016, Vol. 20, Suppl. 4, pp. S1127-S1135

cess. The main bottlenecks of this renowned process trans-esterification, are the usage of large amounts of methanol and formation of glycerol as a by-product while deriving biodiesel. To overcome these problems alternative chemical treatment methods for vegetable oils are under intensive research [4, 5]. As such, to improve the characteristics of vegetable oils, researchers have also suggested advanced treatment methods such as pyrolysis, cracking and distillation either at high temperature or in the presence of catalyst. Significantly, amongst these techniques, cracking improves both the fuel viscosity and calorific value of vegetable oils which in turn would enhance the engine performance and combustion [5, 6]. The engine characteristics of cracked vegetable oils are not addressed by many researchers unlike biodiesel. Therefore, in this present study, inedible oil Jatropha curcas was cracked in the presence of a catalyst to improve its fuel properties and the operational feasibility of this cracked oil in a Diesel engine was also studied.

## Materials and methods

### Jatropha vegetable oil

Jatropha vegetable oil used in the current study was procured from local market and it is an inedible oil, which belongs to the *Euphorbiaceae* family, commonly termed as *Pungai* oil in India. Normally it is cultivated in tropical and subtropical regions around the world. The plant can grow in wastelands and grows on almost any terrain, even on gravelly, sandy, and saline soils. Complete germination is achieved within nine days. Jatropha curcas starts yielding from 9-12 months time. The best yields are obtained only after 2-3 years time. The seed production is around 3.5 tons per hectare yielding 540-680 litres. The resulting jatropha oil can be processed to produce a high quality biofuels or biodiesel that can be used in a standard Diesel engines and the residue can be used as an organic fertilizer. The physical properties of jatropha oil and diesel are shown in tab. 1.

**Table 1. Properties of diesel and jatropha curcas oil**

| Properties | Diesel | Jatropha curcas oil |
|---|---|---|
| Density [gmcm$^{-3}$], 30 ºC | 0.836-0.850 | 0.93292 |
| Kinematic viscosity [cSt] | 4-8 | 52.76 |
| Cetane number | 40-55 | 38.00 |
| Flash point, [ºC] | 45-60 | 210.00 |
| Calorific value, [MJkg$^{-1}$] | 42-46 | 38.20 |

### Preparation of catalyst pellets

Catalysts are commercially available in the form of powder and the catalyst slurry is prepared with the help of NaOH as a bonding material added to the $CeO_2$ catalyst. The slurry is in the form of semisolid and produced in the shape of pellets in the size of the pellets are approximately 20-30 mm diameter. The pellets are kept into the oven and heated upto 80 ºC for a period of one hour. Then the pellets are removed from the oven and exposed to ambient temperature.

The pellets are then fed into the reactor and then heated with the help of an electrical coil until it reaches 250-300 ºC and an electrical controller maintains the required temperature. At this temperature, the Jatropha oil is fed into the reactor. The reaction take place with the catalyst $CeO_2$ and finally, cracked Jatropha oil in the gaseous form is produced in the reactor. Out let of the reactor is connected to the engine intake manifold the cracked Jatropha oil in the gaseous form is directly injected in to it.

### Cerium oxide

In this study, $CeO_2$ is used as a catalyst for the cracking process. The properties of $CeO_2$ are listed in tab. 2. Figures 1 and 2 show the scanning electron microscopy (SEM) image

Mylswamy, T., *et al.*: Production of Gaseous Fuel from Jatropha Oil by Cerium ...
THERMAL SCIENCE: Year 2016, Vol. 20, Suppl. 4, pp. S1127-S1135

S1129

**Table 2. Properties of cerium oxide**

| Properties | |
|---|---|
| Chemical formula | $CeO_2$ |
| Molar mass | 172.115 g/mol |
| Appearance | Pale yellow solid, slightly hygroscopic |
| Density | 7.215 g/cm$^3$ |
| Melting point | 2,400 ºC (4,350 ºF, 2,670 K) |
| Boiling point | 3,500 ºC (6,330 ºF; 3,770 K) |
| Solubility in water | Insoluble |



**Figure 1. The SEM image of $CeO_2$ catalyst (5500 x) before cracking**



**Figure 2. The SEM image of $CeO_2$ catalyst (300 x) before cracking**

of $CeO_2$ catalyst before cracking. Technically, $CeO_2$ particles are having generally regular and irregular morphologies, shows that range of particles in size from 5-25 μm. In fig. 1 shows the higher magnification view of $CeO_2$ particles confirms the particles regular and irregular shapes. Figures 1 and 2 shows that there is some porous in this structure. It promotes chemical reaction in a continuous manner. This is beneficial to the catalyst, since it reduces the weight of the catalyst chamber and reduces the time to crack the Jatropha oil and will not absorb the HC produced in this process. In the catalytic cracking process of Jatropha vegetable oil. Catalytic reaction involves conversion of one organic substance into another by means of heat in the presence of a catalyst, unlike thermal cracking process that requires only heat [4].
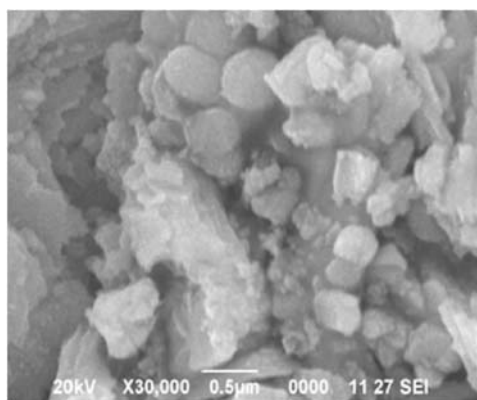
Initially, the vegetable oil undergoes thermal decomposition with the formation of heavy oxygen-containing compounds, mainly monobasic fatty acids. Followed by this, the obtained products undergo decarboxylation reaction to yield CO, $CO_2$, $H_2O$, and a HC residue. Thus, the mechanism of triglyceride cracking suggests that catalytic transformations involve mainly semi products such as alkyl substituents of fatty acids, *i. e.* linear paraffins and olefins with the chain length of 15-17 carbon atoms [3, 7]. Subsequently, these products formed by the thermal decomposition of triglycerides are further transformed by the influence of catalyst.

## Experimental set-up

The test engine used in the current study is a stationary single cylinder constant speed (1500 rpm) Diesel engine, used mainly for agricultural application and in industries for generating electricity. The engine is coupled with an eddy current dynamometer. Piston with hemispherical bowl, three hole mechanical injector and inline fuel pump have been the integral key components of the engine and the fuel injection system. All other engine specifications are listed in tab. 3. The attachment of fuel reactor with engine intake manifold is shown in fig. 3. The arrangement of engine set-up has been depicted in a schematic diagram as shown in fig. 4.
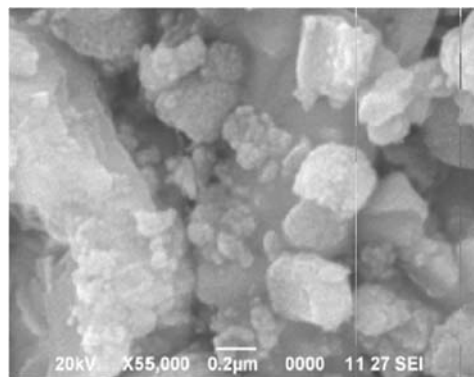
S1130

Mylswamy, T., *et al.*: Production of Gaseous Fuel from Jatropha Oil by Cerium ...
THERMAL  SCIENCE: Year 2016, Vol. 20, Suppl. 4, pp. S1127-S1135

**Table 3. Test engine specification**

| Make | Kirloskar-TV 1 |
|---|---|
| General details | Four stroke, compression ignition, constant speed, vertical, water cooled, direct injection |
| Number of cylinder | One |
| Bore | 87.5 mm |
| Stroke | 110 mm |
| Compression ratio | 17.5:1 |
| Rated speed | 1500 rpm |
| Rated output | 5.2 kW |
| Injection pressure | 220 bar |
| Fuel injection timing | 23_ CA bTDC |
| Lubricating oil | SAE 40 |
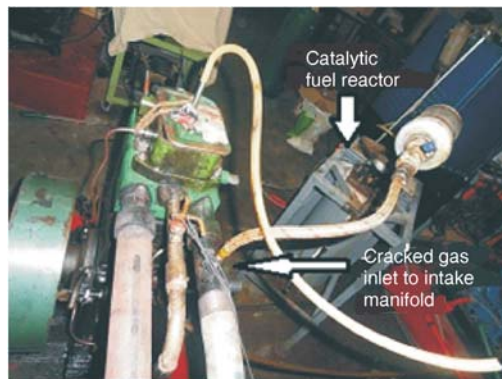


**Figure 3. Photograph of the engine experimental set-up**
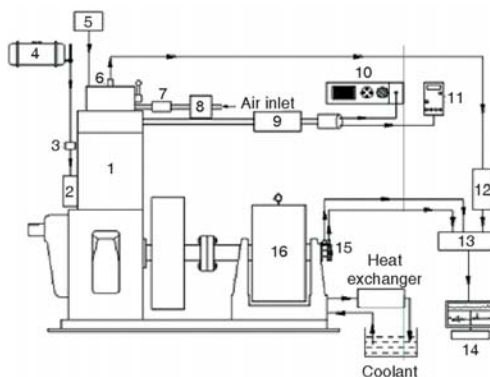


**Figure 4. Schematic diagram of the engine experimental setup**
*1. Kirloskar TV 1 engine, 2. fuel pump, 3. fuel filter, 4. fuel tank, 5. panel board, 6. pressure transducer, 7. air filter, 8. air stabilizing tank, 9. muffler, 10. AVL Di-gas analyzer, 11. AVL smoke meter, 12. charge amplifier, 13. indimeter, 14. computer, 15. crank angle encoder, 16. eddy current dynamometer*

The fuel flow rate was measured manually using a burette and stopwatch, and airflow rate was measured using an orifice meter, installed in the intake air supply system. Measurement of combustion chamber pressure was obtained by installing an AVL pressure transducer with the sensitivity of 16:11 pC/bar. The in-cylinder pressure was recorded for 100 cycles using AVL 619 Indimeter hardware and Indwin software version 2.2, and the recorded pressure signals are then processed to estimate the heat release rate. Exhaust emissions such as HC, CO, $NO_x$, and $O_2$ were measured using a AVL-444 digas analyzer, which works on non-dispersive infrared principle by selective absorption. The exhaust sample to be evaluated was passed through a cold trap (moisture separator) and filter element to prevent water vapor and particulates entering into the analyzer. Notably, the gaseous emissions such as HC and $NO_x$ were measured in ppm, while CO and $O_2$ emissions were measured in terms of percentage volume. Smoke level in the exhaust was measured in terms of Hartridge smoke unit (HSU) using a standard AVL437C smoke meter based on light extinction principle. Catalyst assisted thermal cracking of jatropha oil is sent via intake manifold in the hot gaseous form along with air. [3, 7].

Once the engine is set to operate, it is fueled by the test fuels and all these testing have been carried out at ambient conditions. Categorically, all measurements pertaining to engine experiment were repeated for three times to ensure the accuracy of obtained results and average values were used for computation and analysis. Also, an error analysis was duly performed to ensure the uncertainty of the experiment and list of measurement uncertainties of various equipment's used in this study are shown in tab. 4. From these values, total uncertainty of the experi-

Mylswamy, T., *et al.*: Production of Gaseous Fuel from Jatropha Oil by Cerium ...
THERMAL SCIENCE: Year 2016, Vol. 20, Suppl. 4, pp. S1127-S1135

S1131

ment was computed based on method of propagation of errors, as elucidated in Holman and was found to be ±2.79%. [7, 8]

## Methodology

The experiment is conducted in two phases. In the first phase of experiment, the output of the catalytic fuel reactor is condensed using condenser to study the characteristics of the cracked jatropha oil. In the second phase of experiment, the catalytic fuel reactor is to be augmented with the Diesel engine and the output of the catalytic fuel reactor is connected to the intake air manifold of the engine. The temperature of the catalytic fuel reactor is set to 250 ºC initially and the engine is run at different load conditions. The compression ignition engine has to be run at different load conditions like 20%, 40%, 60%, 80%, and 100% load with and without catalytic fuel reformer to compare and study the performance, emission and combustion characteristics.

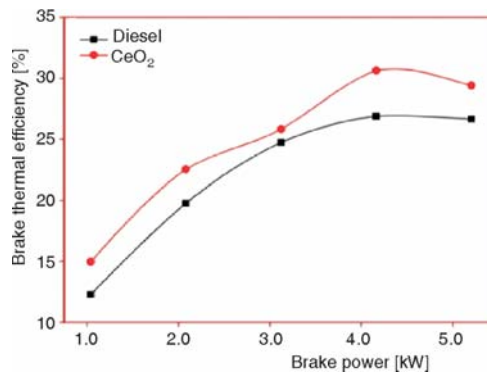**Table 4. Accuracy and uncertainty of the instruments**

| Instrument | Measurement | Accuracy | Uncertainty [%] |
|---|---|---|---|
| Burette | Fuel consumption | ±0.2 cm$^3$ | 1.5 |
| Load cell | Loading device | ±10 N | 0.2 |
| Speed sensor | Speed | ±10 rpm | 1.0 |
| Temperature indicator | Temperature | ±2 ºC | 0.3 |
| Exhaust gas analyzer | CO | ±0.02% | 0.2 |
| | HC | ±10 ppm | 0.1 |
| | NO$_x$ | ±12 ppm | 0.2 |
| Smoke | Smoke density | ±1 HSU | 1 |
| Pressure transducer | Cylinder pressure | ±0.3 kg | 0.3 |
| Crank angle encoder | Crank angle | ±1 º | 1 |

## Results and discussion

### *Brake thermal efficiency*

The variation of brake thermal efficiency (BTE) as a function of brake power for all loads has been shown in fig. 5. In case of normal diesel, the boiling point of it is appropriate and it evaporates immediately after injection, before mixing with air and igniting.

However, processes in the sequence are deemed to get affected when a foreign fuel other than diesel is being used in Diesel engine and so does for the testing of the preheated intake of air and cracked Jatropha gas (CJG) mixture herein. Besides the viscosity, boiling point are reduced because of catalytic cracking of Jatropha oil and have positively affected the fuel evaporation

**Figure 5. Variation of BTE with brake power**

process at the time of combustion to give more premixed charge. Therefore, effective combustion on higher loads of CJG mixture in a Diesel engine takes place. As such, combustion will be duly promoted by the presence of oxygen for the all loads of CJG mixture with diesel [9]. For all these reasons, BTE happens to increase for all test loads with showing the trend with diesel, due to better fuel properties.
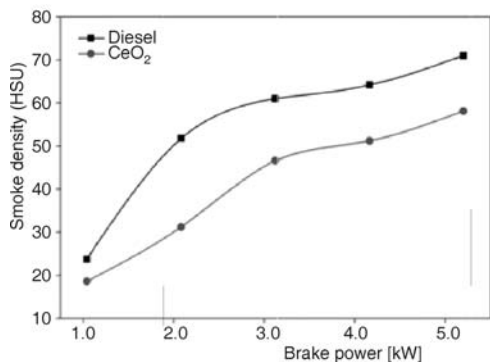
**Figure 6. Variation of smoke density with brake power**
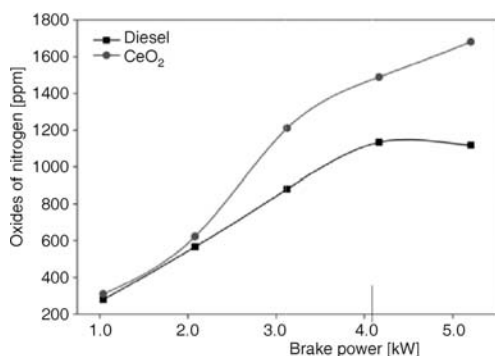


**Figure 7. Variation of NO$_x$ with brake power**
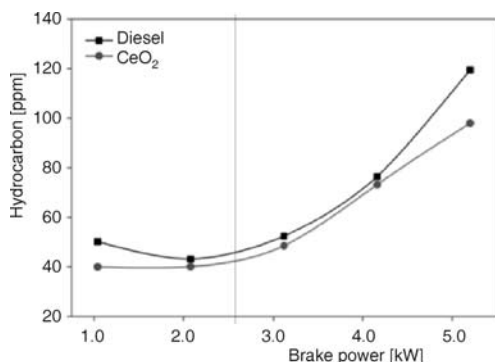


**Figure 8. Variation of HC with brake power**

## Smoke opacity

The lower carbon to hydrogen ratio and absence of aromatics in vegetable oils are reported to reduce smoke emission in a Diesel engine fuelled by vegetable oil based fuel, supported by the presence of oxygen in the fuel. However, in certain cases, dispersion of fuel into fine droplets is affected by higher viscosity of the fuel and in which case, oxidation of soot precursor in diffusion combustion phase is seldom proper and this causes an increase in smoke emission [10, 11].

But in this study the substituted biofuel is in gaseous form and higher incylinder temperature gives more premixed combustion phase. The considerable decrease in smoke emission at all loads has seen from fig. 6 and minimum for 20% load.

## Oxides of nitrogen

In general, NO$_x$ emissions are formed as a result of increased in-cylinder temperature and presence of abundant oxygen in the combustion zone, fig. 7. indicate that higher NO$_x$ emission at all loads as compared to diesel. It is a general token from heat release curve that if the premixed combustion phase is high pronounced, in-cylinder temperature is bound to increase so as to increase NO$_x$ emission [12, 13]. In this connection, much higher pronounced premixed combustion phase for CJG substantiates the reasons for increased NO$_x$ emission.

The oxygen content of the substituted fuel is also one among the factor for higher NO$_x$ emission at all different load conditions.

## Hydrocarbon emission

The HC emission persists in the tail pipe when fuel is completely unburnt or only partially burnt, and it arises from in homogeneity in fuel-air mixing. In this study the HC emission is low in all loading conditions and noticeably low at full load, fig. 8. This is because of the supplement fuel, CJG is in gaseous form and sent in along with the air makes the mixture preparation as homogeneous and high in cylinder temperature makes the proper evaporation of injected diesel fuel.

Mylswamy, T., *et al.*: Production of Gaseous Fuel from Jatropha Oil by Cerium ...
THERMAL  SCIENCE: Year 2016, Vol. 20, Suppl. 4, pp. S1127-S1135

S1133

### Heat release rate

The variation of heat release rate with respect to crank angle (CA) for the substituted Jatropha gas cracked by $CeO_2$ catalyst along with diesel at different load conditions has been portrayed in fig. 9. It showed comparable heat release rate with diesel. The fuel properties of condensed CJG have almost comparable to that of diesel and as such, the combustion characteristics were perceived to be in line with diesel with regards to peak heat release rate and start of combustion. However, peak heat release rate for CJG is early and higher than that of base diesel at full load due to the admission of air and hot



**Figure 9. Variation of heat release rate with CA**

CJG mixing. The preheated intake admission of CJG and air makes the pre ignition and help to reduce the ignition delay as well as increase the premixed phase of combustion.

Normally, vegetable oil based fuel with the presence of fatty acids are reported to have higher bulk modulus or compressibility and because of this, the start of dynamic injection timing is advanced as the high viscous biofuel increases the pressure in the fuel lines to help open the needle value of the fuel injector. Therefore, an advancement of certain CA degree is expected from the static injection timing period for the injection of vegetable oil based fuel when compared with diesel. Further, experimental reports on investigation of trans-esterified vegetable oil in a Diesel engine divulges an obvious reduction in peak heat release rate on account of reduced calorific value of the biodiesel. However, in this case, the CJG does not suffer the drawback of reduced energy density and reduction in peak heat release rate for higher loads is only attributed to the preheated intake of air and CJG mixture. The quantity of diesel is reduced due to the replacement of intake CJG.

### In-cylinder pressure

In a compression ignition engine, in-cylinder pressure depends upon fuel-burning rate during premixed combustion phase and the effect of this has been duly analyzed for all loads. As evident  from heat release curve, the magnitude of premixed combustion phase is high at full load condition shown in fig. 10. The more premixed combustion phase seen from the rate of pressure rise with CA, helps in getting the higher peak pressure than the diesel. The low temperature reaction of the substituted fuel added in intake is helping to get lesser ignition delay and early heat release by making proper mixing of injected diesel.



**Figure 10. Variation of cylinder pressure with CA**

### The CO emission

The CO emission shows noticeable difference in all loads other than 20% load shown in fig. 11. The reason for getting lesser CO emission is because of the presence of oxygen content in the supplement fuel.  The increase in premixed combustion phase seen from the heat re-
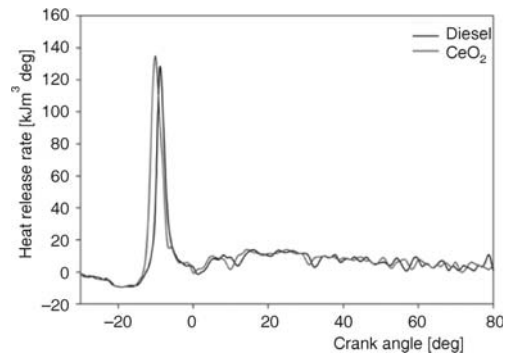
**S1134**

Mylswamy, T., *et al.*: Production of Gaseous Fuel from Jatropha Oil by Cerium ...
THERMAL SCIENCE: Year 2016, Vol. 20, Suppl. 4, pp. S1127-S1135

**Figure 11. Variation of CO with brake power**

lease rate and p-$\theta$ curves due to hot intake of air along with CJG. The preheated air intake helps to get high in cylinder temperature, which causes the reduction in CO emission.

**Conclusions**

Many researchers have tried to find out the benefit of using biodiesel of Jatropha curcas in oil form with different proportions with diesel. The disadvantages of using jatropha oil are its viscosity, transesterification process, and bulk modulus. To eliminate the disadvantages, in this study the oil is cracked under a catalytic environment to make it in gaseous form. From this study the following points were observed. Peak heat release rate for CJG is early and higher than that of base diesel at full load due to the admission of air and hot CJG mixing. The more premixed combustion phase seen from the rate of pressure rise with CA, helps in getting the higher peak pressure than the diesel.

The viscosity and, boiling point are reduced because of catalytic cracking of Jatropha oil and have positively affected the fuel evaporation process shows the effective combustion on higher loads of CJG mixture in a Diesel engine takes place. The BTE happens to increase for all test loads with showing the trend with diesel, due to better fuel properties.

The considerable decrease in smoke emission at all loads and minimum for 20% load. In this connection, much higher pronounced premixed combustion phase for CJG substantiates the reasons for increased $NO_x$ emission. The CO emission shows noticeable difference in all loads other than 20% load. The reason for getting lesser CO emission is because of the presence of oxygen content and higher incylinder temperature. The supplement fuel CJG is in gaseous form and sent in along with the air makes the mixture preparation as homogeneous and high in cylinder temperature makes the proper evaporation of injected diesel fuel.

So the utilization of Jatropha curcas in gaseous form by using thermal cracking technique gives better performance and emission characteristics than its oil form and base diesel.

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Mylswamy, T., *et al.*: Production of Gaseous Fuel from Jatropha Oil by Cerium ...
THERMAL SCIENCE: Year 2016, Vol. 20, Suppl. 4, pp. S1127-S1135

S1135

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