Performance and Durability Test of Diesel Engine Generator Using Hundred Percent of Jatropha Curcas L. Oil

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Abstract— *The research paper aims to develop the process of generation technology using neat Jatropha Curcas Oil (JCO) as diesel engine fuel. In this paper, an experiment on a four-cylinder diesel engine generator is carried out. The research is started by development of fuel oil processing technology from Jatropha seed. The phosphorus, which is forming as phospholipids in Jatropha oil, was removed up to about 10 ppm by water degumming method. The development of power generation technology by straight use of Jatropha oil in diesel engine has been performed. The result is shown that operating conditions of medium size diesel engine with the Dephosphorized Jatropha Oil (DJO) were stable. The effects of DJO on the engine performance, durability and exhaust gas emission had been investigated. The Oxides of Nitrogen (NOx) and Carbon Monoxide (CO) concentrations in exhaust gas of diesel engine with Jatropha oil were lower and higher, respectively, than that of the light oil. The combustion has been improved by raising the fuel injection pressure. The result of the overhaul consideration after long time 300 hours durability test is shown that engine main parts related to the fuel combustion are still in normal functional conditions. Finally, this research experiment confirms that diesel engine generator can be operated by hundred percent of DJO with respect to some modifications of engine cooling system.*

Keywords— **Biofuel, Diesel engine, Generation technology, Jatropha Curcas L.**

1. INTRODUCTION

Due to the depletion of the world petroleum resource and the increasing of exhaust gas, further efforts on the research to seek for new energy and reduce the exhaust gas emission have been made to fulfill the huge energy demands today [1]-[3]. From this aspect, biofuel has been discovered as the most promising fuel for energy production and emission reduction.

Jatropha oil has various uses. Apart from its use as a liquid fuel, the oil has been used to produce soap and biocides (insecticide, molluscide, fungicide and nematicide). The oil can be directly used in older diesel engines or new big motors running at constant speed (e.g. pumps, generator), blending with fossil diesel and/or other fossil fuels belongs to options as well. The oil can be transesterified into Jatropha methyl esters that can be used in conventional diesel engines with adapted parameters.

In present experiment, Jatropha oil is a promising alternative fuel that can be used in diesel engine since its properties, except viscosity, are similar to those of diesel fuel. This viscous oil has been studied in various ways. Some researchers have investigated the viscosity of the light/Jatropha oil blends to be used in diesel engine [4]-[7]. It is shown that the viscosity of the blend is low as much proportion of diesel fuel is contained. Due to high viscosity and the present of wax and gum, raw jatropha oil as such cannot be used in diesel engine properly [8].

An approach to use it appropriately is considered that JCO must be de-gummed before it is supplied to a diesel engine so that why the simple dephosphorization processing technology was developed to remove gum in the oil through an examination test devices and was able to achieve an expected aim.

The objective of this research paper is to study the development of power generation technology utilizing hundred percent of JCO and to investigate behavior of an unsteady power of diesel engine. The research was covered the process of oil squeezing technology from the Jatropha seed, technology of removal phosphorus from Jatropha oil and the process of the generation technology in order to operate engine by neat JCO. In this case, preheating of the dephosphorous oil had been prevented before it supply to the engine fuel system to avoid the difficulty of pumping. Diesel engine had been modified to be used in dual fuel, light oil and neat DJO. The emissions, gum formation and injector deposits have been observed in standard condition and in the case that the injection pressure is increased about five percent to sixteen percent. Engine overhaul was checked after 300 hours running test to evaluate the effects of the phosphors remaining in utilized JCO. Diesel engine generator was also tested for performance comparison between light oil and DJO. Experimental results such as

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This research is one of the international joint research projects funded by New Energy and Industrial Technology Development Organization (NEDO) for International Cooperation Research Program, which has been done with Chugoku Electric Power Co. Inc., Japan under the supervision of Ministry of Industry, Mines and Energy. Special thanks to NEDO for providing the fund and to the Chugoku EPCO team for the cooperative research during fiscal years 2009 and 2010.

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limit of phosphorus content, brake specific fuel consumption (BSFC), thermal efficiency and also amount of exhaust gas composition during long term and performance tests will be reported in the next sections.

Finally, the research and development of performance and durability test of diesel engine generator using hundred percent of JCO had been applied and achieved at the Institute of Technology of Cambodia. Base on our research plan, the development of biomass gasification devices are under construction in objective to mix combustion between Jatropha oil and biogas produced from Jatropha squeezing cake and other mixtures consisting of agriculture wastes that are available in Cambodia.

2. EXPERIMENTAL SETUP

The pilot plant is composed from six units: oil pressing machine, de-phosphorizer, filter press machine, diesel engine generator, switch board and Jatropha seed roast machine. The new model of SP100 screw press machine was used for the oil pressing from Jatropha seed. The squeezing capacity is 80 to 100 kg seed/h. The de-phosphorizer type BDK-100S was used in research pilot plant with capacity of 130 L, powers supply AC200V with a 30A for heating resistance and together with 1.5 kW of agitator motor. Jatropha oil filter pressing machine was used to screen small debris and other undesired substances from oil before putting it as fuel into engine. The filtering capacity is 100 to 150 L/h.

A four-cylinder water-cooled turbo diesel engine generator developing 40 kW power at 1500 rpm was equipped in pilot plant. Power output from the unit that joining to the switch board unit are installed with main circuit breaker for supplying electricity to all devices and connected to four heating resistance loads of five kilowatt each. A several thermocouples are arranged to the generating sets for recording all necessary data values from the heat. These sensors are connected to the digital data acquisition interfaces "Data logger GL 800" for recording and documentation. An exhaust gas analyzer "Testo 350" is also interfaced to data logger for measurement of exhaust gas composition. Jatropha seed roasting device had been reserved for heating the seed by using an extra-heat from exhaust gas during diesel engine operation.

Experiments were initially carried out on dual fuel diesel engine generator. Light oil is used to start and warm engine for maintaining the temperature of cooling water about 80ºC. The last one is used like heat-exchanger for heating DJO as fuel before it switch on to fuel injection system. Light oil is also resupplied to the fuel injection system at the end of diesel engine operation for cleaning DJO from the fuel system to avoid any difficulty in starting process of the next operation.

3. DEVELOPMENT OF THE FUEL OIL PROCESSING TECHNOLOGY

The reference [9] had been reported the methodology for development of the fuel oil processing technology from Jatropha seed, development of removal technology of phosphorus from Jatropha oil and also development of power generation technology by using DJO.

Squeezing process

As reported hereinabove screw press machine SP-100 is used for the experiments. The Jatropha seed supplied from the seed hopper moves into the space of the screw and the screw casing, where capacity becomes small heading for exits, and Jatropha seed is compressed between its. The screw casing is a slit where tens of square sticks were combined like the cylinder, and the Jatropha oil is squeezed from this space. Jatropha crude oil squeezed contains fine residues of seed cake. It is naturally precipitated spending at least three days. The supernatant is filtered with the cloth while naturally precipitating. The Jatropha seed cake is defecated by small shape if the_frequency of squeezing oil increases. This cake contains various toxins and is therefore not usable as fodder. However it is useful as fertilizer. The seed cake can serve also as feed for biogas production in gasifier.

Seed heating before oil squeezing was conducted because it was reported that oil and the protein separate when the temperature of the seed is adjusted to 70ºC or more to which the protein denatures and oil pressing efficiency improves. The exhaust gas of the diesel engine passing through roasting unit was used for heating the seed.

It is noted that the efficiency of squeezing oil is in range of 80%. In average, for Cambodian Jatropha seed, oil yield in the seed is equal to 36% by weight. The seed roasting at 70ºC to 100ºC is effective to improve the oil press efficiency. The time squeezing is also reduced. Oil can be hardly squeezed at second or third time processing. But it is preferable to squeeze oil by one time at best seed condition from the viewpoint of the power consumption, in average 0.05 kWh/kg seed, for this type of oil pressing machine. Particularly, oil squeezing efficiency is depended also from the quality of the seed collected, from the types of squeezing machine and from qualification of the operator who managed this work.

Dephosphorization process

The phosphor removal process was examined using the water degumming method, basically by adding water to the Jatropha oil and exhausting phosphorus with drain. This method had been developed in laboratory scale by joint researchers from National Institute of Advanced Industrial Science and Technology, Japan and ITC.

In pilot project, the amount of JCO after first filtration was poured into dephosphorizer. Oil is preheated and stirred by machine agitator for about 20 minutes to reach a temperature 70ºC. After that, the amount of water (5% by weight regarding to JCO) must be added like shower into JCO. Afterward, the temperature of 70ºC was maintained and the process of agitation is continuing for 30 minutes at 180 rpm. During this time the emulsion of oil and water was formed immediately. For separation of waste water from oil the agitation was stopped and the mixture was left for 30 minutes at the room temperature. After that the drain water with soluble substances was drawn out from the bottom of dephosphorizer. Water was added three times for one dephosphorisation experiment. The second and third washing were done with the same process as the first one. The samples of DJO and drained water after each washing process were obtained for measuring its phosphor content. In pilot scale DJO is filtered second time by press filter before it use as diesel engine fuel.

Project experiments provided the results as following: crude oil after seed squeezing contained phosphor about 1328 ppm, then this amount is reduced to about 50 ppm and to around 10 ppm respectively for Jatropha oil before and after dephosphorization. The experiments were confirmed that the amount of around 10 ppm of phosphor remained in oil is satisfied to be used as fuel in diesel engine without any troubleshooting.

Production cost analysis

According to the quality of Jatropha seed for the whole process, in average, we need 4 kg seeds for producing 1 kg DJO. In Cambodian market the price of Jatropha seed is around 0.175US$/kg seed. The labor cost for producing DJO is estimated to 0.02US$/kg seed. As mentioned hereinabove we spends in average 0.05 kWh/kg seed, so electricity cost is equal to 0.0125 US$/kg seed. And for the mass production we count also for the equipment amortization that costs about 0.005US$/kg seed. Finally, including some other expenses (0.005 US$/kg seed) for producing 1 kg of DJO we spend around 0.87 US$. This price is considered high. We expect that it will be decreased in term when the price of the seed reduces with growing of Jatropha plantation against the price of fossil fuel.

4. DEVELOPMENT OF POWER GENERATION TECHNOLOGY USING DJO

In this experiment diesel engine generator was modified to be used dual fuel system. Light oil is supplied to diesel fuel system directly while DJO was oriented for passing by heat exchanger. A special faucet is installed for changing fuel supply from light oil to Jatropha oil and inverse. Cooling water with operational temperature varied from 70ºC to 85ºC exited from engine head cylinder is flown through heat exchanger and exchanged heat with DJO before entry back to radiator.

Experimental data records are shown that during diesel engine operation the temperature of DJO was in average 50ºC, when the temperature of cooling water in heat exchanger reached above 80ºC. In consequence, the kinematic viscosity of JCO at this time was less than 30 mm^2/s. The value of kinematic viscosity is considered decrease to around 20 mm^2/s in instant of fuel jet from injector nozzle into engine cylinders.

Engine combustion has been improved also by rising injection pressure. In experiments, we changed the injection pressure two times. Injection pressure is increased by adding the thickness of injector adjusting shim. Engine was operated using neat DJO by standard fuel injection pressure (21.6 MPa), then by 7% and 16% pressure rising respectively. New injectors with corresponding pressure adjustment were changed after every 40 hours engine review check. An engine head cylinder was disassembled to examine the situation of the fuel injector nozzle. The results showed that the abnormal carbon sedimentation inside of engine and obstruction of jet pressure of fuel injector nozzle were not recognized. For long term durability and performance tests a 16% of fuel injection pressure rise (25.0 MPa) was adjusted. This choice is done due to it good fog spray injection which improved the combustion of heating DJO.

5. DURABILITY TEST

From the result of the combustion improvement and the collection of the basic data in the JCO raising fuel injection pressure improved fuel injection characteristics inside of engine. It was confirmed that the CO density is fall down by the improvement of the incomplete combustion; the NOx density is increased by rising the combustion temperature.

The long term durability test was carried out in this pilot project. The duration of the test is 300 hours with proximately constant load equivalent to 20 kW of power generation. The purpose of the test is to investigate the effects of the fuel on exhaust gas emission and on engine components. Engine had been running consecutively from eight to ten hours per day. The test conditions were the same as mentioned hereinabove. Light oil is used for starting and ending the operation and in the remaining time engine was running by neat DJO.

Results and discussion

Table 1 shows the long term test result of exhaust gas temperature and four kinds of exhaust gas emission respectively such CO, NOx, carbon dioxide (CO_2) and oxygen (O_2). For comparison, in average the exhaust gas temperature of JCO measured at exhaust gas manifold increased around 39ºC regarding to which of light oil. It is reasonable, because the high viscosity and low cetane number of JCO provoke the late pre-ignition and main combustion. In consequence, the retardation of main combustion results to remain more fuel burnt at late combustion.

Table 1. Data of exhaust gas emission in average

Fuel type	CO, [ppm]	NOx, [ppm]	CO2, [%]	O2, [%]	Exhaust gas temperature
Light oil	225	499	5.54	14.32	250ºC
DJO	425.9	425.2	6.0	13.3	289ºC

The Figure 1 presented more details about evolution of exhaust gas emission during long term durability test. The amount of CO emission for engine running by DJO is higher than which of the light oil, but it is still limited under standard environmental requirement (500 ppm). We observed that the amount of CO became higher at the end of long time testing period. Some time it was closed to standard limit value. This explained the incomplete combustion due to some formation of the gums in injector nozzle and due to effect of viscosity of JCO. The NOx emission of DJO is decreased compared to light oil. The lower combustion temperature results the reduction of NOx emission. CO2 emission is an exhaust gas producing by the fuel oxidizing reaction. The amount of CO2 increases due to increasing of the mass of DJO consumed. Oxygen content in the exhaust gas is the rest of O2 in the combustion reaction. For this experiment, the amount of O2 contained in the exhaust gas of DJO is lower compared to the light oil.

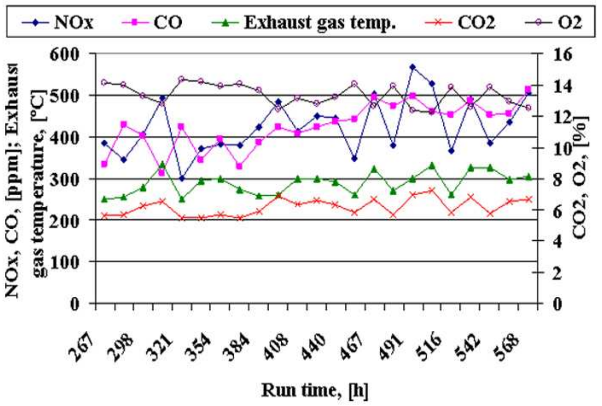

Fig.1. Evolution of exhaust gas emission during durability test.

Fig.2. State of injector nozzle after overhaul.

Fig.3. State of top side of pistons after overhaul.

During long time durability test engine was operated smoothly, no any troubleshooting was found. The overhaul of engine after long running time was allowed us to recognize the effect on inner engine components. Figure 2 shows that the gums were found only around injector nozzles in small quantity. Separated injectors were checked for injection spray by manual injection pump. Injection spray was in good condition for all injectors, obstruction of nozzle holes was not found. Besides that, as shown in Figure 3, the inner side of combustion chamber and top side of the pistons are still cleaned. That means the gums caused by phosphorus content in oil are reduced and the remaining was burnt by high combustion pressure. The other components related to combustion chamber were in normal conditions.

6. PERFORMANCE TEST

The long term durability test was surely confirmed that diesel engine can be operated by DJO. Performance and exhaust gas emission tests were pursued an experiment for comparing the results of engine performance and exhaust gas emission. Diesel engine generator was run on constant speed 1500 rpm using light oil and DJO with the variation of the power output. Four resistances heaters and one heating resistance of dephosphorizer were used as the engine loads corresponding respectively to 20, 35, 50, 65, and 80 percent of engine loads. The data of exhaust gas emission such as CO, NOx, Hydrocarbon (HC), CO2, and O2 were recorded by exhaust gas analyzer during performance test period.

The main properties of diesel and Jatropha oils are given in Table 2, as in [6]-[8]. The results show that the calorific value of the vegetable oil is comparable to the diesel oil and cetane number is slightly lower than the diesel fuel. However, the kinematic viscosity of JCO is several times higher than the light oil.

Table 2. Fuel properties

Properties	Light oil	Jatropha Curcas oil
Density at 40 °C, [g/cm^3]	0.8253	0.933
Kinematic viscosity at 40 °C, [mm^2/s]	3.15	34.4
Calorific value, [MJ/kg]	42.7	38.2
Cetane number	51.5	38

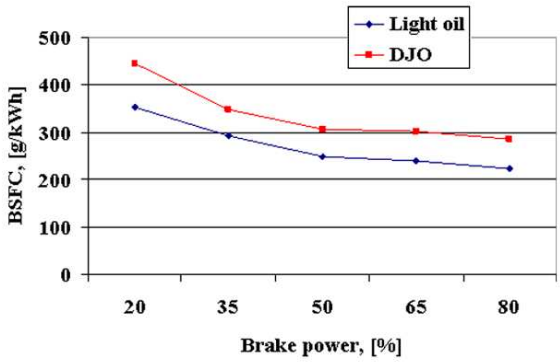

Fig.4. Evolution of brake specific fuel consumption.

Results and discussion of the performance test

The performance of the diesel engine was evaluated in term of brake specific fuel consumption, brake thermal efficiency and exhaust gas temperature.

The figure 4 compares the BSFC of light oil and DJO at varying brake power loads in the range of 8 to 32 kW. It was observed that the specific fuel consumptions of the light oil as well as the DJO were decreased with increasing of the loads. The fuel consumptions for DJO were found higher for about 19% compared to light oil in the entire load range. This is mainly due to the combined effects of the relative fuel density, viscosity and heating value of the oils.

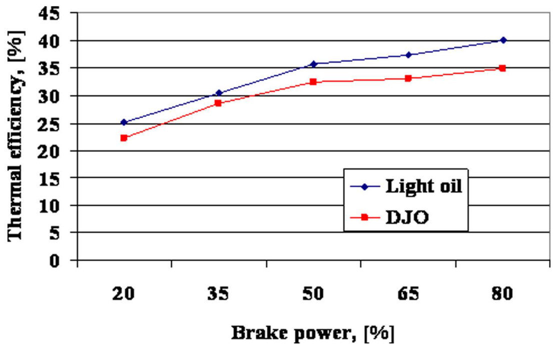

Fig.5. Evolution of brake thermal efficiency.

The variation of brake thermal efficiency of the engine running by light and Jatropha oils is shown in Figure 5. From the test results it was observed that initially with increasing of brake powers the thermal efficiencies of both fuels were increased. The efficiency of DJO is low for about 8% with large deviation at high load compared to light oil. This is because of it low heating value and its poor combustion which reduce the ability to convert the energy from the oil.

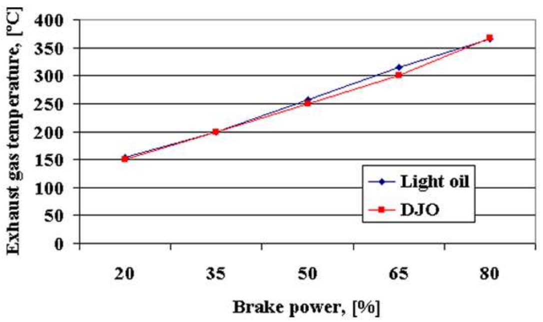

Fig.6. Evolution of exhaust gas temperature.

The Figure 6 shows the variation of exhaust gas temperature with loads in the range of 8 to 32 kW for light oil and DJO. The results show that the exhaust gas temperatures increased with increasing of brake power in all cases. Exhaust gas temperatures of each fuel are not so much different, this shows that most of the fuel burn in the main combustion and they have similar combustion temperatures. For records these values are started from 150ºC to 368ºC respectively for 20% to 80% loads.

Results and discussion of emission test

The Figure 7 shows that CO emission levels are higher with DJO as compared to light oil at all loads. The concentration of CO is become higher with increased load on the engine. It is noted that for the performance test the maximum value of CO emission is around 382 ppm. The amount of CO concentration for DJO is too high at low brake power load. It is due to low temperature of cooling water in this condition that effected to viscosity of DJO and in consequence the combustion was not complete.

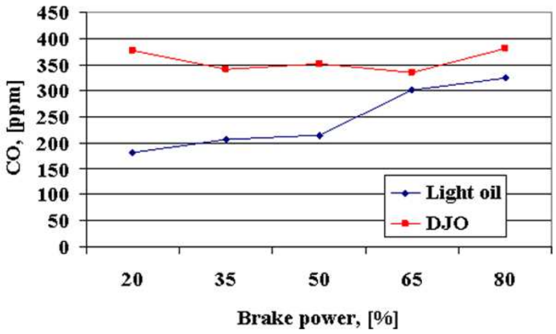

Fig.7. Evolution of CO emission.

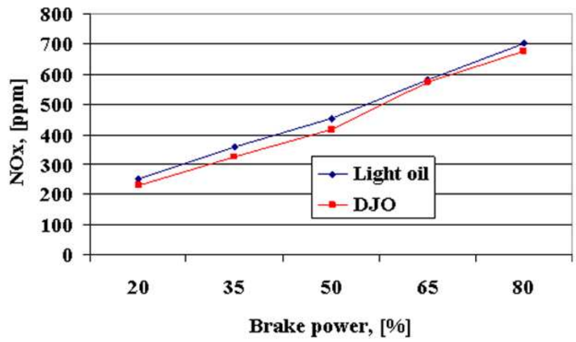

Fig.8. Evolution of NOx emission

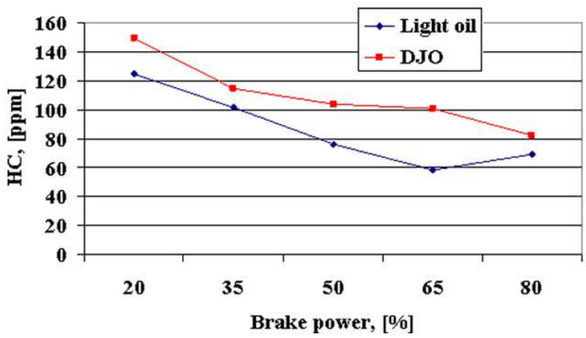

Fig.9. Evolution of HC emission

The NOx emission is related to the combustion temperature. Higher combustion temperature gives more NOx emission. The Figure 8 shows that the values of NOx emission for light oil and DJO are close each to other. These values are increased with increasing of the loads. The values of NOx were varied from 231 ppm to 701 ppm respectively for 20% and 80% loads.

The HC concentration found in exhaust gas is shown in the Figure 9. Jatropha oil exhibits higher HC emissions compared to standard diesel operation. This is because JCO have higher viscosity which causes poor atomization. The poor atomization leads the incomplete combustion and increases more unburned fuel in exhaust gas. The gap of HC density between these two kinds of fuels is in average 22%. The Figure 9 shows for both fuels the drop of HC density when loads are increased. For DJO it changes from 149.4 ppm to 82.24 ppm while for light oil the variation is from 124.37 ppm to 69.2 ppm.

An evolution of the CO2 and O2 emissions with variation of the power loads is shown in Figure 10. The concentrations of the CO2 for light oil and DJO are similar. The values of CO2 for both fuels were increased from 3.04% to 7.51% with increasing of the loads respectively from 20% to 80%. In inverse, the values of oxygen for the both fuels were decreased with increasing of the loads. The amounts of O2 emission for both fuels are very close each to other in range of 16.73% for 20% load and around 10.71% for 80% load. This shows the regular proportion of the combustion product after fuel is burned with oxygen in air.

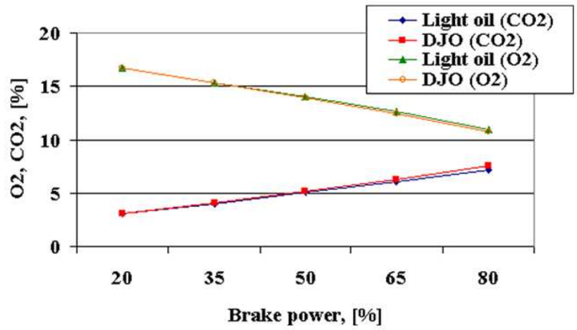

Fig.10. Evolution of CO2 and O2 emissions.

7. CONCLUSIONS

An experimental investigation was conducted to explore the performance of Jatropha oil in diesel engine generator. The improvement results show that roasting seed is squeezed efficiently. Jatropha crude oil can be extracted 30% by weight from the seed. Phosphor remaining in DJO was around 10 ppm. It has been removed by development of water degumming method. The combustion has been improved by rising injection pressure for 16%. The kinematic viscosity of DJO was reduced to around 20mm^2/s by using the heat released from cooling water that allows engine operated smoothly.

The results of exhaust gas emission during durability test show that only the amount of CO concentration for DJO was higher than which of light oil, but it is still acceptable for this kind of machine. The values of the other exhaust gas emission for DJO are comparable with light oil. Overhaul check has been done and shown that the engine components are still in normal operational conditions.

The engine performance test provided us very satisfied results which is proven that the higher BSFC and low thermal efficiency of DJO are proportional to it properties as vegetable fuel regarding to fossil fuel, whereas an exhaust gas temperature was presented the similar evolution with the loads. The results of emission test were also acceptable. The amount of NOx, HC, CO2, and O2 gases were very close each to other for both tried fuels, except for CO emission that shown higher at low power load. As mentioned hereinabove it is not exceed 382 ppm. This result seems better comparing to value recorded at durability test.

The durability and performance tests are fully confirmed the possibility of straight use of dephosphorized Jatropha oil as alternative fuel in diesel engine generator. The research and development is continuing to improve the combustion technology and energy efficiency from Jatropha seed oil.

For improvement of the combustion we recommend that the viscosity of DJO should be reduced more than indicated value by modifying heat exchanger. This change is not caused any damage for diesel engine, just to extend the flown time of DJO in heat exchanger.

As mentioned before, we advise to use DJO as fuel for diesel engine generator. In this case we can increase energy balance by using biomass gasification from Jatropha seed cake to mix with DJO for running diesel engine generator. The development of generation technology by mixed combustion of biomass fuel from JCO and Jatropha seed cake is being experimented.

In the near future, we expect that with increasing of the price of the light oil Rural Electrification Entrepreneurs (REE) in remote areas, where Jatropha seeds are available, will refer to use straight DJO or biomass gasification in their power plant to generate electricity. We estimate also, when DJO production is grown, in term of industrial scale, widely practical applications of DJO will be suitable for many kinds of agricultural machines with modification of diesel engine fuel supply system.

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