

Emission Characteristics of a Diesel Engine Fuelled with Preheated Vegetable Oil and Biodiesel

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Currently, there are many studies carried out aimed at finding alternative fuels. These renewable resources are potentially useful for the environment since they could replace the depleting fossil fuels. The emission characteristics of diesel engine fueled with diesel oil (DO), biodiesel from *Jatropha* oil (JOME), and preheated coconut oil (PCO) were used for comparative analysis. The fuels were tested at full load and different revolution, from 1000 rpm to 2000 rpm of engine speed. The exhaust gas temperature (T_{ex}) and emission parameters such as carbon monoxide (CO), unburnt hydrocarbons (HCs), smoke, and oxides of nitrogen (NO_x) were measured and compared. Results showed that, relative to diesel fuel, the CO and HC emissions were higher in the case of using preheated coconut oil and lower in the case of using JOME. The NO_x emissions were also seen higher for JOME and lower for PCO in comparison with DO. Findings of this paper denote that JOME and preheated coconut oil up to 100° C (PCO_t100) can be considered as fuels for diesel engines.

Key words: biodiesel, bioenergy, bio-fuels, emission, vegetable oil

INTRODUCTION

Currently, air pollution is ruining massively our life, environment, and health, as speedy depletion of fossil fuels is occurring and energy demands are ever increasing. These urgent matters require us to find the alternative fuels that would satisfy our energy demands and provide sustainable and maximum benefits for the environment. The use of fossil fuels for transportation (e.g., car, motorcycle, airplane, ship, and train) causes most of the air pollution. Hence, manufacturers have designed and fabricated engines that can run on various alternative fuels and satisfy regulatory emission limits. Many past and ongoing studies worldwide – even in many developing countries – have sought to evaluate the performance of existing engines in terms of power, moment, specific fuel consumption (SFC), exhaust emission, and combustion

characteristics. Alternative fuels explored for use by internal combustion engines (ICE) include alcohols, liquefied petroleum gas (LPG), biogas, biodiesels, preheated vegetable oil, hydrogen, compressed natural gas (CNG), bio-ethanol, bio-methanol, dimethyl ether (DME), diethyl ether (DEE), and fossil fuel blends. Several researchers have concluded that biodiesel and preheated vegetable oils hold highly promising potential when used as alternative fuels in ICEs if their properties are improved to the same level as those of diesel fuel (Canakci et al. 2003).

Hence, biodiesel and preheated vegetable oils may be used to replace conventional diesel fuels in diesel engines without modifications. Well-mixed blends of diesel fuel with biodiesel or preheated vegetable oils have high lubricity, which reduces the wear on the engine injector/ injection pump and increases its longevity. In addition, biodiesel and vegetable oil are

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renewable and biodegradable, aromatics-free, and oxygen-containing (10–11% by weight) with molecular structures deemed comparable with fossil diesel fuels. Some engine manufactures have also confirmed that if biodiesel and vegetable oil are to be used as alternative fuels in diesel engines without any modification, their properties could be improved to approximate those of diesel fuel but more research is required (Canakci et al. 2006). Engine emissions such as particulate matter (PM), carbon monoxide (CO), and unburnt hydrocarbons (HCs) are reduced significantly in compression ignition engines in the case of biodiesel usage. Otherwise, these emissions increase in the case of vegetable oil. However, a slight increase in emissions of nitrogen oxides (NO_x) is reported in the case of biodiesel usage in comparison with diesel fuel (Ming et al. 2008). Moreover, the increase in NO_x formation and emission from engines fueled by biodiesel or blends may be explained by lower soot levels in the engine combustion chamber resulting to the reduction of radiation heat transfer, which raises the temperature in the combustion chamber. Certainly, as implied, the temperature is directly proportional to the NO_x formation and emission (Zheng et al. 2006; Puhan et al. 2005). However, the homogeneous mix of combustion at low temperatures is considered as an advanced technology that offers a highly-promising solution that could dramatically reduce the formation of NO_x , PM, and smoke.

Among many researchers, Monyem and colleagues (2001) have shown investigation results implying that the oxidation of biodiesel after storing for a period of time might affect the biodiesel properties due to heating while oxygen is bubbling. Srivathsan and colleagues (2008) showed that the ignition delay was shorter and unburnt HC emission was lower after this process. Dorado and colleagues (2003) used olive oil methyl ester (OOME) and diesel fuel for a four stroke-three cylinder-diesel engine. They observed a constant combustion efficiency for both fuels but a significant decline in biodiesel SFC, wherein emission reductions were observed for CO (58.9%), CO_2 (8.9%), NO (37.5%), and NO_x (32%) in comparison with diesel fuel. The results with an increase in SFC and a reduction CO, CO_2 , and NO_x emissions (especially -63% for HCs and -70% for smoke) while using 100% biodiesel for a four-stroke-direct injection-diesel engine (in comparison with diesel fuel) are reported by Puhan and colleagues (2005).

Vegetable oils may be compared to diesel fuel in terms of cetane number (CN), vaporization heat, and ratio between stoichiometric air and fuel. Furthermore, vegetable oils are biodegradable, non-toxic, renewable fuel materials that offer significant reduction in sulfur oxides (SO_x), polyaromatic hydrocarbons (PAH), smoke,

PM, and noise (Sendzikiene et al. 2006). However, the influence of greenhouse gases (GHGs) from vegetable oils is not worth mentioning, because GHGs produced in combustion are recycled as CO_2 during photosynthesis and absorption process by the plants (Agarwal et al. 1998). Several researchers have shown that vegetable oils can be directly used or diesel-blended in diesel engines (Forson et al. 2004; Ramadhas et al. 2005a). In addition, Almeida and colleagues (2002) have reported about using 100% vegetable oil with minor fuel system modifications. Some results indicate that SFC, CO, and HC emissions were higher, otherwise NO_x and PM emissions were lower than those of diesel fuel (He & Bao 2003; Yu et al. 2002). Nevertheless, some disadvantages of using directly pure vegetable oils as fuels are manifested as lubricating oil thickening, deposits, ring sticking, coke in injector, and gum formation (Altin et al. 2001). These issues are mainly due to higher kinematic viscosity and surface tension, poor volatility, and atomization due to larger molecular weight than those of diesel fuel. Under these conditions, volatility is low, mixing of fuel with air is inefficient and, of course, combustion progress is incomplete. These factors not only increase PM, CO, and HC emissions and deposits but also enable gum formation and occurrence of unburnt fuel in the lubricating oil. Because of the aforementioned problems, pure vegetable oils have to be modified and improved in order to bring their properties closer to diesel fuel.

There are four known techniques that could reduce kinematic viscosity and thereby improve biofuel properties: heating or pyrolysis, emulsion with low viscosity liquid, dilution or blending, and transesterification (Nwafor 2004; Nabi et al. 2006). However, the heating method is the simplest one and may be applicable for static generator, small ship, or forestry/agricultural diesel engine. The heating method that utilizes the energy from exhaust gas/cooling water or electricity is usually mentioned. However, the high-energy exhaust gas from diesel engine may be used and utilized in order to heat up high- viscosity biofuels such as vegetable oils.

In this study, the researchers used pure biodiesel from *Jatropha* (JOME) and preheated PCO available in Vietnam for a small diesel engine with 58.88 kW of power, which may be installed in small ships/boat or agricultural field in the country's Southern Mekong Delta region. The experimental results in terms of exhaust gas temperature, fuel mass, and emission characteristics are carried out on the test bed with JOME and preheated PCO in comparison with DO.

MATERIALS AND METHODS

Materials

Jatropha oil methyl ester

Jatropha is also known as the "diesel tree", with the scientific name *Jatropha curcas* L. It is a perennial shrub that grows and develops well in areas with near-sea level altitude. One of the tree's prominent characteristics include drought tolerance, as it can grow in Vietnam's arid areas for 8-9 months without dying. Furthermore, it can grow on sandy soil and in many different types of land, including rocky and salty lands but not flood lands. This plant grows very rapidly and bears fruits after growing 6 months to 1 year and about 5 years for stable yield, completing its life cycle within 30-40 years. Fruit productivity depends on breed and cultivation technique, ranging 3-10 tons of seeds/ha and 1-3 tons of crude oil/ ha. Oil ratio also varies from 25% to 38%. In Vietnam, biodiesel from Jatropha oil can be produced by the catalyst $SO_4/ZrO_2/SBA-15$ or some oxides (e.g., WO_3/ZrO_2 , $TiO_2/ZrO_2/SO_4$, MCM-41) in the transesterification reaction with methanol.

Coconut oil

Coconut trees are cultivated in most cities and towns in Vietnam's southern region. The use of PCO as fuel for family generators in the Mekong Delta has been known for many years, but there have been no studies that evaluate the effect of coconut on engine performance and emission characteristics. During Jan 2016, quantity of exported coconut oil amounted to 37.862 tons for the Cochin grade, 22.632 tons for crude grade, and 344 tons for RBD grade. Therefore, with Vietnamese Government policy on bio-fuels development, using PCO as fuel is very significant. The characteristics of JOME and PCO in comparison with DO are given in Table 1.

Table 1 shows that the density, surface tension and kinematic viscosity of JOME are slightly higher than those of DO and hence, JOME may be used directly as fuel in

diesel engine without improving properties. However, PCO density is about 10% higher, PCO surface tension is 35% higher, and PCO kinematic viscosity is 8-12 times higher than those of DO. In fact, fuel surface tension and kinematic viscosity will greatly affect the atomization, mixture, combustion, emission characteristics, and exhaust gas temperature of diesel engines. However, PCO properties are able to be improved by heating method. In addition, relative to DO, calorific value is about 7% lower for JOME and about 15% lower for PCO. Therefore, these values cause lower obtained engine power in comparison with DO.

Methods

The research study used heating method for PCO. To measure kinematic viscosity of the PCO samples, the ASTM D 445 standard and CANNON viscometer tube were used for this purpose. This viscometer constant was 0.0359 and measurable kinematic viscosity had a range of 2- 40 cSt with 2% accuracy. The used water bath temperature to heat PCO had a range of 40-110° C. Kinematic viscosity of PCO as a function of temperature is shown in Fig. 1.

Fig. 1 shows that the kinematic viscosity of coconut oil at 100-110° C is equal to that of DO, although surface tension and density are still slightly higher. However, to get exact results due to latency temperature, this study used preheated coconut oil at 80° C (PCO_t80), 100° C (PCO_t100), and 120° C (PCO_t120) unlike JOME and DO, which were used at room temperature.

Experimental setup

In this study, the engine parameters (i.e., exhaust emissions and temperature) were investigated and determined by the high-dynamic engine test bed at Lab of IC Engine. The diesel engine D243 was used as testing object because

Table 1. The characteristics of JOME, coconut oil, and DO at 30° C.

Fuel	ASTM standards	JOME	Coconut oil	DO
Density (g/cm ³)	D1298	0.87	0.91	0.845
Kinematic viscosity (cSt)	D445	4.5	37.3	3.5
Surface tension (mN/m)	D971	28	34	25.5
Cetane number	D613	50	40	45
Calorific value (MJ/kg)	D240	42	39	45
Flash point (°C)	D93	170	200	71
Cloud point (°C)	D 97	-3	21	-12

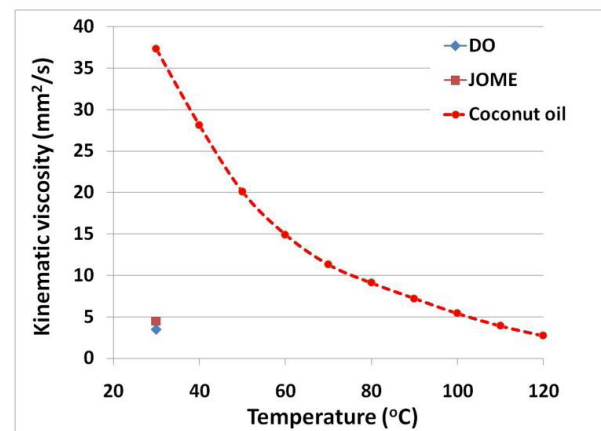


Figure 1. Kinematic viscosity of coconut oil as a function of temperature.

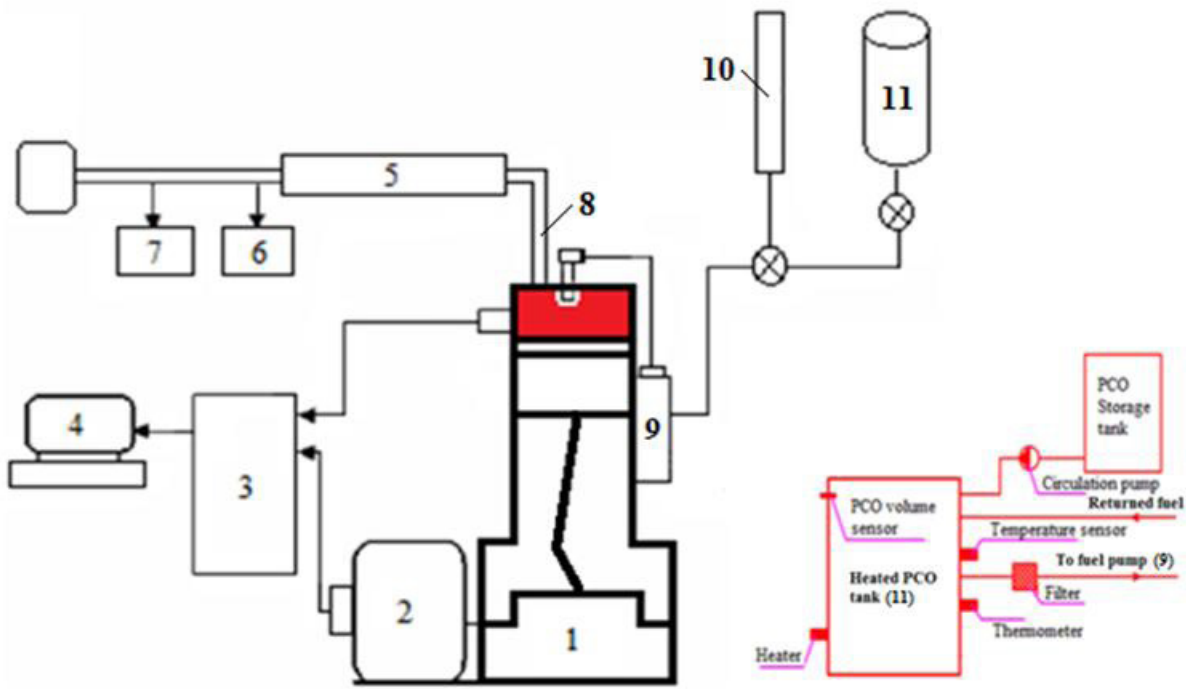


Figure 2. Schematic of experimental setup on D243 test bed. 1) diesel engine D243, (2) electronic brake APA100, (3) data acquisition system, (4) PC, (5) exhaust gas flowmeter, (6) smoke meter, (7) gas analyzer, (8) exhaust gas temperature sensor, (9) fuel pump, (10) fuel balance, and (11) fuel tank

of its cheapness and familiarity to people in rural areas. This engine can be used in agricultural devices as well as a power generator. This engine was fuelled with JOME, PCO (PCO_t80, PCO_t100, PCO_t120), and DO. To maintain the stability of the whole testing system during experiments, the engine was supplied with conditioning lubricant and cooling systems. The experimental setup schematic is shown in Fig. 2, while engine specifications are briefly described in Table 2.

Table 2. Technical parameters of D243 diesel engine.

Parameters	Abbreviation	Quantity
Power (kW)	N	58.88
Maximum revolution (rpm)	n_{max}	2200
Bore/ Stroke (mm/mm)	D/S	110/125
Compression ratio	r	16.7:1
DO fuel consumption (g/HP.h)	g_e	183

Cabinets for analyzing exhaust gas (CEB-II) was a system that included modules for the analysis of exhaust components and accurately ensured the working conditions of the system such as heating block (HSU), diagnostic blocks, and control blocks. In addition, the analysis cabinet was also fitted with an industrial computer with control software (GEM110). The computer connection with the

analyzer was done through a digital signal. The analyzer installed in cabinets was used to measure components in the exhaust gas such as CO with 0.0006 accuracy, carbon dioxide (CO₂) with 0.003 accuracy, oxygen (O₂) with 0.001 accuracy, nitrogen oxides (NO_x) with 1 ppm accuracy, HCs with 4 ppm accuracy, and smoke. Exhaust gas temperature was determined by a sensor.

RESULTS AND DISCUSSION

Exhaust gas temperature

The experimental study showed the difference between the PCO, JOME, and DO in terms of exhaust gas temperature. However, the increase in exhaust gas temperature was proportional with increase in power. The increase of engine speed and supplied fuel mass resulted to greater engine power, as the combustion process occurred more completely and perfectly, hence raising the exhaust gas temperature. The temperature of exhaust gas at 100% of the load and at different speed of the diesel engine – in the case of using PCO_t80, PCO_t100, PCO_t120, and JOME in comparison with DO – is shown in Fig. 3. The relationship between fuel mass and engine speed is shown in Fig. 4.

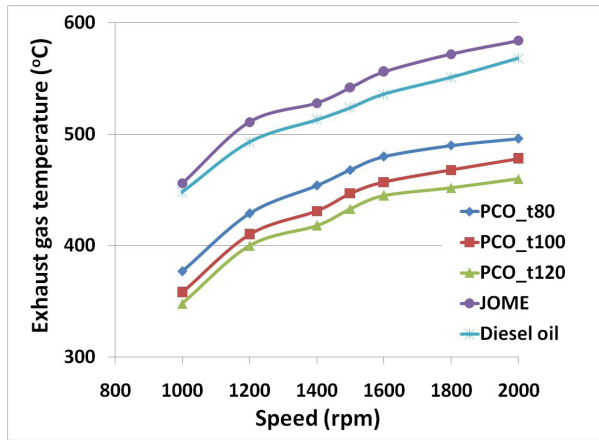


Figure 3. Exhaust gas temperature at different speed.

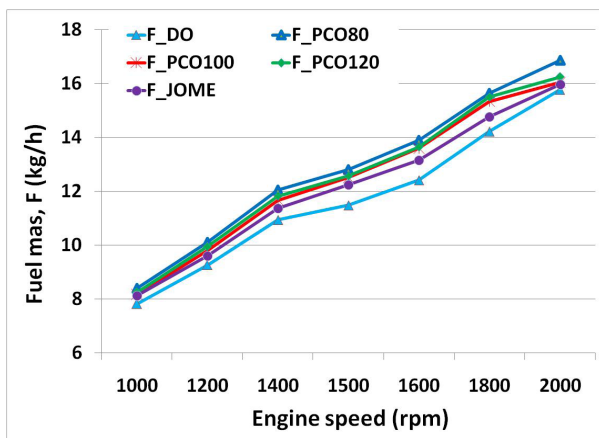


Figure 4. Exhaust gas temperature at different speed.

Fig. 3 shows the effect of engine speed on temperature of exhaust gas; while the test engine was fueled with JOME, the highest temperature of exhaust gas was 584°C at 2000 rpm. The exhaust gas temperature of engine fueled with PCO showed a lower trend in comparison with DO: the exhaust gas temperature of PCO_t80 was highest and PCO_t120 was lowest in the case of using PCO. Fig. 4 shows that the fuel mass of PCO_t80 leads in comparison with PCO_t100 and PCO_t120. This causes poor volatility and long chain formation (-C=C-) of PCO, leading to intense, prolonged process of delayed combustion in the exhaust pipe (Hanbey & Huseyin 2010). The highest exhaust gas temperature was 496°C with PCO_t80 versus 568°C with DO.

Unburnt hydrocarbon (HC) emissions

Unburnt HCs are the incomplete combustion products. As presented by Kalam & Masjuki (2004), the HCs were the result of combustion with rich air-fuel ratio, quenchable and misfiring flame, crevice flows, and appearance of

oil film in and around the engine cylinder caused by HC desorption or big size of fuel droplet. Schumacher and colleagues (1996) showed the reduction in HC content with increased rate of blended biodiesel. HC reduction amounted to 13.4% with B10, 22.7% with B20, 25.8% with B30, and 40.2% with B40. This reduction in HCs might have been caused by increased oxygen content in the blend of biodiesel, which facilitated a more complete combustion resulting to lower HC promotion. This trend was further proved and reported by the study of Zheng and colleagues (2008), whose results showed a 20-70% HC reduction while the Yanmar NFD170 engine was fueled with biodiesel from soy-based yellow grease, in comparison with diesel fuel. Moreover, Al-Widyan and colleagues (2002) reported lower HC concentrations while using the blends of B25, B50, B75, and B100 derived from waste vegetable oil. This might be explained by higher CN, which triggered the formation of ignitable mixtures and resulted in better combustion. Fig. 5 shows the HC emissions of PCO, JOME, and DO.

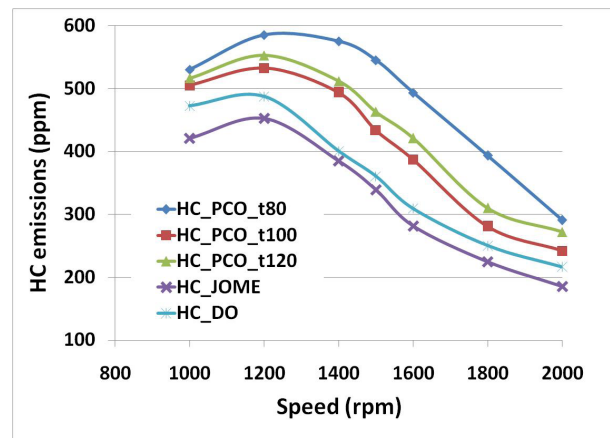


Figure 5. HC emissions at different speed.

Fig. 5 shows that HC emissions of PCO_t80 and JOME were the highest and the lowest, respectively. At 100% load at different revolution, HC emission (relative to DO) was 12.12% for PCO_t80 (59.49% higher), 6.89% for PCO_t100 (25.15% higher), 9.27% for PCO_t120 (36.12% higher), and 3.88% for JOME (14.88% lower). On the average, the HC emission (relative to DO) of PCO_t80, PCO_t100, and PCO_t120 increased 39.7%, 15.54%, and 23.51%, respectively. Conversely, the value for JOME decreased 8.78%. The HC emission from PCO was much higher than that of DO. This may be due to poor atomization and vaporization resulting to heterogeneous mixing with air. Moreover, the coconut oil CN is lower than that of DO, leading to incomplete combustion. Furthermore, the increase in HC emission may be due to larger droplet size of PCO with higher viscosity that

mainly affects the regions with rich fuel. Lastly, the HC emission is low with JOME compared with DO because of the former's higher CN value.

Carbon monoxide (CO) emissions

CO is an intermediate outcome of combustion, as it is formed earlier during the oxidation process stages before converting fully into CO₂. It is generated in the stream of exhaust gas when its conversion into CO₂ is incomplete, when the fuel's flame temperature is cooled or the engine is operated with oversaturated fuel that inhibits burning within a short time span. The oxygenated nature in JOME aids in limiting the regions with rich fuel, which improves the combustion progress and limits CO emission. However, CO emission of PCO is still higher than that of DO even though it only has nearly 11% oxygen by mass, which may be explained similarly with HC emissions. CO emission of test engine fueled with PCO_t80, PCO_t100, PCO_t120, JOME, and DO is shown in Fig. 6.

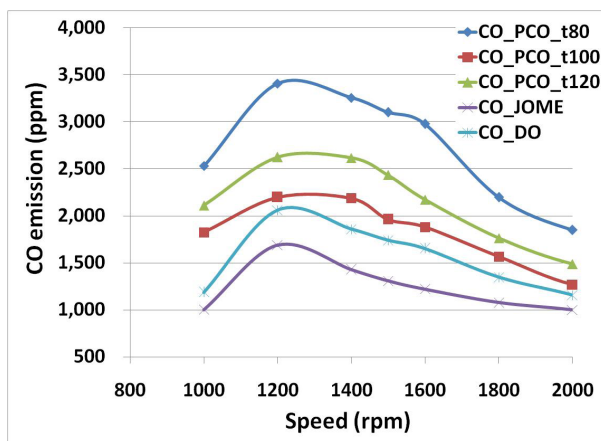


Figure 6. CO emissions at different speed.

It can be seen from Fig. 6 that the CO emissions of all test fuels were high at low revolution (peaking at 1200 rpm), and the CO emissions from PCO was much higher than that of DO. The above results show that CO emission (relative to DO) was 59.92% for PCO_t80 (113.29% higher), 6.72% for PCO_t100 (53.85% higher), 27.39% for PCO_t120 (78.06% higher), and (3.06%) for JOME (26.1% lower). Relative to DO, the CO emission of PCO_t80, PCO_t100 and PCO_t120 increased 88.65%, 23.1%, and 46.74%, respectively, while the CO emission of JOME decreased 20.64%.

The higher HC and CO emissions of PCO-t120 - in comparison with PCO_t100 and PCO_t80 - were attributed to its very low fuel mass and kinematic viscosity, which reduced the injection pressure and subsequently created a poor mixture. Moreover, the lower

fuel mass led to low combustion temperature. Contrarily, the very high fuel mass and higher kinematic viscosity of PCO_t80 resulted to hard atomization, vaporization, incomplete combustion, and subsequently a rich mixture. Thus, low combustion temperature, richness of mixture, and incomplete combustion may be the primary reasons in increasing the HC and CO emissions. However, the PCO_t100 properties are closest to those of diesel fuel, hence the HC and CO emissions of PCO-t100 are lowest in comparison with PCO_t120 and PCO_t80. In addition, the increase in engine speed resulted to higher combustion temperature and complete combustion, which explains the decrease in HC and CO emissions. These findings were also investigated by Nandkishore (2012).

Nitrogen oxides (NO_x) emissions

The NO_x emission values for PCO_t80, PCO_t100, PCO_t120, JOME, and DO on D243 diesel engine as a function of revolution are plotted in Fig. 7.

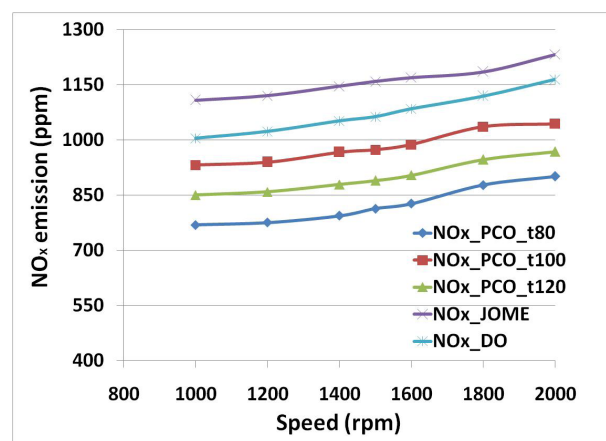


Figure 7. NOx emissions at different speed.

Fig. 7 shows that the NO_x amount produced while using PCO was between 769 ppm and 1044 ppm, as compared to 1108-1233 ppm for JOME and 1005-1165 ppm for DO. The increase in NO_x emissions of JOME in comparison with DO and PCO is seen in Fig. 7. This may be explained and attributed to the increase of exhaust gas temperature for JOME (Nabi et al. 2006; Ming et al. 2008). Besides, the double bonds (-C=C-) in JOME may take part in pre-combustion and combustion of HC-free-radicals. The formation of NO (an NO_x gas) directly stems from high levels of HC-free-radicals, which appear in the fuel-rich regions of the fuel spray jet. Moreover, JOME promotes NO_x formation since it contains about 10.8% of oxygen mass. Generally, the NO_x concentration increases with the increase in engine speed and overall fuel-air ratio. However, although PCO_t80 exhaust gas temperature is

higher than that of PCO_t100, the NO_x concentration of PCO_t100 ranks the highest in the case of using PCO. This proves that the spray characteristics and fuel properties at 100° C of coconut oil is the closest to DO, therefore the PCO_t100 ranks the best in terms of fuel-air mixture and combustion rate. The NO_x concentration has a direct ratio to exhaust gas temperature and inverse ratio to the smoke and CO concentration. In terms of engine speed, the NO_x concentration of DO was higher in comparison with PCO_t80 (21.61-24.46%), PCO_t100 (7.27-10.34%), and PCO_t120 (15.38-16.89%), but lower than that of JOME (5.85-10.28%).

Smoke number

The smoke emissions, the function of engine speed, from the D243 diesel engine using PCO_t80, PCO_t100, PCO_t120, JOME, and DO are plotted in Fig. 8.

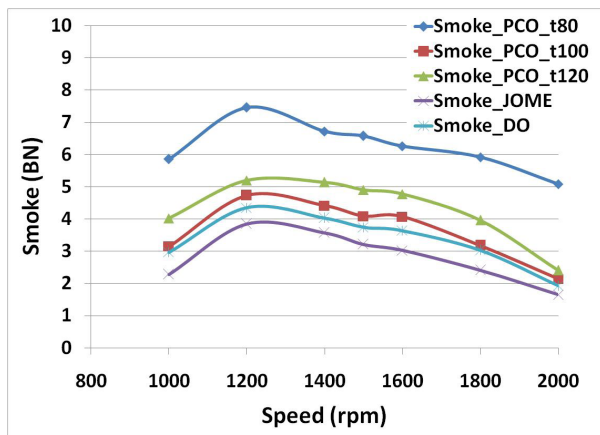


Figure 8. Smoke emissions at different speed.

As seen in Fig. 8, the smoke emissions produced from JOME and DO are less than those of PCO. The smoke emissions are high at low speed and the highest at around 1200 rpm because at these rates, the air-fuel ratio is low resulting to incomplete combustion as the rich fuel enters the combustion chamber. Smoke opacity was higher with PCO and lower with JOME, in comparison with that of DO. Smoke opacity relative to DO was 66.74-163.21% higher with PCO_t80, 4.95-11.81% higher with PCO_t100, 19.54-35.35% higher with PCO_t120, and 11.41-23.23% lower with JOME. In the case of PCO_t80 use, the increase in smoke opacity is explained by its heavier molecular structure and higher viscosity. These factors facilitate poor atomization, even if PCO contains oxygen. However, the smoke opacity of PCO approximates that of DO when heated up to 100° C. On the other hand, the smoke opacity of JOME ranks the lowest due to its similar properties with DO. However, the former's CN value ranks higher than that of DO even as both substances

contain oxygen. Similar results were also presented by other researchers (Ramadhas et al. 2005b) for different vegetable oils and biodiesel.

CONCLUSIONS

Based on the experimental results, a number of conclusions can be drawn. First, the fuel properties of JOME and PCO_t100 satisfy the fuel requirements for diesel engines, even though the kinematic viscosity of JOME at temperature for experimental set-up is slightly higher and the CN of PCO_t100 is slightly lower relative to DO. Second, exhaust gas temperatures of JOME and PCO_t120 rank the highest and lowest, respectively. Lastly, the CO emissions of PCO_t80 are much higher than in the case of using PCO_t100, PCO_t120, JOME, and DO. This occurs similarly for the unburnt HC emissions and smoke opacity emissions. However, nitrogen oxide emissions of JOME and PCO_t80 rank the highest and lowest, respectively. The above results prove that the JOME and PCO_t100 combustion are more complete than those of PCO_t80 and PCO_t120. Certainly, JOME and PCO_t100 are potentially usable as alternative fuels for diesel engines in the future.

ACKNOWLEDGMENT

The authors acknowledge the Ho Chi Minh University of Transport; Key Lab of ICE, School of Transportation Engineering - Hanoi University of Science and Technology; and the National Key Laboratory for Refining and Petrochemical Technologies for supporting this research.

REFERENCES

- AGARWAL AK. 1998. Vegetable oils versus diesel fuel: development and use of bio-diesel in a compression ignition engine. TERI Information Digest on Energy (TIDE) 8: 191-203.
- ALMEIDA SCAD, BELCHIOR CR, NASCIMENTO M.V.G, VIEIRA LDSR, FLEURY G. 2002. Performance of a diesel generator fuelled with palm oil. Fuel 81:2097-2102.
- ALTIN R, CETINKAYA S, YUCESU HS. 2001. The potential of using vegetable oil fuels as fuel for diesel engines. Energy Conversion and Management 42:529-538.
- AL-WIDYAN MI, TASHTOUSH G, ABU-QUDAIS M. 2002. Utilization of ethyl ester of waste vegetable

- oils as fuel in diesel engines. *Fuel Process Technology* 76(2):91-103.
- CANAKCI M, VAN GERPEN JH. 2003. Comparison of engine performance and emissions for petroleum diesel fuel, yellow-grease biodiesel and soybean-oil biodiesel. *Trans ASAE* 46:937-944.
- CANAKCI M, AHMET E, EROL A. 2006. Performance and exhaust emissions of a biodiesel engine. *Applied Energy* 83:594-605.
- DORADO MP, BALLESTEROS E, ARNAL JM, GOMEZ J, LOPEZ FJ. 2003. Exhaust emissions from a diesel engine fuelled with transesterified waste olive oil. *Fuel* 82:1311-1315.
- FORSON FK, ODURO EK, DONKOH EH. 2004. Performance of jatropha oil blends in a diesel engine. *Renewable Energy* 29:1135-1145.
- HANBEY H, HUSEYIN A. 2010. Performance and emission evaluation of a CI engine fueled with preheated raw rapeseed oil (RRO)-diesel blend. *Applied Energy* 87:786-790.
- HE Y, BAO YD. 2003. Study on rapeseed oil as alternative fuel for a single cylinder diesel engine. *Renewable Energy* 28:1447-1453.
- KALAM MA, MASJUKI HH. 2004. Emissions and deposit characteristics of a small diesel engine when operated on preheated crude palm oil. *Biomass and Bioenergy* 27(3):289-297.
- MING Z, MWILA CM, GRAHAM TR, MEIPING W, DAVID SKT, JIMI T. 2008. Biodiesel engine performance and emissions in low temperature combustion. *Fuel* 87(6):714-722.
- MONYEMA, VAN GERPEN JH, CANAKCI M. 2001. The effect of timing and oxidation on emissions from biodiesel-fueled engines. *ASAE* 44:35-42.
- NABI MN, AKHTER AS, SHAHADAT MMZ. 2006. Improvement of engine emissions with conventional diesel fuel and diesel-biodiesel blends. *Bio-resource Technology* 97:372-378.
- NANDKISHORE DR, SUDHEER PB, YOHAN M. 2012. Performance and emission characteristics of straight vegetable oil-ethanol emulsion in a compression ignition engine. *Asian Research Publishing Network (ARPN)* 7(4):447-452.
- NWAFOR OMI. 2004. Emission characteristics of diesel engine running on vegetable oil with elevated fuel inlet temperature. *Biomass and Bioenergy* 27(5):507-511.
- PUHANS, VEDARAMANN, SANKARANARAYANAN G, BHARAT RAM BV. 2005. Performance and emission study of mahua oil (*Madhuca indica* oil) ethyl ester in a 4-stroke natural aspirated direct injection diesel engine. *Renewable Energy* 30:1269-1278.
- RAMADHAS AS, JAYARAJ S, MURALEEDHARAN C. 2005. Characterization and effect of using rubber seed oil as fuel in the compression ignition engines. *Renewable Energy* 30:795-803.
- RAMADHAS AS, MURALEEDHARAN C, JAYARAJ S. 2005. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. *Renewable Energy* 30:1700-1709.
- SCHUMACHER LG, BORGELT SC, FOSSEEN D, GOETZ W, HIRES WG. 1996. Heavy-duty engine exhaust emission tests using methyl ester soybean oil/diesel fuel blends. *Bio-resource Technology* 57(1):31-36.
- SENDZIKIENE E, MAKAREVICIENE V, JANULIS P. 2006. Influence of fuel oxygen content on diesel engine exhaust emissions. *Renewable Energy* 31:2505-2512.
- SRIVATHSAN VR, SRINIVASAN LN, KARUPPAN M. 2008. An overview of enzymatic production of biodiesel. *Bio-resource Technology* 99(10):3975-3981.
- YU CW, BARI S, AMEEN A. 2002. A comparison of combustion characteristics of waste cooking oil with diesel as fuel in a direct injection diesel engine. *Proceedings of the Institution of Mechanical Engineers: Part D: Journal of Automobile Engineering* 216(3):237-243.
- ZHENG M, MULENGA MC, READER GT, WANG M, TING DSK. 2006. Influence of biodiesel fuel on diesel engine performance and emissions in low temperature combustion. *SAE* 2006-01-3281.
- ZHENG M, MULENGA MC, READER GT, WANG M, TING DSK, TJONG J. 2008. Biodiesel engine performance and emissions in low temperature combustion. *Fuel* 87:714-722.