Fuel Continuous Mixer – an Approach Solution to Use Straight Vegetable Oil for Marine Diesel Engines

D. Van Uy & T. The Nam

Vietnam Maritime University, Haiphong, Vietnam

ABSTRACT: The vegetable oil is well known as green fuel for diesel engines due to its low sunphur content and renewable stock. However, there are some problems raising when vegetable oil is used as fuel for diesel engines such as highly effected by cold weather, lower general efficiency, separation in layer if mixed with diesel oil and so on. To overcome that disadvantiges, the authors propose a new idea that to use a continuous fuel mixer to blend vegetable oil with diesel oil to make so called a mixed fuel supplying to diesel engines inline. In order to ensure a quality of the mixed fuel created by continuous mixer, a homogeneous testing was introduced with believable results. Then, the continuous mixer has been installed into fuel supply system of diesel engine 6LU32 at a lab of Vietnam Maritime University in terms of checking a real operation of the fuel continuous mixer with diesel engine.

1 INTRODUCTION

Vegetable oil can be used as an alternative fuel for diesel engines and for heating oil buners. When vegetable oil is used directly as a fuel, in either modified or unmodified equipment, it is referred to as straight vegetable oil (SVO) or pure plant oil (PPO). SVOs have some advantages in comparison with fuel oils such as: renewability, local availability, lower sulphur content, avoiding the environmental issues caused by sulphuric acid, lower aromatic content and high biodegradability [1,2]. However, SVOs also attach several disadvantages such as: high viscosity, low heating value, high fatty content, influencing on injection process and causing engine coking if misused.

Table 1. Features of blended palm oil

No	Fuel characteristic	Blended fuels and DO				
		DO	PO10	PO20	PO30	PO100
1	Density at 15°C, [kg/dm^3]	0.8464	0.8538	0.8599	0.8668	0.9225
2	Viscosity at 40°C, [cSt]	2.6	3.42	5.31	6.45	40.24
3	Cetane number	42.89	50.13	50.91	52.11	52.92
4	Flash point, [^{o}C]	72	73	75	77	135
5	Freezing point, [^{o}C]	-6	-1	1	2	16
6	Lower Heating Value, [MJ/kg]	43.4	39.72	39.55	38.69	37.11

To prevent such bad effects, a blended fuel between SVOs and diesel oil is one of potential solutions. Table 1 shows the physical features of mixed diesel oil with palm oil [3].

In order to apply blended SVOs for diesel engines and particularly for marine diesel engines, there should need a proper modification of the engine fuel supply system. In this paper, there will introduce a method to create a fuel continuous mixing system (or fuel continuous mixer) to produce on line a blended fuel or mixed fuel (SVO and DO) used as alternative fuel for marine application.

2 FUEL CONTINUOUS MIXER DESIGN

Based on the theory of mixing fluid and the requirements of the fuel quality for marine diesel engines [4,5], the authors have developed a theoretical method to design a fuel continuous mixer. The quality of a mixed fuel can be understood on base of a level of homogeneousness of mixed fluids. The higher is degree of homogeneousness, the better is quality of a mixed fuel. To assess the quality of mixed fluid or effectiveness of the continuous mixer, it normally has to use a concept so called a "mixing time". So, in general, the quality of the fuel continuous mixer is defined as following [5]:

$$Q = f\left(t_m, V, N, \mu, impeller\ type\right) \qquad (1)$$

where: Q—quality of mixing; t_m—mixing time [s]; V—volume of mixing fluid [m³]; N—speed of impeller [rpm]; μ—dynamic viscosity [cP].
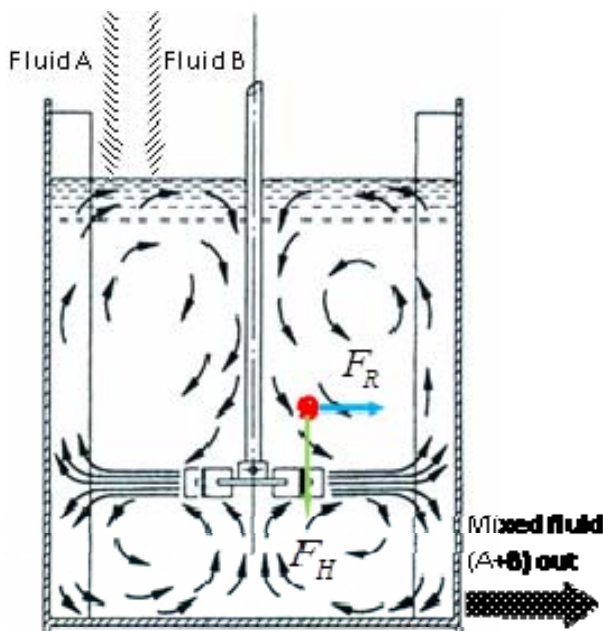

Figure 1. Continuously mixing mechanism

To ensure the quality of a mixing process, a flow pattern created by the impellers must be selected properly. Therefore, a type of impeller must be chosen properly and then the fluid flow pattern, as well as the mixing mechanism will be visible as shown in Fig.1. In this article, a proper type of

impeller is the turbine flat blade, because it can create two zones of a fluid flow: one is above and other is below the impeller. Thanks to such arrangement, the mixing quality will not be affected by the input of fluids.

An idea of a fuel continuous mixer is that an input of fluids must be equal to output one and is also equal to the fuel consumption of a diesel engine.

$$Q_{in} = Q_{out} = G_f = N_e \cdot g_e \quad [kg/h] \qquad (2)$$

where: Q_{in} and Q_{out} — input and output of fluids respectively [kg/h or m³/h]; N_e—output of diesel engine [kW]; g_e—specific fuel consumption [kg/kWh].

As mentioned above, the mixing quality depends on some factors, but the mixing time is a main one and it is also a function of a circulation time of fluid inside mixing tank. Therefore, in order to assess the mixing quality, a number of times of fluid circulation must be taken into consideration. For a single-phase liquid in a mixing tank with some baffles and small impeller, the relationship between mixing time and circulation time is as follow [6,7]:

$$t_m = 4t_c \quad [s] \qquad (3)$$

where: t_m—mixing time[s]; t_c—circulation time and it can be determined by a formula as: $t_c \approx \left(\frac{\rho.N^2.d^2}{\Delta\rho.g.H}\right)$, ρ—density of mixed product; $\Delta\rho$—difference of density between the liquids to be mixed; N—number of revolutions of impeller per minute [rpm]; d—diameter of impeller[m]; H—height of liquid in mixing tank; g—gravity acceleration [m/s²]; a—constant depending on a type of impeller.

However, in reality of fluid continuous mixer, the circulation time is very difficult to be measured. Therefore, more pratically the circulation time will be subtituted by a "remaining time" [3]. The remaining time is a time, in which an element of mixed product will be remained inside of mixing tank for circulation untill its discharge out. Let take any element of mixed product to be considered and found that an element of mixed product has a going way from the top to the bottom of mixing tank as showed in the Fig.1 and the element of a mixed product is affected by two forces. One is the centrifugal force F_R and another is a sum of the gravity force and additional force created by liquid moving down due to output of the mixed product. So, there can summarize that the element of mixed product will be affected mainly by a level of mixed product moving down with a velocity $/v_{down}/$. Therefore, a remaining time of the product element inside the mixing tank can be calculated as follow:

$$t_{remain} = \frac{H}{v_{down}} = \frac{V_{tank}}{G} \quad [s] \qquad (4)$$

In which: t_{remain}—remaining time of mixed product in mixing tank [s]; v_{down}—velocity of the product level moving down [m/s]; V_{tank}—volume of mixing tank [m³]; G—output of mixed product [m³/s]. Finally, the remaining time can be determined as follow:

$$t_{remain} = \frac{C.\pi.D^2.H}{4.G} \ [s] \tag{5}$$

and

$$G = \frac{g_e.N_e}{3,600.\rho} \ [m^3/s] \tag{6}$$

here: D—diameter of mixing tank [m]; g_e—specific fuel consumption of a diesel engine [g/kWh]; ρ—density of mixed product or fuel [kg/m³]; C-storage coefficient of tank complying with classification rules with value from 1.5 to 2.

In accordance with experimental results, a quality of mixed product will be satisfied, if the mixing time is smaller than from 2 to 3 times of remaining time of product [3].

$$t_m \le (2 \div 3).t_{remain} \tag{7}$$

Therefore, the remaining time $/t_{remain}/$ is a key factor that must be taken into consideration during design of a fuel continuous mixer.

For design application, there must use shape factors from S1 to S9 as defined in Table 2 and Fig.2 [6,7].

Table 2. Shape factors

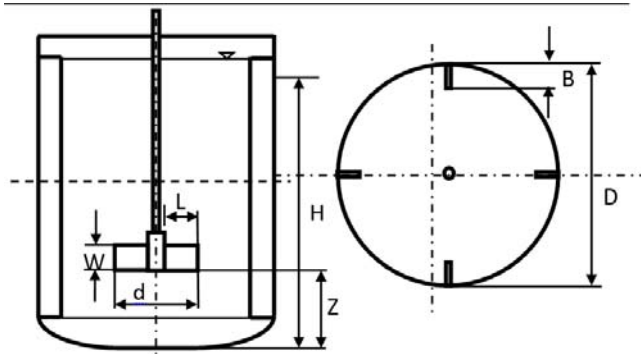| Shape factor	Ratio	Values
S1	T/D	3
S2	Z/D	0.75-1.3
S3	L/D	0.25
S4	D/W	5
S5	T/B	6
S6	H/D	2.7-3.9
S7	Number of impeller	6
S8	Pitch/angle	0 deg
S9	Number of baffles	4

Figure 2. Shape parameter of mixer

Designing of the fuel continuous mixer means that it has to calculate all parameters as mentioned in the Table 2, as well as to meet the condition as mentioned in Eq. (7). To complete design process, it must go through several stages which should need a computer support for calculation. A calculation algorithm of a fuel mixer parameters is presented in Fig.3.

3 USING CFD SIMULATION FOR EVALUATING THE MIXTURE QUALITY

In the scope of study on designing a fuel continuous mixer, a computational fluid dynamics (CFD) simulation is used to evaluate the quality of blends, optimizing the mixer's performance. ANSYS Fluent software is the most powerful and suitable that includes well-validated physical modeling capabilities to deliver fast, accurate results across the widest range of CFD and multiphysics applications.
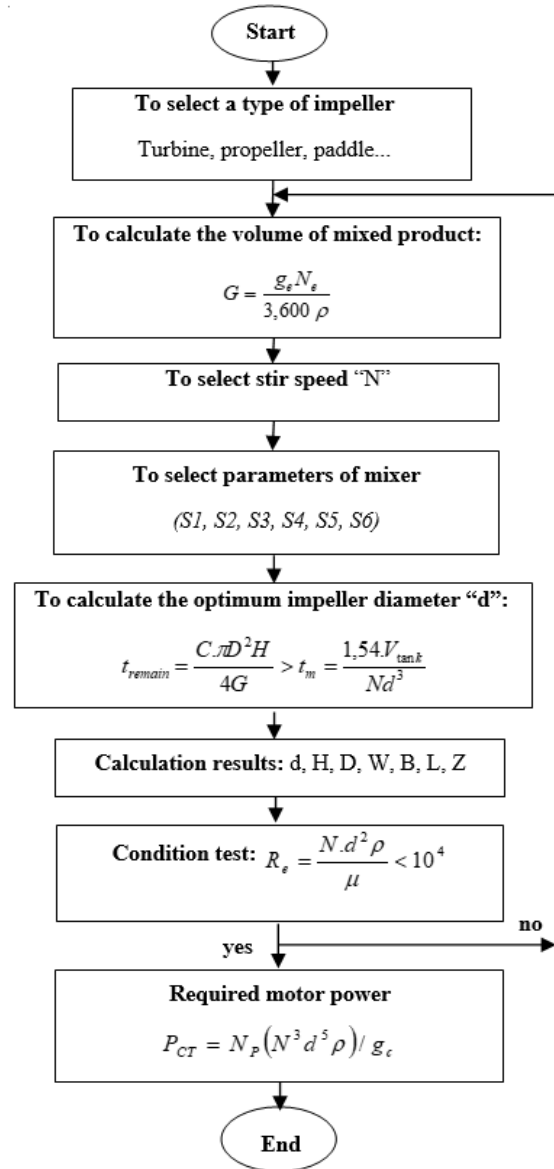

Figure 3. Calculation algorithm of mixer parameters

Applying for mixing liquids in the cylinder type mixer, CFD simulation is built upon the primary equations:
− Continuity equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{8}$$

− Navier–Stokes equations

$$\frac{d\vec{V}}{dt} = \vec{F} - \frac{1}{\rho} grad\, p + v\Delta\vec{V} \tag{9}$$

153

In which: $\vec{V}(u,y,w)$ - velocity vectorof survey liquid element; F - strain tensor; Δ: Laplacian operator.

The simulation focuses on distribution of two undissolved liquid phases, including vegetable oil (let take palm oil-PO) and diesel oil. Based on the designed parameters of fuel continuous mixer (temparature, impeller profile, positions of impeller and discharge mouth, etc.), the phase homogeneity of a mixed fuel depending on impeller speed and PO ratio in the mixture, shall be reviewed, specially the optimum mixture time.

3.1 *Typical case study:*

1 Case of constant impeller speed (60rpm) and variable mixture ratio leads to the results in Fig. 4. It can be seen clearly that at mixing ratio of 20%, PO molecules dispose in the diesel oil with high density and occupy a large portion of experimented area.
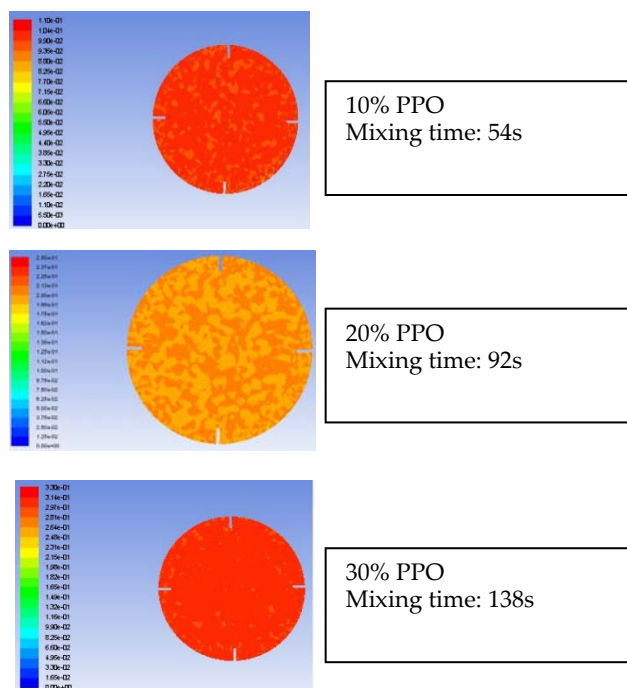

10% PPO
Mixing time: 54s

20% PPO
Mixing time: 92s

30% PPO
Mixing time: 138s

Figure 4. Case study with impeller speed of 60rpm

2 Case of constant mixing ratio at 20% PO and adjusted impeller speed brings to the Fig. 5. The results show that at speed of 50rpm, almost PO phase locates nearby the value of 20% but still high amplitude. When the speed of impller is increased, the amplitude will be more concentrated at center. However, there is not much diffrence between 60rpm and 70rpm or more, so the result can be acceptable in order to save energy providing to the mixer.
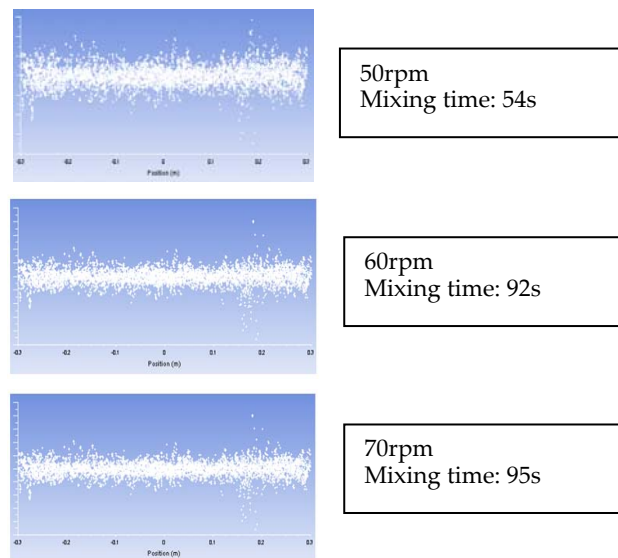

50rpm
Mixing time: 54s

60rpm
Mixing time: 92s

70rpm
Mixing time: 95s

Figrue 5. Case study with mixing ratio of20% PPO

4 TEST OF FUEL CONTINUOUS MIXER

The above study is impemented in regards to using palm oil as alternative fuel for marine application. A marine diesel engine selected to be an investigation object is HANSHIN6LU32 (Japan) which is normally used as main engine of vessels with capacity from 1,500 to 2,500 DWT. The technical specifications of this diesel engine are shown in the Table 3 and physical features of the palm oil in Table 1.

Table 3. Technical data of diesel engine

Technical parameters	Value
Number of cylinders	6
Revolution [rpm]	340
Effective power [kW]	970
Cylinder bore [mm]	320
Stroke [mm]	510
Specific fuel consumption [g/kWh]	200
Max. pressure [kG/cm²]	90

On a base of the calculation algorithm (Fig.3) and the technical data of diesel engine 6UL32 together with the physical features of palm oil and diesel oil, required parameters of a fuel continuous mixer applied for this diesel engine is calculated and presented in Table 4.

The fuel continuous mixer then was built and installed in fuel supply system of marine diesel engine 6UL32 at the Center for Marine Diesel Engine Research (Vietnam Maritime University) upon the diagram on Fig. 6.

The real production system and samples of mixed fuel (blended fuel) are showed in Fig. 7.

Table 4.The parameters of fuel continuous mixer

Tank diameter	D [m]	0.6
Impellerdiameter	d [m]	0.2
Number of blades		6
Width of impeller	W [m]	0.05
Length of impeller	L [m]	0.1
Width of baffles	B[m]	0.06
Height of liquid	H [m]	1.0
Distance from impeller to tank bottom		0.2

Before running the engine with blended fuel, samples of mixture were taken to scientifically examine on homogeneity by a microscope Axio Lab A1. At each mixing ratio, there were two samples collected at different time: T1 and T2.

The Table 5 and Fig.8 shows the result of visual experiment.

Table 5.Testing result of fuel samples

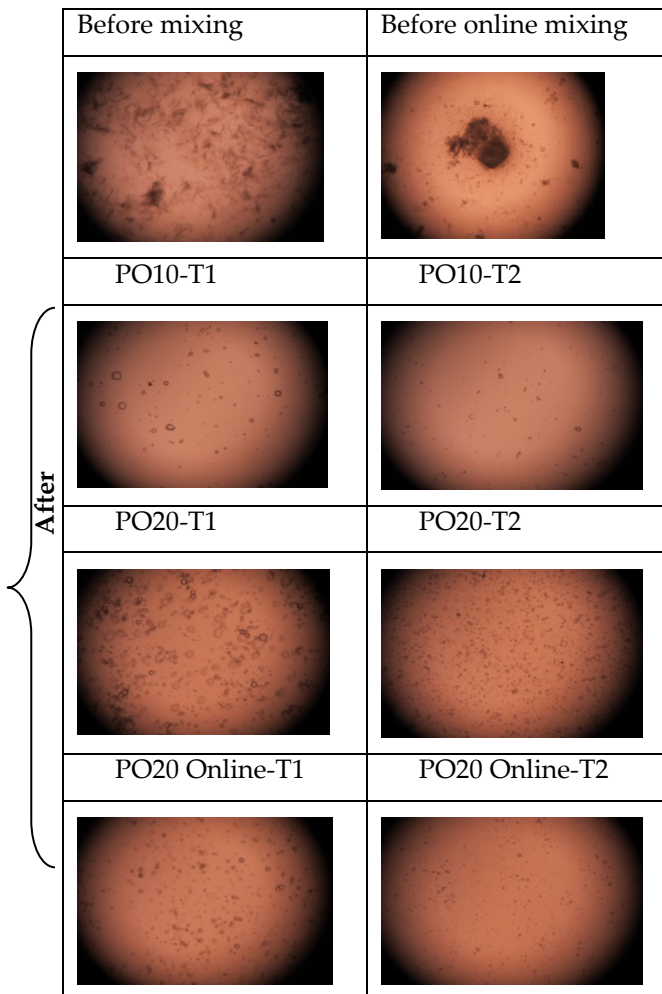| Mixing ratio	Mixing time [s]	Maximum molecule of palm oilin blended fuel[μm]
PO10 - T1	60	42
PO10 - T2	120	15
PO15 - T1	100	47
PO15 - T2	200	51
PO20 - T1	120	15
PO20 - T2	240	8
PO20 Online - T1	180	35
PO20 Online - T2	360	12

Figrue 8. Samples seen by microscope Axio Lab.A1

It can be recognized that:
- As homogeneity of palm oil in diesel fuel over 95%, the quality of blended fuel is confirmed and acceptable for operating the engines;
- At continuous proces (online supply), maximum size of palm oil was 35μm after 3 minute mixing and 12μm at 6 minutes. Actually, these sizes do not affect to injection nozzle (200μm) of engine 6LU32.

5 EXPERIMENTAL RESULTS

Experimental research on real marine diesel engine 6LU32 with support of high accuracy measuring equipment have been at two regimes: 50% load and 75% load.

- Peak pressure

The characteristics of the combustion pressure changes are showed in Fig.9, 10 and the details are also presented in Table 6.
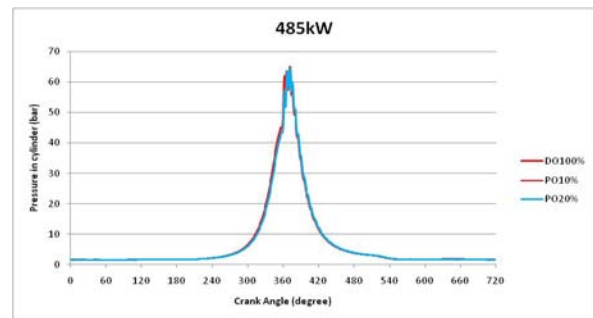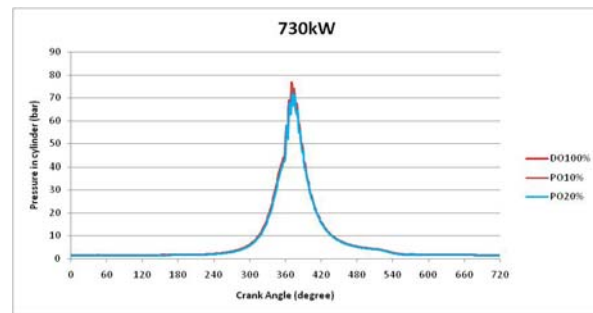

Figure 9. Pressure in cylinder at 50% load

Figure 10. Pressure in cylinder at 75% load

Table 6. Peak pressure at different engine loads

Engine load	Peak pressure [bar]			Difference [%]
	DO	PO10	PO20	
50%	65.808	64.352	64.106	2.59
75%	76.321	73.555	72.068	5.58

Changes of pressure in cylinders of all blended fuels and DO are the same. The biggest difference of peak pressure is recognized for PO20 and DO with the value of 5.58%.

- Ignition delay

The results of ignition delay of blended palm oil are showed in Fig. 11. The research team tried to enlarge the pictures of ignition start moment for all

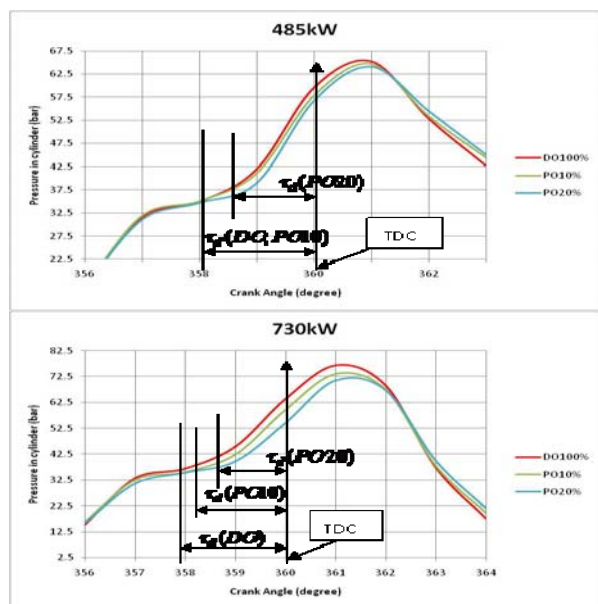kind of test blended fuels and real values measured are presented in Table 7.

Figure 11. Ignition delay of blended palm oils

Table 7. Ignition start of fuels before top dead center (TDC)

No	Engine load [kW]	Ignition start of blended fuels before TDC [s]		
		DO	PO10	PO20
1	485	0.0017	0.0017	0.0008
2	730	0.0021	0.0016	0.0012

Figure 12. Ignition start and burning of fuels

156

It can be seen that the ignition start of PO10 before TDC is the same as that of DO at low load and delayed 1.31 times at higher one. Also, the delay increases approximately linearly with raising volume of palm oil in the blended fuels.

To demonstrate this judgment, the Video Scope equipment was used to observe combustion process in cylinder, especially ignition start of different kinds of blended fuels including DO, PO10, PO15, PO20. Experimental results are shown in Fig. 12.

– Emissions

Emissions in exhaust gas of the diesel engine such as CO, CO_2, HC and NO_x are analyzed by special measuring system AVL AMA i60 R1. The results of experiment are plotted in Fig. 13.
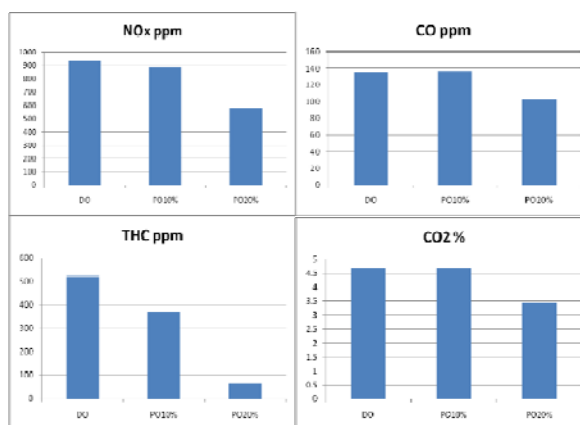

Figure 13. Emissions depending on kind of fuels

Among emissions, for marine field, IMO focuses seriously on the NO_x content control. The absolute values of NO_x in the experiment associated with different fuels are shown in Table 8.

Table 8. NO_x emissions of diesel engine 6LU32

NOx emissions					
DO		PO10		PO20	
ppm	g/kWh	ppm	g/kWh	ppm	g/kWh
940.45	19.4	894.06	18.6	576.62	13.6

The results show that the more volume of palm oil in the blended fuels, the lower the NO_x emissions in the exhaust gas of the tested diesel engine. Specially, the NO_x emissions of PO20 is only 13.6 [g/kW.h] which is lower than allowable NOx emissions requested by IMO for test diesel engine 6LU32 with nominal revolution 320rpm (requested NOx emission for the test engine is 14.19 g/kW.h).

6 CONCLUSIONS

To use straight vegetable oils as alternative fuel for marine diesel engines is very potential due to their important advantages in environment protection and renewable possibility. However, SVOs which is used directly as fuel for marine diesel engines may cause some troubles for engines themselves like bad combustion, coking engines, significantly lower output and so on. Therefore, to avoid above
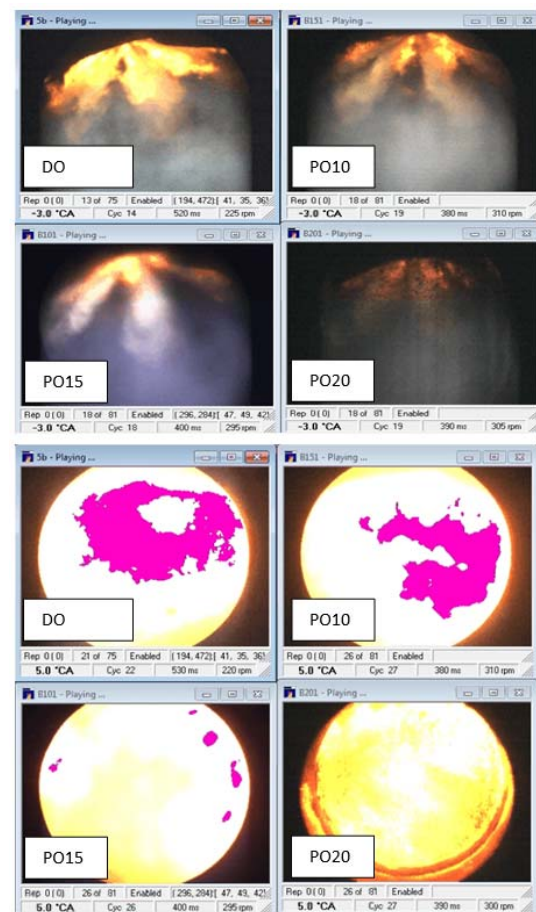
mentioned problems, there is recommended that blended SVOs should be applied.

The fluid continuous mixing is not new but the fuel continuous mixer applied in marine sector is very few. As demanding on using the straight vegetable oils as alternative fuel for the marine application, a group of researchers of Vietnam Maritime University has been developing the fuel continuous mixer and being applied for marine diesel engines. Based on reaserch results as quality of mixed fuel, possibility of the fuel mixer work together with fuel supply system, low emissions and so on, there are some conclusions as follows:

− The idea which has been developed as mentioned above is potential method to design and make a fuel continuous mixer for marine application;
− The quality of the mixed fuel made by the fuel continuous mixer is satisfied the requirements of the marine fuel;
− The real fuel supply system with the fuel continuous mixer built in can be acceptable to be applied for marine application.

It is hopeful that the fuel continuous mixer will be applied and installed widely onboard ships in order to play a role in evironment protection in near future.

REFERENCES

[1] Krzysztof Kołwzan, Marek Narewski, Polski Rejestr Statków, *"Study on Alternative fuels for marine applications"*, Clean Shipping Currents Vol 1, No 3, 2012;
[2] J. Blin, C.Brunschwig, A.Chapuis, *"Characteristics of vegetable oils for use as fuel in stationery diesel engines-towards specification for a standard in west Africa"*, HAL archives-ouvertes, 2013;
[3] Dang Van Uy and research team, *"Research and develop a technology solution in order to convert marine diesel engines of small and medium scale to use blended straight vegetable oils as alternative fuel"*, No.04.11/NLSH, 2014;
[4] Kees Kuiken 2008. Diesel Engines for Ship Propulsion and Power Plants, Part I, Target Global Energy Training, Onnen, The Netherlands;
[5] Jan Gerrit Van De Vusse 2010.*Mixing by Agitation of Miscible Liquids*. Rotterdam, Netherland;
[6] John Frank Pietranski 2012. Mechanical Agigator Power Requirements for Liquid Batches; PDH Center; 5272 Meadow Estaes Drive;
[7] Chapter 6 Mixing, Dalian University of Technology;
[8] Mixing and Agitation, Process Automation Control (PAControl).