EFFECT OF BIODIESEL BLEND RATIO DERIVED FROM RUBBER SEED OIL ON THE FUEL CONSUMPTION WHEN USING IN THE DIESEL ENGINE WITHOUT STRUCTURAL MODIFICATION BY SIMULATION AND EXPERIMENT

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(Received: July 14, 2022; Accepted: August 29, 2022)

Abstract - In this study, The model Mazda WL diesel engine, 4-cylinder, 4 straight-line cylinder with biodiesel blends ratio of 0%, 15%, 20%, 25%, 30% derived from rubber seed oil and DO has been simulated on ANSYS FLUENT software to analyze fuel consumption characteristics. Experimental engine has been using fuel with diesel (DO) and biodiesel blends (B15, B20, B25, B30) derived from rubber seed oil for a Mazda WL diesel engine installed on Mazda 2500 and Ford Ranger cars. The simulation results show that the average increase in fuel consumption rates for all modes for B15, B20, B25 and B30 compared to DO fuel are 0.71%, 1.69%, 2.77% and 3,83% respectively. Experimental results show that the average increase in fuel consumption rates for all modes for B15, B20, B25 and B30 compared to DO fuel are 0.58%, 1.39%, 2.19% and 3,19% respectively.

Key words - Biodiesel; Diesel engine; Fuel consumption; Specific energy consumption; Rubber seed oil.

1. Introduction

Combustion process in the combustion engine determines the power, efficiency, economic level, pollution emission level and engine features when operating. A large number of studies have shown that biodiesel is one of the renewable, promising alternative and environmentally friendly bio-fuel that can be used in the diesel engine with little or no change in engine structure [1÷5]. Strict emission laws, the exhaustion of fossil fuels and the relationship of fuel with politics have forced the world to find an alternative to fossil fuels. Many vegetable oil esters (biodiesel) have been studied for use in internal combustion engines and have been shown to have higher potential to reduce CO2 emissions [6], [7]. The effects of different fuel types on engine performance and specifications have been widely reported. Common engine parameters on which quantitative effects are included include: Fuel consumption, utility capacity and thermal efficiency. Many studies have compared the performance of engines using biodiesel and its mix with conventional diesel fuel engines. The results showed that using biodiesel for fuel efficiency and higher combustion efficiency than using traditional diesel fuel in diesel [8 ÷ 11].

However, the use of different biodiesel for the same engine will have variable results in engine efficiency, engine performance and engine exhaust due to changes in physical properties and chemistry of biodiesel [12]. The effects of physicochemical properties of fuel on fuel supply systems such as high pressure pumps, fuel filters and cylinder mixing rates between gas-fuel mixtures have been reported [13]. To improve the performance and emissions of biodiesel fuel engines and understand the effects of fuel physics on engine efficiency and emissions, a number of detailed studies of heat transmission properties has been made on traditional diesel engines. The rate of heat release, combustion pressure and combustion temperature affects the characteristics of engine performance and emissions, but most researchers have so far linked the relationship between efficiency and emissions. Characteristics of biodiesel with experimental parameters are biodiesel mixture ratio, engine speed, engine load, injection time, injection pressure and compression ratio of the engine. However, there are very few published works on combustion characteristics, combustion law and heat generation phenomena corresponding to different biodiesel rates and their mixes [14 ÷ 15].

Simulation with mathematical models is necessary to develop a new engine construction or modernize an existing one. Modeling of the processes inside the cylinder allows in a first approximation to evaluate engine performance, choose the rational value of adjustment or constructive parameter, to reduce material, labor and time required to conduct experimental research. One of the most difficult processes for simulation is the combustion process in diesel engines. Diffusion combustion model and turbulence combustion model are the base model to study combustion process in diesel engines using diesel fuel mixture biodiesel phase. Theoretical basis diffusion combustion and turbulence model is the foundation for the integrated simulation and simulation software from ANSYS 14.5. Ansys 14.5 has the ability to optimize geometry, can automatically adjust the structural parameters of special designs until they reach the desired optimal design goals. Based on Ansys 14.5 software, it is possible to set up a combustion model of the diesel-biodiesel fuel mixture to study engine performance [16, 18]. Simulation results in this paper are shown through the variation of pressure, temperature, fuel level, speed the mixture of different fuels in the same boundary conditions.

Therefore, the objective of this study is investigating and studying the characteristics of combustion of biodiesel fuel in separated combustion chamber diesel engines such as: the technical characteristics, fuel consumption, with different loads condition, biodiesel ratios, thereby contributing to research to perfect diesel engines when using biodiesel fuel derived from rubber seed oil with different ratios as well as contributions the orientation to promote the use of this fuel in practice. This paper also will present experimental results to study the combustion characteristics of biodiesel fuels with different proportions (B15, B20, B25, B30) derived from rubber seed oil and conventional diesel (DO) in the pre-combustion chamber diesel engine is implemented at: Internal Combustion Engine Laboratory - Department of Transportation Engineering, The University of Danang - University of Science Technology.

2. Simulation model setup

2.1. Simulation modeling

Simulation results to predict the combustion, economy, technical and emissions characteristics of diesel engine using B15, B20, B25 and B30 biodiesel fuel mixtures. Be the basis for evaluating experimental results on real engine.

Turbulence modeling: In the turbulence modeling $k-\varepsilon$, the equations are constructed as follows: Under the assumption of Boussinesq's viscosity [19], to have:

$$-\rho\overline{u_i^{'}u_j^{'}} = \mu_t\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\frac{2}{3}\left(\rho k+\mu_i\frac{\partial u_i}{\partial x_i}\right)\delta_{ij} \quad (1)$$

The above equation shows the relationship between Reynolds stress $-\rho\overline{u_i^{'}u_j^{'}}$ and mean velocity variation.

The general equation represents the diffusion spray: In order to model the supply of fuel for diesel engine, simulation software demonstrates diffusion spray by continuous equation as follows [19]; Continuous equation; Equation of momentum conservation; Full Enthalpy conservation equation; Equation of conservation element; Equation for turbulence kinetic energy k; Equation for Dissolution Dissipation Rate ε:

The main combustion model of J. Abraham: Consider the variability of substances such as: O_2, N_2, CO_2, CO, H_2, H_20 in the duration of time combustion J. Abraham [20] calculates both low temperature and high temperature. In particular, the rate of time-varying mass of a substance m in the combustion chamber due to chemical changes from one substance to another is determined by the equation:

$$\frac{d\rho_m}{dt} = -\frac{\rho_m-\rho_m^*}{\tau_c} \quad (2)$$

Where: ρ_m: partial density of substance *m*; ρ^*_m: instantaneous and local thermodynamic equilibrium value of partial density; τ_c: characteristic time to reach equilibrium.

Energy brought by fuel injection into the engine combustion chamber is determined by the equation [19]:

$$E_{nl} = m_f.Q_{HV} \quad (3)$$

Where: m_f - is fuel consumption (the amount of fuel); Q_{HV} - is the calorific value of the fuel.

Ignition Delay model of Kong and Reitz: Ignition Delay model of Kong and Reitz [20] computes the ignition delayed time of eight reactions between the five. Determine the coefficients of formation substance's velocity.

Building combustion chamber geometric and discrete model: The experimental engine is a Mazda WL-Turbo 4-stroke engine, 4 in-line cylinders are mounted on Mazda 2500 and Ford Ranger cars with the pre-combustion chamber. The combustion chamber is divided into 2 parts: the main combustion chamber and the auxiliary combustion chamber, forming 2 different vortex lines as shown in Figure 1.

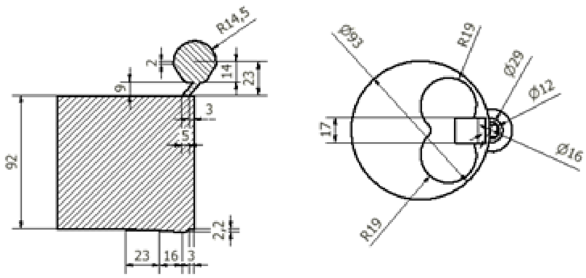

Figure 1. *Combustion chamber geometric*

Meshing model: Meshing of the combustion chamber separating WL-turbo engines is done on Ansys Fluent 14.5 software. With the automatic meshing feature (Automatic Method), Quad/Tri grid type, the mesh model of the 2D combustion chamber includes 9917 nodes and 9677 elements as shown in Figure 2.

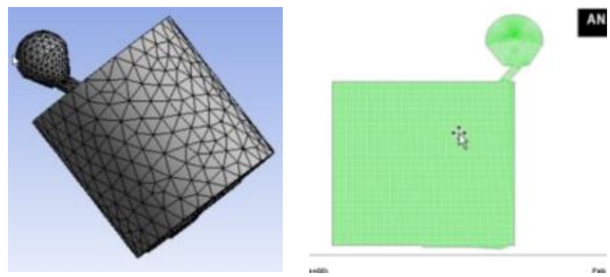

Figure 2. *Mesh of the Mazda engine combustion chamber*

Simulation mode will be as follows: Step 1: Input the corresponding parameters when the engine is running at 1500 rpm and 2250 rpm with advance angle injection 10 deg. before TDC, pressure is 114 (bar). Step 2: Enter the fuel models corresponding to DO, B15, B20, B25, B30. For each fuel, change the load corresponding to the 25%, 50% and 75%. Step 3: Run the calculation model and record the results of the combustion process, power, fuel consumption and emissions.

2.2. Characterization of biodiesel fuel used for Simulation and experiment

The fuel used for this study includes 4 types: biodiesel blends B15, B20, B25 and B30 (eg. B25 is the ratio of 25% biodiesel and 75% conventional diesel) derived from rubber seed oil and traditional diesel fuel (DO fuel): The chemical composition of rubber seed oil is mainly triglycerides, so they have the full characteristics of a typical ester. Biodiesel synthesized from rubber seed oil contains mainly unsaturated fatty acid roots with a total content of up to 76.69%. This component makes biodiesel flexible at low temperature. The total amount of methyl ester present in biodiesel is 100%, indicating a very high purity of synthetic fuels. In the chemical formula of biodiesel, the weight ratio is 77% C, 12% H, 11% O, the ratio between air and standard fuel = 12.5; for diesel, the mass density is 87% C, 13% H and the ratio between air and standard fuel = 14.5. Proceeding to mix DO fuel samples with 15%, 20%, 25% and 30% biodiesel (from rubber seed oil) in volume, to make the mixture stable for a period of 5 days with no impact on mechanics. Then take the sample to analyze at the laboratory of the General Department of Standards, Metrology and Quality - Technical Center for Quality Measurement No.2 and compare control with DO fuel samples of the same type with diesel phase into the mix is shown in Table 1.

Table 1. *Comparison main characteristics of B15, B20, B25 and B30 with diesel*

Characteristic, units	Experimen	Diesel	B15	B20	B25	B30
Sulfur content, mg/kg	ASTM D5453	500	295	238	238	217
Heating value, kJ/kg	ASTM D240 - 06	43738	42217,3	41910,4	38730	37500
Lightning flash burn, ºC	ASTM D93	55	68	72,0	74,0	74,0
Kinematic viscosity at 40ºC, cSt	ASTM D445	3,070	3,310	3,990	4,693	4,693
Water and mechanical impurities, % volum	ASTM D2709 – 06		<0,005	<0,005	<0,005	<0,005
Particulate matter, mg/l	ASTM D2276 –06	10	<1	<1	<1	<1
Density at 15ºC, kg/m^3	ASTM D1298	840	845,2	848,0	853,4	853,4
Cetane index	ASTM D 6751	45	46,9÷ 49,9 min	46,9÷ 49,9 min	46,9÷ 49,9 min	46,9÷ 49,9 min

2.3. Experiment Specifications used for Simulation and experiment

The experimental engine is a Mazda WL-Turbo 4-stroke engine, 4 in-line cylinders are mounted on Mazda 2500 and Ford Ranger cars. With the pre-combustion chamber: Capacity: 2499 (cc); Maximum torque: 266 Nm@ 2000 rpm; Maximum power: 85 kW@3500 rpm; The type of combustion chamber separates. The engine is fully mounted with sensors to record the engine's parameters when working such as fuel pressure before high pressure pump, fuel pressure on the high pressure pipe, intake air pressure, exhaust pressure, pressure in the cylinder, the lift of the injector etc. Indiset 620 device is used in the experiment of measuring the indicator parameters of the engine such as the combustion chamber pressure. The basic specifications of the Mazda WL engine are shown in Table 2.

Table 2. *The specifications of MAZDA WL engine*

Specifications	Symbol	Unit	Value
Max power at 3500 (rpm)	N_e	kW	85
Compression ratio	ε		19,8:1
Maximum Torque at 2000(rpm)	Me	Nm	266
Cylinder diameter	D	mm	93
Length of connecting rod	L	mm	152
Piston stroke	S	mm	92
displacement	V	cc	2499
Number of cylinders	i		4
Number of strokes	τ		4
Advance injection timing TDC	φ	deg	10
IVO	φ_1	deg	10
IVC	φ_2	deg	44
EVO	φ_3	deg	51
EVC	φ_4	deg	9
Fuel pressure at start of injection		bar	114÷121

3. The Experiment layout and installation

The experiment engine is mounted behind the APA test strip, which is connected to the motor by the connecting shaft. The schematic diagram of the experiment setup is shown in Figure 3 and installation of experimental engine Figure 4.

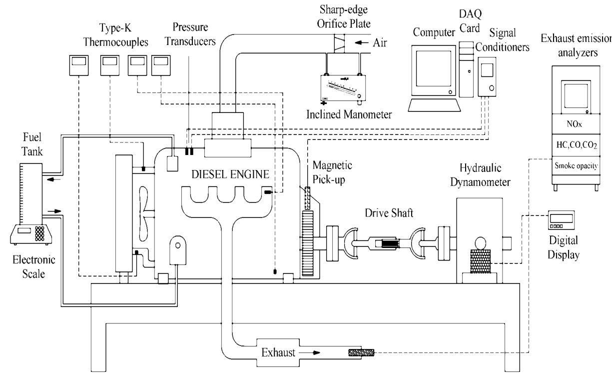

Figure 3. *Schematic diagram of experiment setup*

Figure 4. *Engine experimental installation*

Experimental conditions: In order to experiment with satisfactory results, the author chooses the initial conditions for the experimental process:

- Do not change temperature conditions such as intake air temperature ($T_{intake} = 32 \pm 0.5^0C$), fuel temperature ($T_{fuel} = 33 \pm 0.5^0C$) and lubrication oil temperature ($T_{oil} = 35 \pm 1^0C$).
- Flow of cooling water: 15m^3/h; Cooling water temperature in: 40 ÷ 85^{0}C; Lubricating oil pressure: 3 ÷ 5 bar.

Content of experimental modes: In this study, when using DO fuel, biodiesel blends B15, B20, B25 and B30, the operation mode of the test engine is constructed such that the speed of rotation and load of the engine are equivalent to those of common values of vehicles. The test modes according to the ECE R49 test cycle are shown in Table 3.

Table 3. *Contents of experimental modes*

Experimental fuels	DO, B15, B20, B25 and B30
Engine speed	1000 rpm÷3000 rpm step: 250 rpm
Load conditions	25%, 50% and 75%
Repeatability 1 measurement point	3 times, the average pressure data 100 cycles

Limited condition of experiment:

- Do not change the advance injection timing of high-pressure pump (φ = 10deg before TDC) and the injection pressure of MAZDA WL test engine is 114 bar.
- Limit the maximum engine speed to 2500 rpm in 25% throttle position and 3000 rpm in 50%, 75% modes.
- Do not use additives when mixing DO fuel with biodiesel from rubber seed oil into B15, B20, B25, B30 blends.

4. Result and discussion

Fuel consumption rate (g_e): is the ratio between the amount of fuel consumed per unit time and the useful power of the engine. Because diesel fuel and biodiesel fuel have different specific gravity and calorific value, the fuel consumption rate is converted to energy consumption rate (e_e) to compare fuel economy according to the formula $e_e = g_e.Q_H$, where Q_H is the calorific value of the respective fuel. Thus, at the same load or fixed amount of fuel for a cycle, when the engine's power decreases, the energy consumption rate decreases or the fuel consumption rate of the engine increases. The main reason leading to the increase in fuel consumption of biodiesel is because the calorific value is smaller than that of DO.

The results of changes in the value of energy consumption rate of the engine when using DO, B15, B20, B25 and B30 fuel according to simulation are presented in data Table 4. The simulation results show that the energy consumption rate of DO has the largest value and then gradually decreases when increasing the biodiesel ratio. The average reduction in energy consumption for all modes for B15, B20, B25 and B30 compared to DO fuel are -2.79%, -2.56%, -9.00% and -10.98%, respectively.

Table 4. *Comparison of specific energy consumption by simulation*

speed	Load (%)	Biodiesel blend ratio and DO								
		DO	B15	change	B20	change	B25	change	B30	change
1500 (rpm)	25	13521	13147	-2,76	13167	-2,61	12302	-9,02	12003	-11,23
	50	13833	13416	-3,01	13478	-2,56	12590	-8,99	12271	-11,29
	75	14444	14046	-2,76	14057	-2,68	13176	-8,78	12943	-10,39
average				**-2,84**		**-2,62**		**-8,93**		**-10,97**
2250 (rpm)	25	29967	29184	-2,61	29201	-2,56	27234	-9,12	26601	-11,23
	50	14736	14315	-2,86	14382	-2,40	13425	-8,90	13090	-11,17
	75	12753	12401	-2,76	12426	-2,56	11581	-9,19	11406	-10,57
average				**-2,74**		**-2,51**		**-9,07**		**-10,99**
The average value				**-2,79**		**-2,56**		**-9,00**		**-10,98**

The trend of changing energy consumption of the engine when using DO and biodiesel in the simulation at both revolutions is almost the same in the decreasing direction shown in the graph of Figure 5.

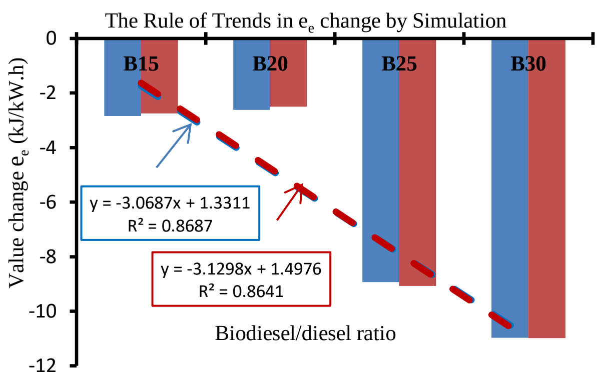

Figure 5. *Trend of change in energy consumption rate by simulation*

Experimental results show that the energy consumption rate of DO has the largest value and then gradually decreases when the biodiesel ratio is increased, which is shown in Table 5. The average reduction in energy consumption for all modes for B15, B20, B25 and B30 compared to DO fuel is -2.91%, -2.85%, -9.51% and -11.53%, respectively. whereby B15 is not significantly reduced compared to DO.

Table 5. *Comparison of specific energy consumption by experiment*

speed	load (%)	Biodiesel blend ratio and DO								
		DO	B15	change	B20	change	B25	change	B30	change
1500 (rpm)	25	12902	12467	-3,37	12461	-3,42	11659	-9,63	11423	-11,47
	50	13582	13201	-2,80	13203	-2,78	12380	-8,84	12078	-11,07
	75	14049	13643	-2,89	13650	-2,84	12680	-9,75	12326	-12,27
average				**-3,02**		**-3,01**		**-9,41**		**-11,60**
2250 (rpm)	25	29428	28615	-2,76	28556	-2,97	26479	-10,02	26320	-10,56
	50	14396	13997	-2,78	14109	-2,00	13124	-8,84	12754	-11,41
	75	12312	11956	-2,89	11931	-3,09	11084	-9,97	10785	-12,40
average				**-2,81**		**-2,68**		**-9,61**		**-11,46**
The average value				**-2,91**		**-2,85**		**-9,51**		**-11,53**

Comparing the trend of changing energy consumption rate of Mazda WL engine when using biodiesel fuel derived from rubber seed oil compared to DO fuel is shown on the graph in Figure 6. The results show that the trend of changing the energy consumption rate in the simulation has a rule close to the experimental.

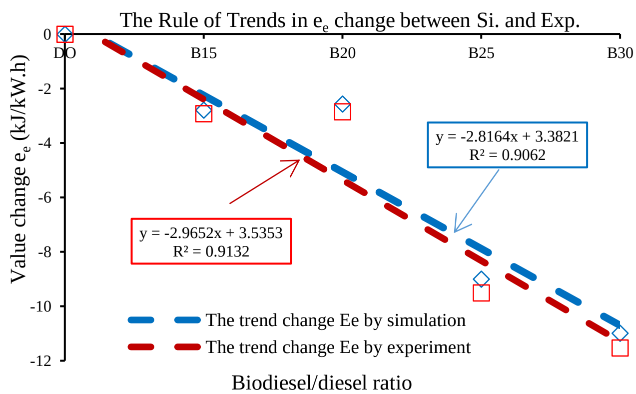

Figure 6. *Comparison of The Rule of Trend between simulation and experiment of the energy consumption rate when using biodiesel*

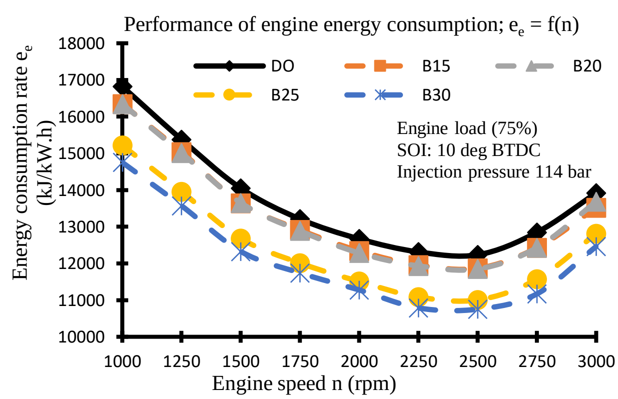

Figure 7. *Performance of engine energy consumption by experiment*

According to the experimental results, the characteristic curve of the engine energy consumption according to the experiment is shown on the graph of Figure 7 with the energy consumption rate when using the largest DO at all engine speeds, B15 has the not much difference compared to DO. Engine energy consumption decreases as the biodiesel blending ratio increases at all engine speed modes.

Comment: Compared with DO fuel, biodiesel fuel has a small calorific value, high kinematic viscosity and high elasticity or is a large compressive stress, so it affects the misting process, the evaporation process, and creates a poor mixture. Therefore, the economic indicators of the Mazda WL engine decreased. Based on experimental data, it can be seen that B15 has a reduced energy consumption rate compared to DO in all load modes but not significantly. Therefore, considering the economy of the Mazda WL engine with a cylinder capacity of 2.5 liters, it is possible to recommend the use of B15 fuel for the engine in all load modes without modifying the structure as well with little effect on the economy fuel consumption.

5. Conclusions

The model Mazda WL diesel engine, 4-cylinder, 4 straight-line cylinder with biodiesel blends ratio of 0%, 15%, 20%, 25%, 30% derived from rubber seed oil and DO has been simulated on ANSYS FLUENT software to analyze combustion parameters, compare economic and technical characteristics as well as emission targets, to ensure reliability and suitability to the reality.

Through the developed model, it is possible to analyze and evaluate the combustion characteristics of biodiesel in the internal combustion engine as well as to explain and evaluate the experimental results. The simulation results show that the average increase in fuel consumption rates for all modes for B15, B20, B25 and B30 compared to DO fuel are 0.71%, 1.69%, 2.77% and 3,83% respectively.

The results of the experimental study have also identified factors that can be used to analyze the effects of biodiesel fuel derived from rubber seed oil to substitute on economic indicators, operational parameters of diesel engine. Experimental results show that the average increase in fuel consumption rates for all modes for B15, B20, B25 and B30 compared to DO fuel are 0.58%, 1.39%, 2.19% and 3,19% respectively.

The study also shows that: It is possible to use biodiesel fuel with a maximum 15% (B15) blending ratio for Mazda WL diesel engine without modifying the structure.

Acknowledgment: This work belongs to the project in 2022 funded by Ho Chi Minh City University of Technology and Education, Vietnam.

NOMENCLATURE

ASTM:	American Society for Testing and Materials
RSO:	Rubber Seed Oil
BMEP:	Brake Mean Effective Pressure
IMEP:	Indicate Mean Effective Pressure
MFBR:	Mass Fraction Burn Rate
HRR:	Heat Release Rate
Ce:	Combustion efficiency
Cd:	Combustion duration

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