JMES The International Journal of
Mechanical Engineering and Sciences
https://iptek.its.ac.id/index.php/jmes
e-ISSN 2580-7471

The Effect of Compression Ratio on a Diesel Engine Fueled with a Mixture of Medium Sulfur High Speed Diesel and Ethanol

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Received: 1 July 2019, Revised: 2 September 2019, Accepted: 8 September 2019

Abstract

Various design modifications made by transportation equipment companies aim to increase the efficiency of fuel consumption. One of them is by reducing the dIndonesia relies on the use of fossil fuels (conventional), particularly in the fields of industry, transportation, and power generation systems. Fossil fuels are not sustainable energy sources, so their availability is limited. To reduce dependence on fossil fuels and reduce the negative impact on the environment, it is necessary to conduct research on energy sources, especially renewable and environmentally friendly ones. Bioethanol is a form of renewable energy that can be produced from plants. So that the use of fossil fuels can be replaced by ethanol fuel, especially for spark-ignition engines (SIE). However, when used in compressed ignition engines (CIE), plant fuels or vegetable oils have weaknesses that affect CIE performance, such as cetane number, calorific value, etc. so that engineering related to the fuel and engine is needed. This study will examine the effect of changes in the compression ratio in CIE fueled by a mixture of Indonesia medium sulfur content of Diesel Fuel (commercially name: Dexlite), Ethanol, and Emulsifier Tween 80 on engine performance and emissions. The results showed that the 10% emulsifier was used in all fuel mixtures because the separation time was the longest. After determining the emulsifier level, the DEX70 (70% Dexlite - 30% Ethanol) and DEX 80 (80% Dexlite - 20% Ethanol) fuels were determined because they have the best characteristics for exhaust gas emission parameters. Then, by changing the compression ratio on the engine, there is a change in engine performance and emission parameters. For DEX80 and DEX70 with CR 17.9 have the maximum brake thermal efficiency (BTE) as much as 25.52% and 25.16% respectively at maximum load, higher than Dexlite with CR 17.9 in which BTE as much as around only 24%. Increasing compression ratio significantly decrease smoke opacity of exhaust gas. DEX80 with CR 17 and CR 16 experienced an increase in smoke opacity by (175.41%) and (3.11%) against DEX80 with CR 17.9. Meanwhile, DEX70 with CR 17 and CR 16 experienced an increase in smoke opacity by (17.01%) and (236.05%) against DEX80 CR 17.9.

Keywords: Dexlite, diesel, emission, emulsifier, ethanol, compression ratio, performance

1. Introduction

Indonesia still depends on the use of fossil fuels (conventional), especially in the fields of industry, transportation, and power generation systems. Fossil fuels are not sustainable energy sources, so their availability is limited. Massive and continuous use will reduce the available reserves of these fossil fuels. Energy sources from plants or vegetable oils are one solution. Bio-ethanol is a form of renewable energy that can be produced from plants. Ethanol can be made from common crops, such as sugar cane, potato, cassava, and corn. In its use, Ethanol can be used as the main fuel or mixed fuel.

Research on the performance of diesel engines with a mixture of diesel fuel and ethanol (dual fuel) has been widely carried out. Subbaidah et al. [1] conducted a study on a mixture of biodiesel fuel (rice bran) with ethanol on performance and exhaust emissions in 4 stroke-diesel engines, naturally aspirated. The experimental results show that the maximum BTE (Brake Thermal Efficiency) (28.2%) is found in a mixture of 30% ethanol with a mixture of diesel-biodiesel-ethanol fuel.

Gnanamoorthi etc [2] concluded that with a mixture of E30 fuel (70% Diesel - 30% Ethanol), the average BTE (Brake Thermal Efficiency) was 35% greater than that of Diesel fuel due to the increase in the compression ratio. However, other studies conducted by Pbakaran et al. [3], and Mofijur et al. [4], concluded that the Brake Thermal Efficiency (BTE) produced in an engine fueled by a mixture of Ethanol-Diesel fuel is the same as pure diesel fuel.

Dexlite is the newest fuel oil from PT. Pertamina (Persero) for diesel-engined vehicles in Indonesia. Dexlite was launched in April 2016 as a new variant for consumers who want fuel with a quality above Indonesia high sulfur content of diesel fuel (commercially name: Solar) with a minimum Cetane number of 48, but at a

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lower price than Pertamina Dex with a Cetane number of at least 53. The lower heating value (LHV) of Dexlite is 47,054.2 kJ/kg. Meanwhile, the higher heating value (HHV) is 56,617.7 kJ/kg. Solar, Dexlite and Pertamina Dex have sulfur content as high as around 3,000 ppm (high), less than 1,200 ppm (medium) and less than 500 ppm (low), respectively.

Ethanol is included in a single chain, with the chemical formula C_2H_5OH and the empirical formula C_2H_6O. Ethanol is often shortened to EtOH, where "Et" stands for the ethyl group (C_2H_5).

Ethanol is a colorless substance, has a distinctive aroma, and water-soluble. Ethanol has a Research Octane Number 98-100 with a stoichiometric AFR of 9.0. Ethanol does have a higher octane number than gasoline, but its calorific value is lower than gasoline and diesel fuel, where the higher heating value (HHV) of Ethanol (99.6% purity) in Praptijanto et al. [5] has a value of 47.5%, while the lower heating value (LHV) is 43.5% lower than the heating value of Dexlite. In Table 1 there is a comparison of the characteristics of ethanol and Dexlite.

According to Gnanamoorthi et al [2], by mixing diesel fuel with ethanol with the composition (E0, E10, E20, E30, and E40) and changing the compression ratio (17.5:1, 18.5:1, and 19.5:1) in Direct Injection diesel engines, there were improvements in emissions and engine performance parameters. E30 mixture is a mixture that has the best performance and emission improvements with a decrease in the value of HC, CO, and smoke opacity, respectively, 65%, 15%, and 16%, along with the addition of the compression ratio by 10% (two points). In the NOx parameter, all mixtures (E10, E20, E30, and E40) at a compression ratio (18.5:1) have lower NOx levels than diesel, but at a compression ratio (19.5:1), a mixture of E20, E30, and E40 increased by 10%, 20%, and 40% respectively compared to diesel.

Praptijanto et al. [5] studied a performance test and emission analysis on a 2-cylinder Diesel Engine with Ethanol-Solar (dual fuel). Researchers used mixing Solar-Ethanol, E2.5%, E5%, E7.5% and E10%, with loads of 0, 10, 20, 30, 40, 50 and 60 Nm. From the research, the conclusion is that with the addition of the percentage of ethanol, the engine power increases and the BSFC and exhaust gas temperature decreases. For CO, HC, and smoke exhaust emissions levels also decreased. Changes in the properties of Dexlite-Ethanol blend fuel in the form of a decrease in density, viscosity, and an increase in heating value will certainly have a negative effect because it results in an increase in NOx emissions at a compression ratio of 19.5:1 along with the addition of E20, E30, and E40 by 10%, 12%, and 40%.

2. Research Methodology

The test was carried out experimentally on a constant speed 2,000 RPM diesel engine. The test was carried out on the machine as a test tool with the main shaft that had been connected directly to the electrical generator as an electrical dynamometer. Data was collected for each load variation tested, namely 200 watts to 2,000 Watts in addition to 200 Watts. The test was carried out at the Combustion and Energy Systems Laboratory Workshop.

Table 1. Comparison of Ethanol and Dexlite Fuels

No	Parameter	Unit	Value	
			Ethanol	Dexlite
1	Density at 20°C	kg/m^3	788	837
2	Centane Number	-	5-8	50
3	Kinematic Viscosity at 40°C	mm^3/s	1.2	2.6
4	Surface tension at 20°C	mm^3/s	0.015	0.023
5	Lower Heating Value	MJ/kg	26.8	47
6	Specific Heat Capacity	J/kg.°C	2,100	1,850
7	Boiling Poin	-	78	180-360
8	Oxygen, % weight	%	34.8	0
9	Latent Heat of Evaporation	kJ/kg	840	250
10	Stoichiometric air-fuel ratio	-	9.0	15.0
11	Molecular weight	-	46	170

2.1. Testing Preparation

In this stage, preparations were made for the Diesel engine, the measuring instruments used and the fuel to be tested. This test used an engine with the following specifications

- Brand : Yanmar
- Model : TF 55 R
- Type : 4-stroke, air-cooled
- Combustion System : direct injection
- Number of cylinders : 1 cylinder
- Injection Timing/standard : 17° before TDC
- Bore x Stroke : 75 x 80 (mm)
- Cylinder volume : 353 (cc)

2.2. Preparation Phase and Fuel Properties Test

In this stage, an experiment was carried out on fuels with a percentage of Ethanol 10%, 20%, 30%, 40%, and 50%. This preparation aims to allow the fuel mixture to be mixed with a small separation level for a long time. Tween 80 emulsifiers were added to these mixtures to aid in the mixing process. The Tween 80 emulsifiers were tested by adding 2.5%, 5%, and 10% to each mixture [6], and then tested what is the best percentage to produce the mixture with the smallest separation level and last the longest.

2.3. Fuel Testing with Ethanol Percentage Variations

The tests were carried out on DEX100 (Dexlite 100%; Ethanol 0%), DEX90 (Dexlite 90%; Ethanol 10%), DEX80 (Dexlite 80%; 20% Ethanol), DEX70 (Dexlite 70%; 30% Ethanol), DEX60 (Dexlite 60%; Ethanol 40%) and DEX50 (Dexlite 50%; Ethanol 50%) which had been mixed well. Tests were carried out on the engine to see the performance with parameters of power, torque, BMEP, specific fuel consumption, and thermal efficiency. As well as exhaust emissions parameters of smoke opacity, UHC and CO levels.

2.4. Determination of the Best Fuel for Testing with a Compression Ratio Variation

This fuel determination was determined from the resulting exhaust gas emissions (CO, opacity and UHC). Emissions with the best quality were used as fuel for testing with a compression ratio variation.

2.5. Fuel Testing with a Compression Ratio Variation

This test was carried out on the fuel that had been declared the best from the fuel test results with variations in the percentage of ethanol. Tests were carried out on the engine to see the performance with parameters of power, torque, BMEP, specific fuel consumption, and thermal efficiency. As well as exhaust emissions with smoke opacity parameters, UHC and CO levels. The compression ratio variation is set at 17.9:1, 17:1 and 16:1.

3. Result and Discussion

3.1. Results of Preparation and Fuel Properties Test

For mixed fuels, the blending process was carried out between Dexlite, Ethanol, and Emulsifier Tween 80 with a certain percentage. The goal is that the fuel does not undergo separation in a short time. Table 2 shows the results of adding the best Tween 80 emulsifier percentage variations in all fuel mixtures, obtained:

Table 2. Emulsifier Mixing Results

Fuels	Best Percentage
DEX90	10%
DEX80	10%
DEX70	10%
DEX60	10%
DEX50	10%

In Table 3, the test results on several parameter properties of the fuel, including density, kinematic viscosity, cetane index, lower heating value, and density are shown.

Table 3. Fuel Properties Data

Fuels	Density @ 15°C (kg/m^3)	Kinematic Viscousity @40°C (mm^3/s)	Cetane Index	Lower Heating Value (kJ/kg)
Dexlite	845.7	0.65	50	43,000
Etanol	788	0.15	8	27,000
DEX90	834.2	0.415	47.6	41,400
DEX80	841.9	0.403	46.65	39,800
DEX70	840.7	0.392	45.7	38,200
DEX60	836	0.38	44.4	36,600
DEX50	833.3	0.37	43.1	35,000

In the parameters of cetane index, kinematic viscosity, and density, values are obtained using measuring instruments owned by the PUSDIKLAT MIGAS Cepu Petroleum Laboratory. The method of calculating LHV (Lower Heating Value) refers to the research of Prabakaran et al. [3].

3.2. Fuel Testing Results with Ethanol Percentage Variations

In this test, the performance and exhaust emissions from testing all fuel mixtures with the percentage of ethanol were obtained. But in this case, the focus point for discussion is the results of the exhaust emission test. In Figure 1, it is shown that the CO level is relatively decreasing, where the lowest level is obtained with the use of DEX80 fuel and the highest in the use of DEX50 fuel.

By increasing the percentage of ethanol in the fuel mixture, the resulting combustion is better. In Figure 2, can be seen that the soot content with an indication of the decreased smoke opacity. This is due to the influence of the fuel properties. Reduction from smoke is caused by the viscosity value of all mixtures, causes better atomization, thereby increasing the quality of combustion with oxygen-containing fuels and the fast fire-propagation properties of ethanol so that combustion occurs better.

In Figure 3. It can be seen that the UHC level has increased. This is due to the low temperature of the combustion so that the chemical reactions of carbon, hydrogen, and oxygen proceed more slowly.

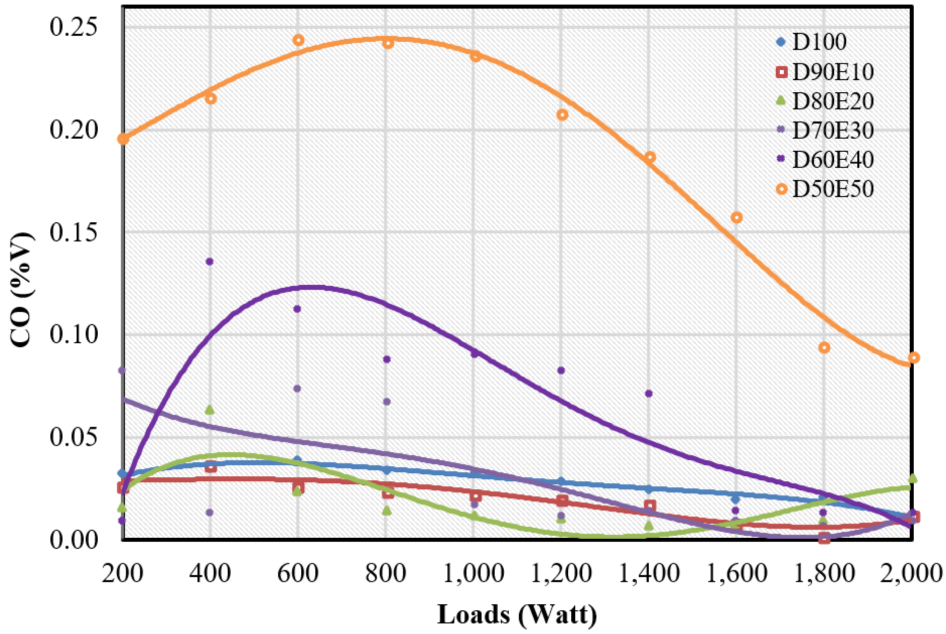

Figure 1. CO levels against Load

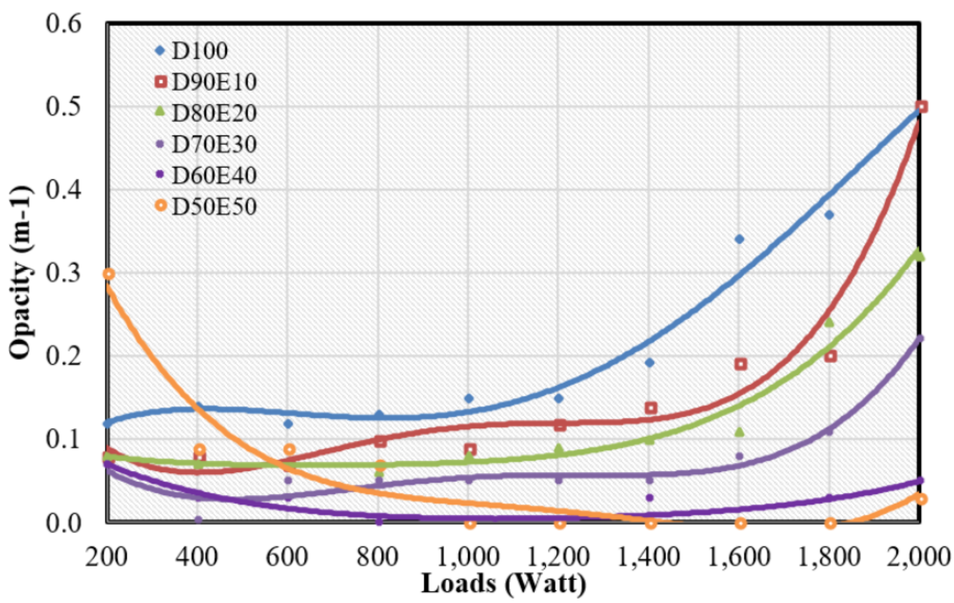

Figure 2. Smoke opacity against Load

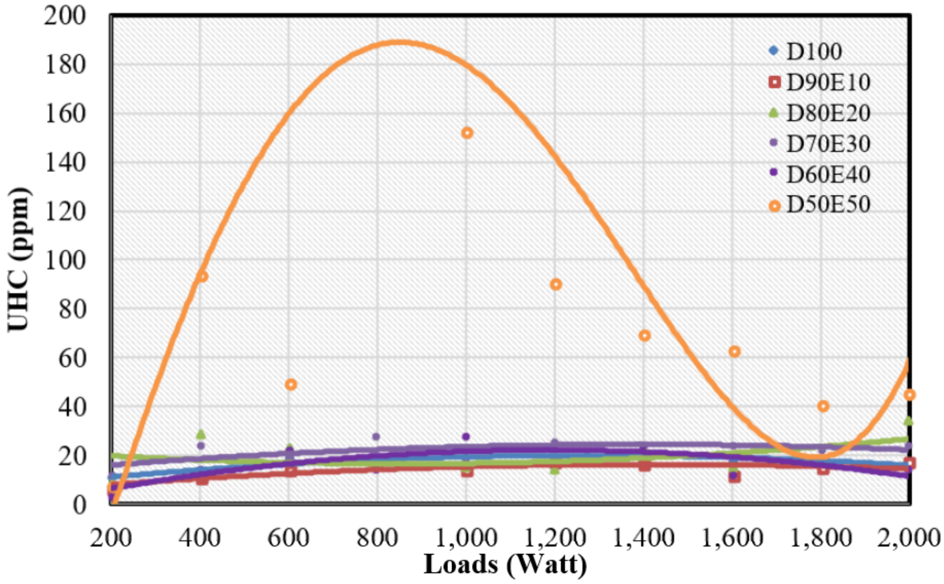

Figure 3. UHC levels against Load

The high LHV value is the cause of the low temperature of the combustion chamber so that the UHC and CO levels are higher with the addition of ethanol. Table 4 shows the results of fuel testing with variations in ethanol's percentage, the emission test results obtained.

Table 4. Exhaust emission level

Fuels	Smoke opacity (%)	UHC Levels (ppm)	CO Levels (%V)
DEX90	0.16	13.9	0.02
DEX80	0.12	15.6	0.02
DEX70	0.07	15.2	0.03
DEX60	0.06	16.7	0.09
DEX50	0.06	96.7	0.19

Based on Table 4, the selection of mixed fuels used in testing performance and exhaust gas emissions, with variations in the compression ratio, is to observe the exhaust emission test results in the control test. DEX70 and DEX80 fuels are the best fuels for exhaust emission parameters. It was found that the smoke opacity of this fuel is relatively better than DEX90 fuel. For the UHC level parameter, it was found that the fuel was lower than DEX50 with a value of 96.7 ppm. The parameter of CO levels shows that the fuel is relatively lower than the other mixed fuels. With the value of the CO, respectively, the DEX80 and DEX70 mixed fuels are 0.02 and 0.03.

3.3. Testing Results and Graph Analysis of Performance and Exhaust Gas Emissions, Dexlite-Ethanol Fuels, DEX80 and DEX70 with Compression Ratio Variations

Performance testing and exhaust gas emissions testing used a mixture of DEX80 and DEX70 fuels with compression ratio (CR) of 17.9:1, 17:1, and 16:1. The performance parameters analyzed and displayed are thermal efficiency, specific fuel consumption, smoke opacity, UHC, and CO levels. For performance parameters, such as power, torque, and BMEP, each fuel is relatively the same. This is because the load given to the engine and engine RPM are the same

In Figure 4, it can be seen that along with the addition of load, the value of thermal efficiency increases. The mixed fuel DEX70 with CR 17.9 has a maximum Brake Thermal Efficiency value (25.16%) at maximum load, but there was a decrease (2.73%) compared to Dex100 with CR 17.9. Then for the DEX70 with CR 17 and CR 16, there was a decrease in the value of thermal efficiency by (4.53%) and (7.12%) respectively when compared to the DEX70 with CR 17.9.

In Figure 5, it can be seen that the DEX80 CR 17.9 mixed fuel has a maximum brake thermal efficiency value of (25.52%) at maximum load, but it decreases in average (0.4%) when compared to D100 with CR 17.9. Then, for DEX80 with CR 17 and CR 16 there was a decrease in the value of thermal efficiency by (12.93%) and (6.71%) respectively when compared to DEX80 CR 17.9.

With the lower compression ratio, will be the lower the compressed air density. Increasing the compression ratio decreases the delay period because an increase in the compression ratio increases air temperature and density, Kawano [7]. The air temperature will decrease with a decrease in the compression ratio so that the delay period will be longer which causes a decrease in the value of the brake thermal efficiency.

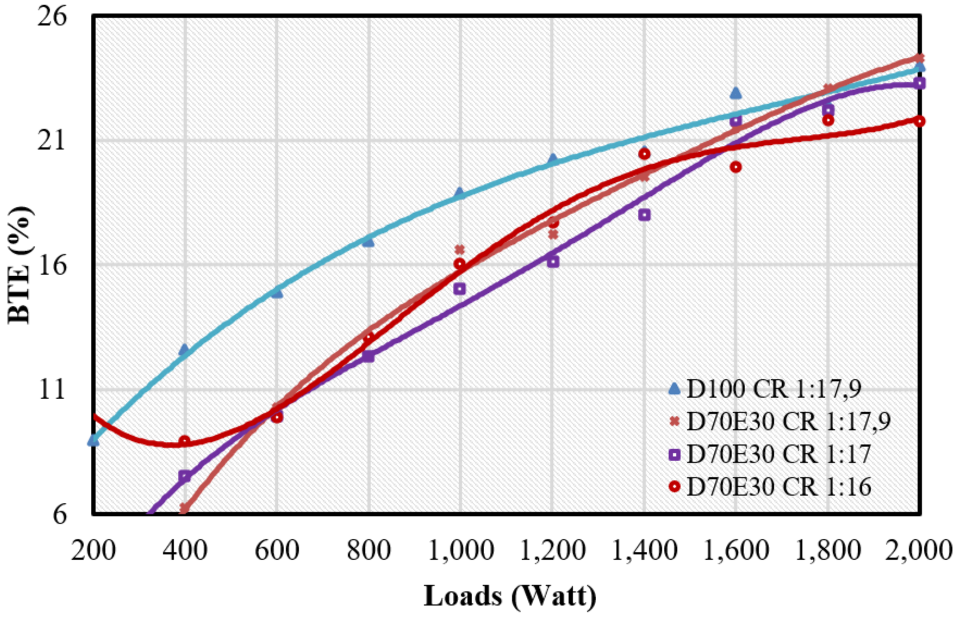

Figure 4. Thermal efficiency against load for mixed duel DEX70

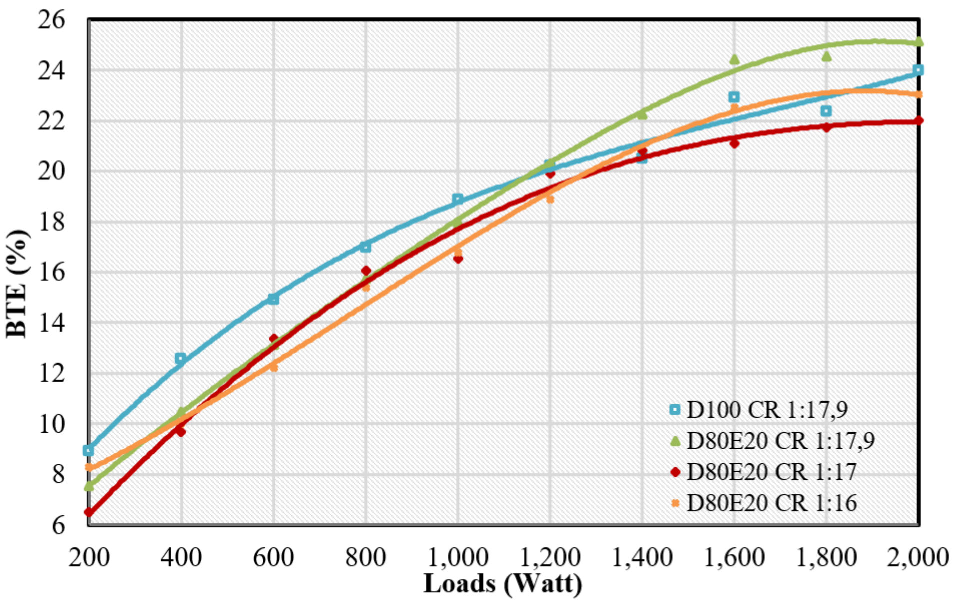

Figure 5. Thermal efficiency against load for mixed fuel DEX80

In Figure 6, it can be seen that along with the addition of loads, the BSFC value decreases. The mixed fuel DEX100 with CR 17.9 has the lowest brake specific fuel consumption value with an average (0.501 kg/kW.h). For DEX80 with CR 17.9, there was an increase in the average BSFC value of (15.37%) compared to D100 with CR 17.9. Then, DEX80 with CR 17 and CR 16 experienced a decrease in BSFC by (12.63%) and (4.44%) against DEX80 with CR 17.9.

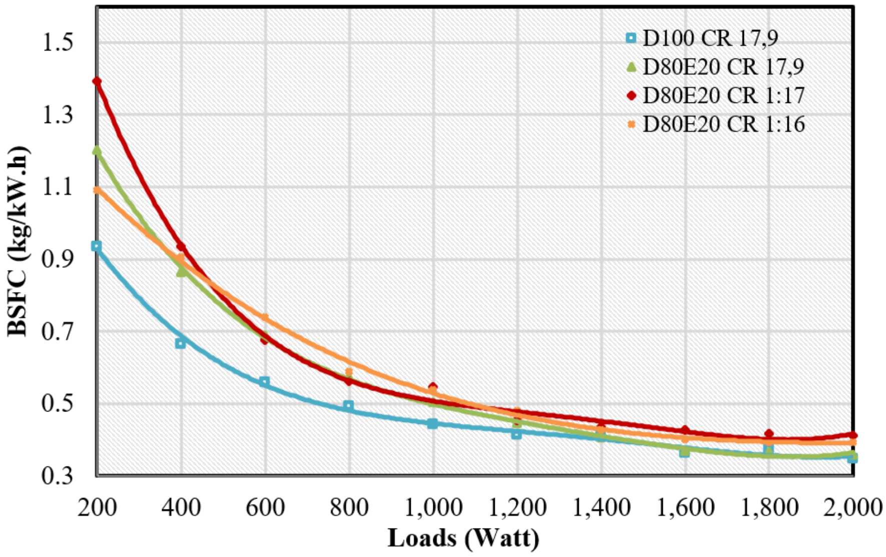

Figure 6. BSFC against Load for mixed fuel DEX80

In Figure 7. It can be seen that the DEX100 with CR 17.9 has the lowest Brake Specific Fuel Consumption value (0.501 kg/kW.h). For the DEX70 with CR 17.9, there was an increase in the average BSFC value of (15.37%) to the D100 with CR 17.9. Then, DEX70 with CR 17 and CR 16 decreased BSFC by (0.04%) and (1.37%) against DEX70 with CR 17.9.

Based on Figure 6 and Figure 7 the BSFC value of standard fuel (Dexlite) is always lower than the mixed fuel (Dexlite-Ethanol). This is because the density and heating value of the mixed fuel is lower than the standard fuel.

In Figure 8, it can be seen that the DEX80 with CR 17.9 has the lowest smoke opacity with an average of (0.122 m-1). For the DEX80 with CR 17.9, there was a decrease in the smoke opacity value by an average of (44.8%) against the D100 with CR 17.9. However, DEX80 with CR 17 and CR 16 experienced an increase in smoke opacity by (175.41%) and (3.11%) against DEX80 with CR 17.9.

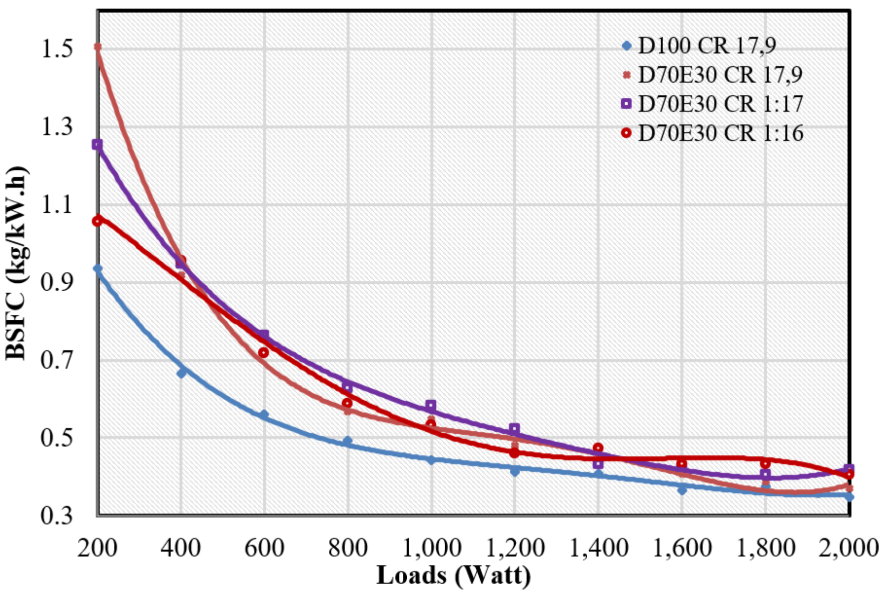

Figure 7. BSFC against Load for mixed fuel DEX70

In Figure 9, it can be seen that the DEX70 with CR 17.9 has the lowest smoke opacity with an average of (0.074 m-1). For the DEX70 with CR 17.9, there was a decrease in the smoke opacity value of an average (66.74%) against the D100 with CR 17.9. However, DEX70 with CR 17 and CR 16 experienced an increase in smoke opacity by (17.01%) and (236.05%) against DEX80 CR 17.9.

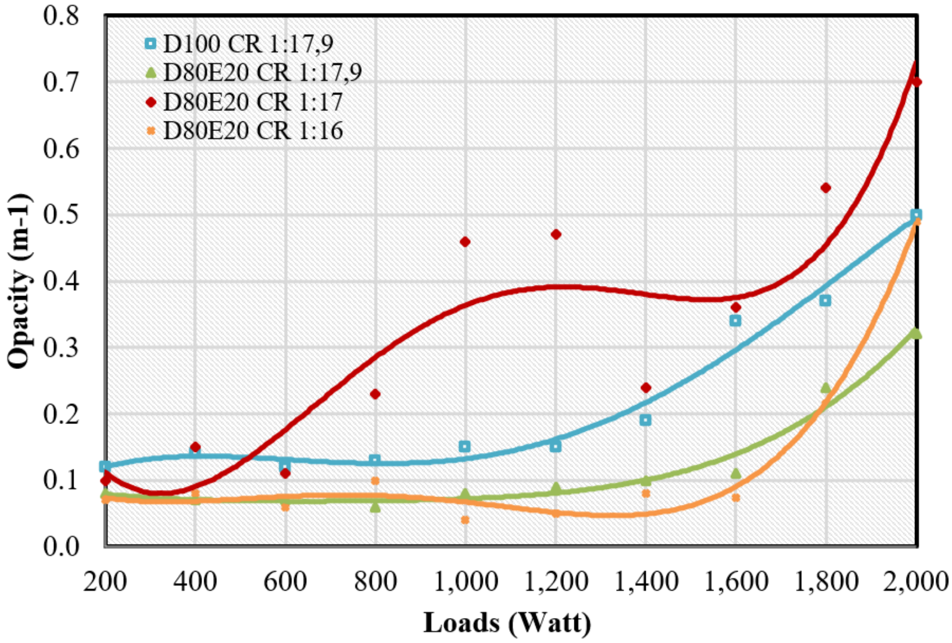

Figure 8. Smoke against Load for mixed fuel DEX80 opacity

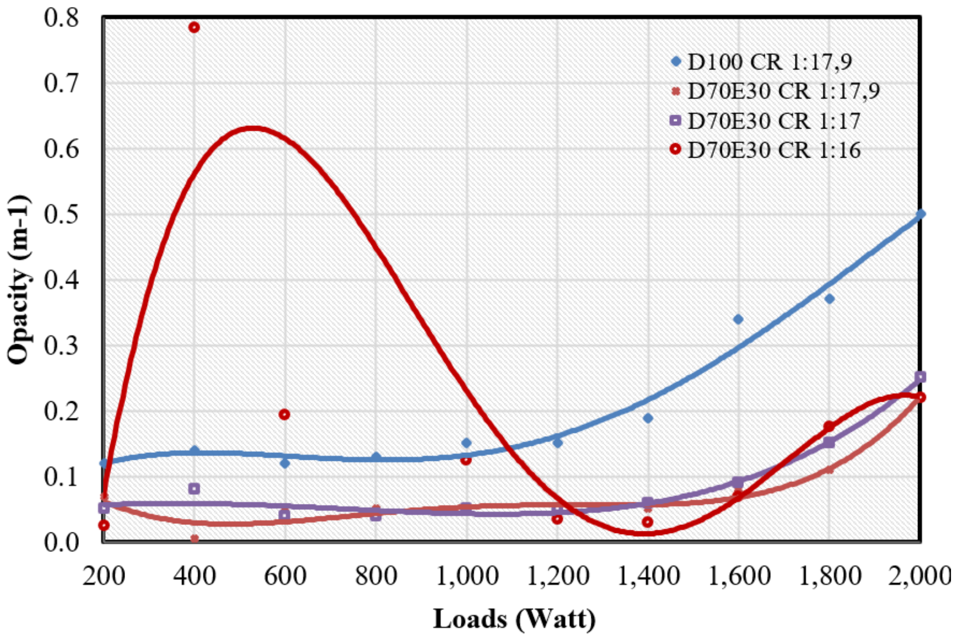

Figure 9. Smoke against Load for mixed fuel DEX70 opacity

In general, the smoke opacity of ethanol blended fuel with a higher compression ratio has a lower smoke opacity value than a low compression ratio.

The ethanol content in the mixed fuel will cause a longer delay period. However, by decreasing the compression ratio to match the delay period, smoke opacity at low compression ratios does not have a stable trendline. This is because the latent heat value of mixed fuel is higher than DEX100.

4. Conclusion

From a series of tests, the following conclusions were drawn. Increasing compression ratio improves engine performanes in term of brake thermal efficiency (BTE) and decreases exhaust gas emissions in term of CO, opacity and UHC. For DEX80 and DEX70 with CR 17.9, provide break thermal efficiency (BTE) as much as 25.52% and 25.16% respectively at maximum load, higher than Dexalite with CR 17.9 in which BTE as much as around only 24%. Average BTE of Dexlite with DR 17.9 is slightly higher than DEX 80 and DEX 70 with CR 17.9.

Increasing the compression ratio slightly increases the break specific fuel consumption (BSFC). DEX80 with CR 17 and CR 16 experienced a decrease in BSFC by (12.63%) and (4.44%) against DEX80 with CR 17.9. In addition, DEX70 with CR 17 and CR 16 decreased BSFC by (0.04%) and (1.37%) against DEX70 with CR 17.9. Increasing the compression ratio also significantly decreases the smoke opacity of exhaust gas. DEX80 with CR 17 and CR 16 experienced an increase in smoke opacity by (175.41%) and (3.11%) against DEX80 with CR 17.9. Meanwhile, DEX70 with CR 17 and CR 16 experienced an increase in smoke opacity by (17.01%) and (236.05%) against DEX80 CR 17.9.

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