POTENTIAL APPLICATION ON ON-LINE BLENDING DIESEL OIL WITH VEGETABLE OIL FOR VIETNAMESE FLEET

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Abstract:

In Vietnam, bio-fuel has been studied and attracted attention of scientists under the concrete support policy from government. Although general diesel engines and especially marine diesel engines are one of main energy consumption factors and influent to environmental pollution, but bio-fuel has been still in theory researches or reached to small production. It leads to very few or nearly empty application of biodiesel in maritime field. Currently, biodiesel has been imported always and it results in high cost in use. The article shows a direction for applying bio-fuel to marine diesel engine that fossil diesel is on-line blended with straight vegetable oil. The blended fuel is made in the additional mixing equipment that is controlled automatically. This is continuous mixing method of diesel oil from service tanks and vegetable oil installed nearby. Upon analyses on the operation situation of Vietnamese fleet and existent marine diesel engine in combination with infrastructure of local biodiesel production, blending with non-esterification vegetable oil seems to be cost-down feasible solution. A sample of on-line blending system has been designed based on mostly the fuel consumption of marine diesel engine and operated automatically under its control system. Experiments on Hanshin 6LU32 at Vietnam Maritime University's lab and on-board diesel engines of actual vessels have been conducted with very good results. Importantly, there is no big modification required on the existent fuel supply system. Besides, the new equipment is quite easily installed and compatible with others on board.

Key words: biodiesel application, Vietnamese fleets, on-line blending.

1. Introduction

With its prominent features, especially reduction of environment pollution and potential alternative of fossil fuels which has been quickly depleting, bio-fuel is recognized as an attractive energy source to ensure the sustainable development and improve the quality of life in the future. In Vietnam, although bio-fuel has been acknowledged on benefits for long-term economic and society and applied partly in road vehicles, but it is lack of comprehensive study on utilizing such advanced fuel for the entire road and waterways transportation.

In almost fleets of the world as well as of Vietnam, most of the vessels are equipped with diesel engines using petroleum-based fuel. According to the latest statistics of the Vietnam Maritime Administration on June 2013 [5], Vietnamese sea-going fleets reach to 1,788 vessels and estimated annual fuel consumption is up to millions of tons per year. Importantly, emission from fleet operation activities affects sea environment and causes to increase the greenhouse. Biodiesel with its advantages has been studied by many local scientists. And it proved that with application infrastructure and conditions of Vietnamese fleet, directly usage of non-esterification vegetable oil supported by conversion devices is the most feasible solution for marine diesel engines.

2. Biodiesel and overview of using biodiesel in Vietnam

Biodiesel is a liquid fuel which has similar characteristics to conventional diesel oil. It is derived from biological sources, such as vegetable oils or fats and alcohol. Chemically, biodiesel is composed of 14 different types of fatty acids which are transformed into Fatty Acid Methyl Esters- FAME by transesterification [2]. Molecular size of biodiesel and traditional diesel fuel oil are basically similar, but different from chemical structure. While molecules of biodiesel fuel include the majority of fatty acid methyl esters, which are the basic components of unsaturated olefins (C_nH_{2n+1}. COOH), but

petroleum-derived diesel is composed of about 75% saturated hydrocarbons (primarily paraffins including n, iso, and cycloparaffins), and 25% aromatic hydrocarbons (including naphthalenes and alkylbenzenes) [1]. The average chemical formula for common diesel fuel is $C_{12}H_{23}$, ranging approximately from $C_{10}H_{20}$ to $C_{15}H_{28}$.

In fuel's properties, cetane number is a measurement of how well a diesel fuel combusts. It measures the ignition of fuel or delay time of ignition. Cetane mumber of a certain fuel oil is determined by comparing the ignition delay of this fuel to the ignition delay of a blend of two pure hydrocarbon reference fuels. One is cetane (n-hexadecane, $C_{16}H_{34}$), a hydrocarbon with high ignition quality, represents the top of the scale with a cetane number of 100. An isocetane, heptamethylnonane (HMN) or $C_{12}H_{34}$, which has a very low ignition quality, represens the bottom of the scale with a cetane number of 15 [3]. In fact, the cetane number affects to delay combustion of medium speed and high speed engine. Normally, cetane values of DO range from 45-55, biodiesel fuel from 38 for rapeseed oil to 56 for palm oil. So if biodiesel fuel is derived from pure palm oil, its combustion process will be equivalent to traditional diesel fuel's. Table 1 shows the emission profile of biodiesel.

Table 1 Average biodiesel combustion emissions [4]

Type of emissions	Pure Biodiesel (B100)	Blending biodiesel (B20)
Total unburnt hydrocarbons	- 67%	- 20%
Carbon Monoxide (CO)	- 48%	- 12%
Particulate Matter	- 47%	- 12%
Nitrogen Oxides (NOx)	+ 10%	+ 2%

In the trend of seeking for new energy sources, though Vietnam uses biodiesel later than other countries in the region and in the world, but Vietnam has the first steps to bring bio-fuels into service applications, especially in the field of transportation. In Vietnam, the process of building the application criteria has been implementing as same time as researching and developing on biodiesel production. Under the program on "Development of biofuels (biological energy) by 2015, a vision to 2025" issued by Goverment, companies have been focusing on building factories and planning feedstocks for production. Table 2 shows the biofuel production companies in Vietnam and implementation roadmap. However, the current factories only produce ethanol (alcohol for mixing with gasoline). For biodiesel, the production is quite small-scale and limited, such as companies in Can Tho city which biodiesel is derived from TRA and BASA fish fat. Besides, biodiesel applications is so far studied on road transportation means: buses, trucks of a few companies. Up to now, there is not any researches on using biodiesel to partially replace traditional diesel fuel for marine sector.

Table 2 The typical companies producing biofuel in Vietnam

No	Name of company	Capacity	Establishment	Location
1	Dong Xanh Company	100 million litter/year	3/2009	Quang Nam
2	Dai Viet Company	50 million litter/year	12/2008	Dac Nong
3	Petroleum Vietnam Oil	100 million litter/year	6/2011	Phu Tho
4	Petrosetco Binh Sơn	100 million litter/year	7/2011	Dung Quat
5	Binh Phuoc factory	100 million litter/year	7/2011	Binh Phuoc

3. The solution using straight vegetable oil mixed with diesel oil for marine diesel engines

According to the survey data, the infrastructure of biodiesel production in Vietnam is quite poor while the national regulations on management and operation have not been established yet. Therefore the applicability of biodiesel is facing with difficulties. In the case of imported biodiesel, its cost is much higher than using conventional diesel (from 1.2 - 1.3 times the fuel DO). It mainly results from

high cost of biodiesel production due to additional process on deriving biodiesel from pure vegetable oil which aims to reject fatty ingredients as glycerin.

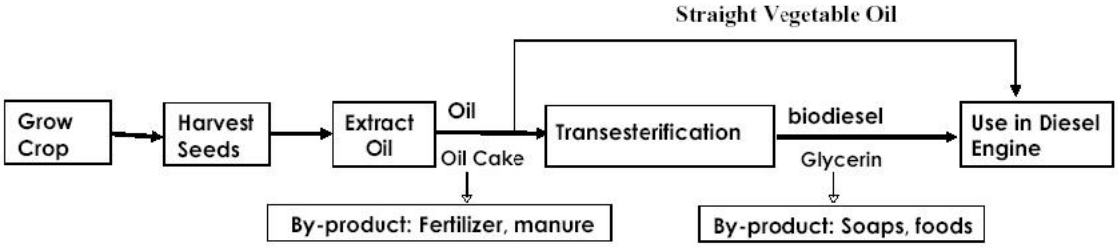

Figure 1 Biodiesel and SVO production and use [6]

In very limited conditions as mentioned above, tendency of bio-fuel application in Vietnam is growing in using pure vegetable oil. Current researches show that the most appropriate vegetable oil for transportation field, especially for marine diesel engines, is palm oil. This is one of most popular vegetable oils in the world, and Indonesia and Malaysia, the neighbors of Vietnam, are main producers and exporters. Palm oil has also being studied to produce at small scale by Vietnamese scientists in recent years. Production of pure palm oil is just extracting oil from pressing palm seeds and filtering to reduce water and impurities. Due to non-esterification, pure palm oil prices in the range of 80% to 85% comparing with its biodiesel.

Upon analyzed results given in Table 3, pure palm oil has some different properties from diesel oil (DO) as follows:

- Density of pure palm oil is 8.99% higher than DO;
- Kinematic viscosity at 40^0C of pure palm oil is 13.4 times greater than DO;
- Flash point of pure palm oil is 3.1 times higher than DO;
- Freezing point of pure palm oil is 16^0C and DO is -6^0C;
- The heating value of palm oil fuel pure is 3.95% lower than DO;

Table 3 Properties of palm oil and blends with diesel No.2

No	Description	Vegetable oil (palm oil) – DO blends							DO
		B100	B5	B10	B15	B20	B25	B30	
1	Density in 15°C, kg/m3	0,9225	0,8489	0,8538	0,8568	0,8599	0,8632	0,8668	0,8464
2	Kinematic viscosity at 40°C, mm^2/s	85,80	7,0	7,42	8,20	9,31	9,87	10,45	6,38
3	Cetan number	42,89	52,11	51,25	50,91	50,66	50,13	49,63	52,92
4	Closed cup flash point, °C	224	72	73	74	75	76	77	72
5	Freezing point, °C	16	-3	-1	0	1	2	2	-6
6	Ash content, % by volume	0,0061	0,0057	0,0057	0,0057	0,0058	0,0058	0,0058	0,0054
7	Piece of copper corrosion at 50 ° C for 3 hours	1A	1A	1A	1A	1A	1A	1A	1A
8	The water content, mg/kg	315	182	189	195	201	208	215	170
9	Acid Number, mgKOH/g	0,4	0,36	0,37	0,37	0,38	0,38	0,4	0,35
10	Heating value, kcal/kg	10.325	10.700	10.625	10.600	10.580	10.475	10.350	10.750

For diesel engine use, pure vegetable oil is directly supplied to fuel system called Straight Vegetable Oil (SVO). Due to needless to build a very professional deriving factory as biodiesel, the

price of SVO is much reduced. Furthermore, quality of biodiesel is easily decreased in storage. The recommended duration of preservation should be less than one year under strict preservation mode. Comparing with SVO that needs to storage in normal conditions, biodiesel makes difficulties to use in variable climate conditions of Vietnam. Using SVO is mainly based on reduction of its viscosity as same as DO through heating combined dilution process. This helps improving quality of atomization and efficiency of combustion. There are some manufacturers to provide special mixture equipment to modern engines for using SVO, such as CDI engine (Common rail diesel injection). The adapter commonly uses heating method to reduce the viscosity of fuel oil.

Currently, almost of diesel engines equipped on Vietnamese vessels mainly belongs to the older generation. It is estimated that Vietnam has about two hundred thousand means of waterway transport and fishing vessels with over 10 million horse power in total. There is no annual specific statistics on fuel consumption of marine diesel engines, but according to the research team's calculations, if operation time is 90 days per year (2.160 hours/year), the total fuel consumption is about 3.67 million tons of DO fuel, equivalent to approximately 28% of total liquid fuel consumption of Vietnam in 2011. Marine diesel engine is usually a large-size and high-power type with medium speed or low speed. Actually, such engine can be operated with low quantity fuels as heavy fuel oil, so it is potential to improve the conversion equipment for SVO utilization.

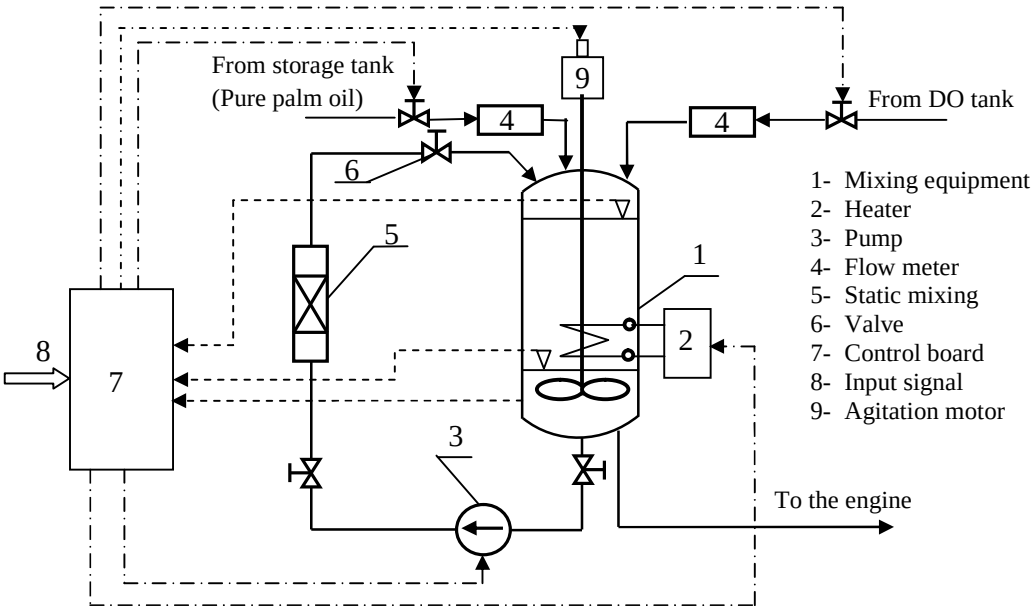

Figure 2 Diagram fuel blending system

Figure 2 shows a diagram of fuel conversion system which has being developed in order to use SVO blends onboard Vietnamese vessels. Main part is the barrel-shaped mixing equipment (1) directly installed in existing fuel system with on-line blending functions of pure palm oil (PPO) and common diesel oil (DO). There are two types of agitation, rotary type and static type, continuously combined in this system which aims to produce high homogeneous blends. A heating coil (2) is designed inside the mixing equipment to increase temperature of liquid up to 40°C and reduce its viscosity. Palm oil is stored in an additional tank equipped a set of heating control and transferred by pump. Besides, two flow meters (4) for DO and PPO lines control the ratio of online blending fuel. Mixture of PPO and DO in the agitation tank is circled through the static-type mixture unit (5) by pump (3) during the mixing process. With special composition of unit, mixture of fuel will be split to thousands pieces and returned to agitation tank. The final blend will be supplied straightly to diesel engine. Based on PLC (Programmable Logic Controller), the control board (7) is designed with functions on setting up the blending ratio, temperature and viscosity control and operation of pumps, etc. Blend produced by the on-line blending system is appropriate to fuel consumption of diesel engine. Some images on experimental on-line blending system and PPO blends are shown in Figure 3.

Figure 3 Some pictures of the actual blending system and the results

4. Experiment results

Theoretical research points that PPO blends of B5, B10, B15, B20 with ratio of 5%, 10%, 15% and 20% repecstively can be used normally for marine diesel engine. There are a few influences on engine's operation and output parameters. The below results are obtained from experiments on 6LU32 Hanshin Diesel engine with hydraulic load consumption Omega 1500 of AVL Zollner GmbH company which are installed at the Vietnam Maritime University. The technical specification of engine and load consumption are given in Table 4.

Table 4 Specification of experimental diesel engine and hydraulic load consumption

No.	Description	Value
A	**Engine**	
1	Model	6LU32
2	No. of cylinder	6
3	Speed, rev/min	340
4	Output, kW	970
5	Bore, mm	320
6	Stroke, mm	510
7	Max. cylinder pressure, kG/cm^2	90
9	Early injection angle	11^o
10	Fuel consumption, g/kW.h	200
B	**Hydraulic load consumption**	
1	Model	Omega 1500
2	Max. Brake power, kW	1500
3	Speed, rev/min	4800

4	Max. Moment, Nm	9500
5	Working temperature, ^{o}C	60
6	Water circulation capacity, m3/h	31.5
7	Water circulation pressure, bar	≥ 0,3
8	Accuracy, %	± 0,2

Fuel consumption

With different loads from 200kW to 800kW, fuel consumption was measured as Figure 4 when engine operated continuously each 1 hour. The fuel consumption of B5 and B10 are quite similar at these load regimes, but DO consumption is the lowest. It results from low PPO portion in the blends and its heating value is near DO. In general, fuel consumption is the lowest at 75% to 80% load of designed rate.

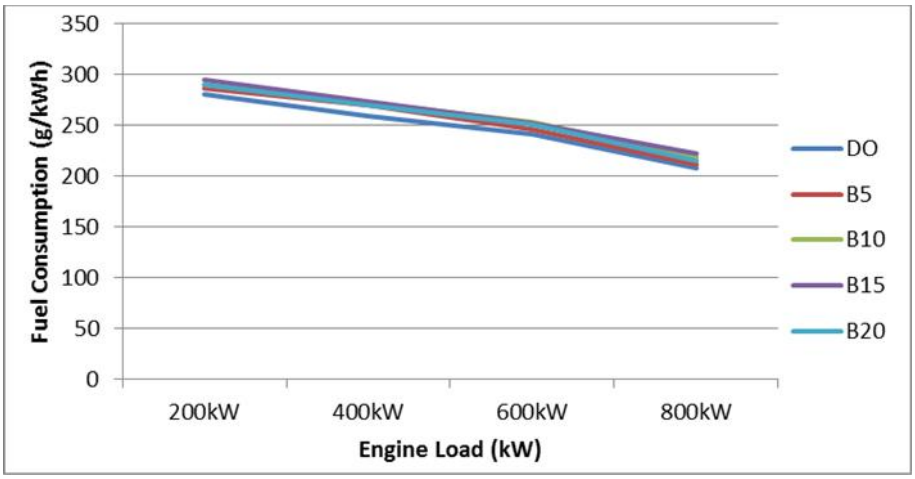

Figure 4 Fuel consumption at different load regimes

In-cylinder pressure

Figure 5 shows the in-cylinder pressure histories obtained from the specific parameter. The in-cylinder pressure crank angle diagram can be used to access the themodynamic behavior of engine. It can be observed that the trend of pressure variablity at different loads (200kW and 400kW) is similar for PPO blends. The peak pressures respectively are not much different, about 5%.

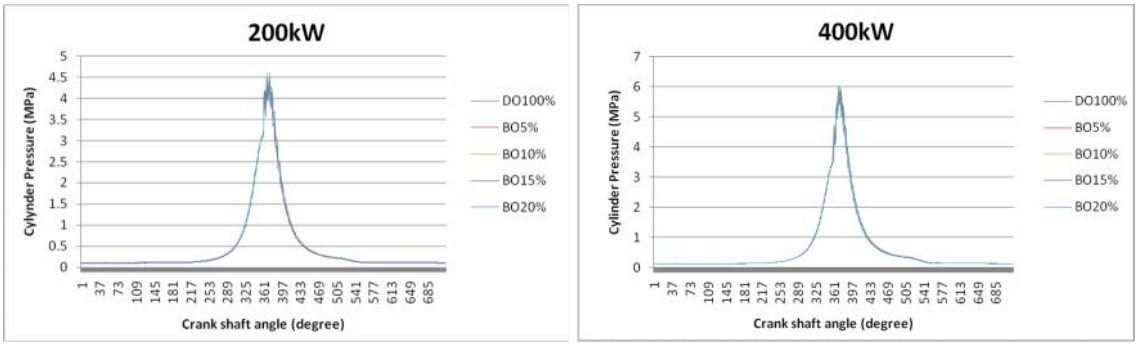

Figure 5 In-cylinder pressure crank shaft angle diagram at different loads

Furthermore, the ignition delay value of PPO blends are also analyzed due to pressure curves for studying on its infulences to the combustion of engine as given in Figure 6. At light load (200kW), the ignition delay values of B5 and DO are similar and about 0.92 mille seconds. Only the start of combustion of B10, B15 and B20 blends are obtained at 0.21 mille seconds, equivalent to about 1 degree of crank angle later than DO. At 400kW load, figure shows there are more clear diffences

betwen pressure curves of PPO blends and in comparision to DO. With pressure at the end of compression stage is higher than of light load, the combustion is assumed to occur 1 crank angle degree earlier. This penomenon is consistent with the working rule of diesel engine due to higher revolution and better preparation for combustion. So while the spontaneous combustion of B5, B10 and B15 are as same as 0.78 mille seconds, nearly 2 times later than for DO, but B20 is obtained to be 0.62 mille seconds.

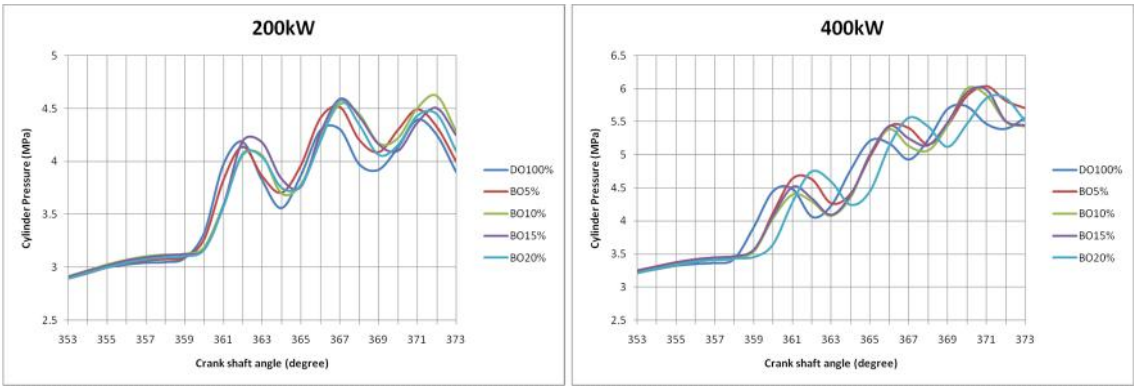

Figure 6 Ignition delay of PPO blends at loads of 200kW and 400kW

The heat release

As shown in Figure 7, at both of loads of 200kW and 400 kW, the heat release when burning DO in the cylinder is lowest. It can be explained that the engine is calibrated to operate with DO, such as early injection angle, mass of intake air, etc., therefore in the same load (200kW or 400kW), the engine requests to be provided with higher quantity of fuel when using other fuels.

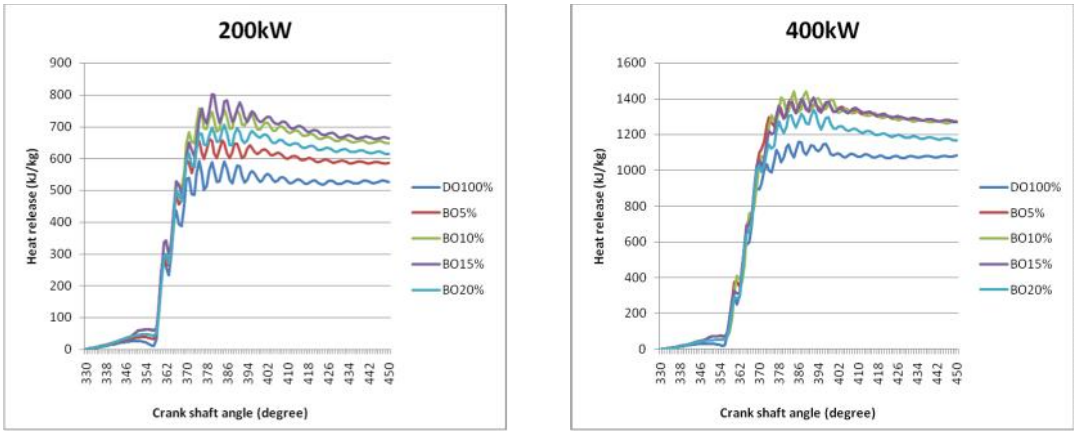

Figure 7 Heat release at loads of 200kW and 400kW

Exhaust emission characteristics

Exhaust emission profile for DO and PPO blends are studied when the load of engine is 400kW and the results are given in Table 5 and Figure 8. It is seen that the combustion efficiency of blends are much better than that of DO. Blend of B5 and B10 is found to be more efficient fuel than others with lowest values of CO, CO2 and NOx.

Table 5 Exhaust emission profile of different fuels

Type of fuel	% CO2	CO (ppm)	NOx (ppm)	% O2	THC (ppm)
DO	4.7856	140.34	940.45	14.105	521.78
BO5%	4.7426	135.85	844.51	14.149	511.65
BO10%	4.7361	136.94	894.06	14.356	367.94
BO15%	4.7753	141.93	873.99	14.465	120.14
BO20%	4.7765	142.99	876.62	16.204	167.65

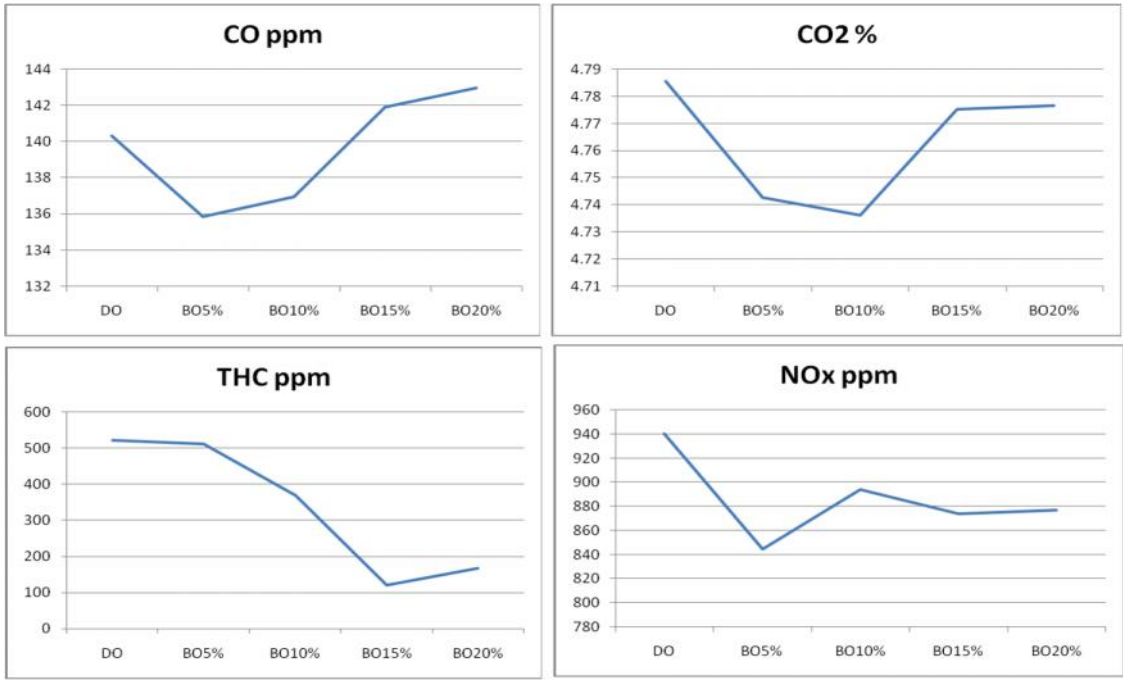

Figure 8 Variable main emission depending on different fuels

5. Conclusion

The on-line fuel blending system designed for mixing pure palm oil and diesel oil No.2 are successfully experimented with installation at laboratory and actual vessels of Vietnam Maritime University. The results shows that the system can be easily setted up and compatible with current fuel supply and unmodified diesel engine. Produced blends of pure palm oil and diesel oil are also completedly tested. Amongst various combustion performance data, it is entirely possible to apply blending fuels to replace common diesel engine without any problem. The suggested ratio of blending fuels should be less than 15% of palm oil.

With the poor infrastructure for producing biofuel in Vietnam and local fleets status, the solution with on-line fuel blending system is very potential. This is really important and meaningful to Vietnamese fleet and corresponds the world trend of bio-fuel and clean fuel development.

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