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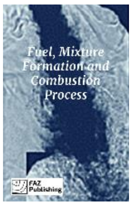

An Investigation of 1.8L Turbocharged Engine on Performance Using the Fuel Oil Blends in Malaysian Commercial Fuels

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Abstract: Researchers have been particularly interested in using alternative energy sources in internal combustion engines to reduce reliance on fuel-derived energy sources. The fusel oil, on the other hand, is a different alternative energy source that is produced as a by-product during the fermentation of alcohol and can be used in internal combustion engines. Fusel oil is a blend of high alcohols that is dark brown in colour and strongly scented. The objective of the study is to evaluate the engine performance using blends fusel oil 10% in variable commercial RON 95 and RON 97. The performance and combustion of a 1.8L Mitsubishi engine were studied. The engine was operated at a speed of 2000 RPM with a 30% throttle load. The engine study concentrated on the In-cylinder Pressure, Coefficient of Variation (COV), Rate of Pressure Rise ROPR), Mass Fraction Burn (MFB) and Rate of Heat Release (ROHR). As a result, the engine show that using the RON97 blends is better compared to the performance of RON95 blends. Indeed, due to the oxygen content in the blended fuel, the engine performance and emission become better than the commercial fuels.

Keywords: Performance, RON95, RON97, fuel oil

1. Introduction

Recently, there is much focus on the search for a cheaper, environmentally friendly, and renewable source of fuel. This is attributed to instability in the world petroleum market caused by perpetual rises in petroleum prices, increasing threat to the environment from exhaust emissions, global warming, and rapidly dwindling crude oil deposits, among other factors [1]. Most studies have been conducted on biomass-based fuels such as alcohol, biogas and vegetable oil as possible substitutes for petroleum based fuels [2]–[4]. According to the relevant sources, alternative fuels can be used as fuel blends in gasoline engines to lower emissions and stabilise fuel prices. Furthermore, fully sustainable propulsion can be achieved by combining modern biofuels and spark ignition (SI) engines.

In Malaysia, gasoline (RON 97 and RON95) is the most often used fuel for small on-road automobiles, making it the primary energy source for this consumer. Malaysia is also one of the Southeast Asian countries with the greatest population growth of 32.7 million people in the first quarter of 2021 and is expected to have 41.5 million by 2040 [5]. The rising number

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**Corresponding author: smrosdisalleh@gmail.com* of automobiles on the road is continuously increasing demand for energy. RON95 and RON97 are blends of 95 and 97 percent iso-octane with 5 and 3%, respectively, of n-heptane by volume. The mixtures of these two elements, known as primary reference fuels (PRF), establish the intermediate points on the RON or MON scale. They are PRF 95 and PRF 97 on the RON and MON scales, respectively. The transportation sector accounted for 4% of employment and 8% of real gross domestic product (GDP) in 2018. Over the past ten years, it has grown at an average annual rate of 3%. The transportation sector contributed 28.8% of all fossil fuel consumption, far more than the average global rate of 24.5% [6]. The 12.4% fall in the number of passenger and commercial vehicles registered in the automotive industry in 2020 is assumed to be the result of the COVID-19 pandemic, which substantially reduced CO_2 and activities in the industrial sector [5].

The increase in the bioethanol process brought on an increase in its by-product. Fusel oil is an alternative fuel that can be used in internal combustion engines. Fusel oil is a by-product produced during the manufacturing of bioethanol and is made up of a combination of higher alcohols, primarily isoamyl and isobutyl alcohols and propanol [7]. When some agricultural products like beets, cones, cereals, potatoes, sweet potatoes, rice, and wheat are fermented, a by-product called fusel oil is produced. Around 12 million tonnes of sugar beets were most recently produced in Turkey, and each year, roughly 550.000 tonnes of beet molasses were extracted. From the molasses, over 30 million litres of ethyl alcohol were produced annually. For every 1000 Liters of ethyl alcohol that were distilled, approximately 1 Liter of acetaldehyde and 5 Liters of fusel oil were produced. Additionally, Brazil usually produces 2.5 litres of fusel oil for every 1000 litres of bioethanol produced. Fusel oil shares several characteristics with alcoholic gasoline, such as a high motor octane number (MON) and research octane number (RON = 106) [8].

Yilmaz [13] was investigated the COV using fusel oil. COVimep dropped as engine load increased. As the engine load increases, the operating temperature of the engine rises. This enhances combustion chamber oxidation reactions and makes them more dependable and stable over time. Additionally, it was shown that adding fusel oil causes COVimep readings to decrease. Kocakulak et al. [2] describe that the COV imep increase when the fusel oil increase in the blends. They concluded that caused by the fuel mixture's increased octane rating, the difficulty of combustion, and the engine's departure from its ideal working condition. Heywood states that comfortable drivability usually occurs when the COV does not exceed 10% [14]. The cycle-by-cycle fluctuations are evaluated using the coefficient of variation of the indicated mean effective pressure (COVimep). COVimep is commonly used in engine studies to examine cycle-by-cycle fluctuations. It is described as in Equation 1:

$$COVx = \frac{\sqrt{\left(\sum_{i=1}^{N}(xi-\bar{x})\right)^2/N}}{\bar{x}} . 100\% \tag{1}$$

Where $\bar{x} = \frac{1}{N}\sum_{i=1}^{N} xi$

The use of a turbocharged engine greatly increases effectiveness. Viability is challenging due to high peak pressure rise rates under heavy load, which cause combustion noises and could harm the engine. The rate of pressure rise (ROPR) is a common metric for describing the level of combustion roughness. Heywood described that the limitation of ROPR not exceed 10 Bar/degree to avoid damage of engine component [14]. The equation used to calculate the rate of pressure rise (dP/dh) is shown below (Equation 2):

$$\frac{dP}{dQ} = \frac{p_{i+1}-p_{i-1}}{\theta_{i+1}-\theta_{I-1}} \tag{2}$$

The Rate of Heat Release (ROHR) is the rate at which heat is generated by a fire, and it is usually expressed in Joules per second or Watts . The first rule of thermodynamics is applied to the closed section of the engine cycle to compute the net rate of heat release from the recorded in-cylinder pressure. Equation 3 is used for calculating the rate of heat release (dQ/dh):

$$\frac{dQ}{d\theta} = \frac{k}{k-1} P \frac{dV}{d\theta} + \frac{1}{K-1} V \frac{dP}{d\theta} + \frac{dQh}{d\theta} \tag{3}$$

Where k denotes the specific heat ratio, h denotes the crank angle, P denotes cylinder pressure, and V denotes cylinder volume.

The entire quantity of energy produced by the heat of the fuel determines the Mass Fraction Burn (MFB). According to the MFB profile, it has the S personality type. Then, in each cycle, there is a normalised measure on a scale of 0 to 1. The three crucial criteria for MFB are the Start of Combustion (SOC), the Duration of Combustion (DOC), and End of Combustion (EOC). Furthermore, MFB can be estimated using the Wiebe function. Rassweiler-Withrow is the model that produces the best MFB outcomes [15]. A 50% progress of MFB represents the highest rate of heat emission. The zone with the best combustion efficiency is 50% MFB. Equation 4 is used to calculate the MFB as shown below.

$$MFB = 1 - exp\left[-a\left(\frac{\theta-\theta_0}{\Delta\theta}\right)\right]^{m+1} \tag{4}$$

Where the θ is crank angle, $\theta 0$ is starting combustion angle, $\Delta\theta$ is total combustion duration, and a and m is weibe parameter.

There are many studies in the literature on the experimental of the usage fusel oil as by-product in SI engine. Some main aspects distinguish this study from other studies in the literature. As the first novelty, the experimental were conducted utilizing blends of 10% fusel oil without water separation, particularly using two command fuels, RON95 and RON97, which are sold as fuel in Malaysia. On the other hand, the engine was operated at 2000 rpm under steady-state conditions with a 30% throttle load resulting same as normal urban driving. The detailed combustion process, flame activity, and pressure wave interactions are investigated. Additionally, In-cylinder Pressure, Coefficient of Variation, Rate of Pressure Rise, Rate of Heat Release and Mass Fraction Burn concentrations are evaluated. The main outcomes of this study are presented in the discussion that follows.

2. Materials and Methods

A Mitsubishi 4G18 SOHC 1.8L four-stroke engine was used in the experiment. The test used a 30% throttle load and a 2000 rpm engine speed. After engine warm-up, RON95 and RON97 commercial fuel was used in the engine to first gather baseline data. After being blended with 10% fusel oil in a beaker, RON95 and RON 97 were tested next. Fuel blends now go by the names RON95F and RON97F. Figure 1 depicts the schematic diagram of an engine test bench. Table 1 shows the detailed engine specifications. The engine was equipped with a TFX crank angle encoder coupled to a Kistler piezoelectric cylinder pressure type 6061B for measuring crank angle and combustion pressure. These were connected to a PC by joining the cable from the signal conditioner. The intake and exhaust manifolds, the system turbo engine cooler, the engine oil, and the engine water cooler were all monitored using K-type thermocouples. All contemporary data recorders and real-time scopes can read thermocouples directly connected to PCs using the TC08 type Pico-Log. The engine was coupled to eddy-current brake dynamometer using a Dynalec load controller. For the combustion analyses, COV was calculated using data from in-cylinder pressure for 200 consecutive engine cycles. Utilizing the first law of thermodynamics, ROHR was determined. Then, MFB and ROPR are calculated using the first derivative of the in-cylinder pressure. The properties of all the fuels are shown in Table 2.

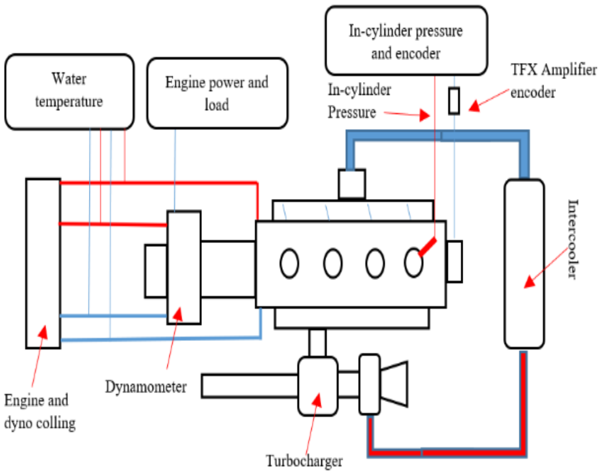

Fig. 1 - Schematic diagram facilities in laboratory setup

Table 1 - Engine specification

Type	SOHC 16 V MPI
Number of cylinders	4
Type of chamber	Pent-roof Type
Displacement	1.8l
Bore	8.1cm
Stroke	8.9cm
Compression ratio	9.5:1
Maximum Output	143 kW (194 PS; 192 bhp) @ 6,000 rpm
Torque Max	270 Nm (199 lb-ft) @ 3,000 rpm
Spark Timing	10 Degree BTDC
Injection Timing	715 Degree BTDC

Table 2 - Properties of gasoline [16]

Properties	Gasoline		Fusel oil
	RON95	RON97	
Density at 15°C, kg/m3	737	742.3	849
Boiling Temperature, °C	209	210	395-411
Octane Number	95	97	106
Motor Octane Number	82-92		84[17]
Latent Heat of Vaporization, kJ/kg	349	373	621
Lower Heating Value, MJ/Kg	44	44	29.5
Flash Point, °C	-45	-40	-41
Auto Ignition Temperature, °C	257	300-400	
Stoichiometry	14.7	14.7	12.5
Reid Vapour Pressure (kPa)	66	65.5	
Lamina Flame Speed (m/s)		0.38	> 0.38
Water and Oxigen content %	0	0	10 and 30

3. Result and Discussion

The investigation on RON95, RON97, RON95F and RON97F were conducted to characterize engine combustion. It was done with a 1.8L Mitsubishi engine and operating at 30% throttle load. The engine was operated in a steady-state condition at the speed of 2000 rpm. The in-cylinder pressure is the primary factor influencing how the performance parameters fluctuate.

3.1 In-cylinder Pressure

Figure 2 illustrates the comparison of four in-cylinder pressure vs crank angle degree at 2000 rpm using commercial RON95, RON97, RON95F and RON97F. After a spark triggered at 10 degrees, the pressure rises rapidly before TDC. The curve of RON95F and RON97F shows slight advance and highest peak pressure at 40–45 Bar. The highest in-cylinder pressure is shown by RON97 which is caused by the higher heating value compared to RON95 [2]. Meanwhile, the commercial RON95 and RON97 showed peak pressure at 34–36 bar. After TDC, RON95F and RON97F showed slightly lower values due to ignition delay. When fusel oil is blended with both commercial fuels, the in-cylinder pressure rises by 8%. Ağbulut et al. [18] mentioned that using fusel oil blends in gasoline contributes to longer ignition delay before combustion. But commercial RON95 and RON97 show a high gradient without any interference. Here there may be a significant difference in terms of COV between fuels. They added that fuel accumulates during the premixed combustion phase, causing engines fueled with higher alcohol blends to run noisily [19]. The increase in cylinder pressure is related to the increased volumetric efficiency of the charge flow into the engine cylinder as a result of the increased burning rate of alcohol fuel [20]. Higher vaporisation rates and a faster laminar flame velocity of fuels are also caused by alternate fuel blends, which helps to reduce the time it takes for flame kernels to form and develop [7]. Because of the water present in alcohol fuels, the flame speed is reduced, which lengthens the burn duration 19].

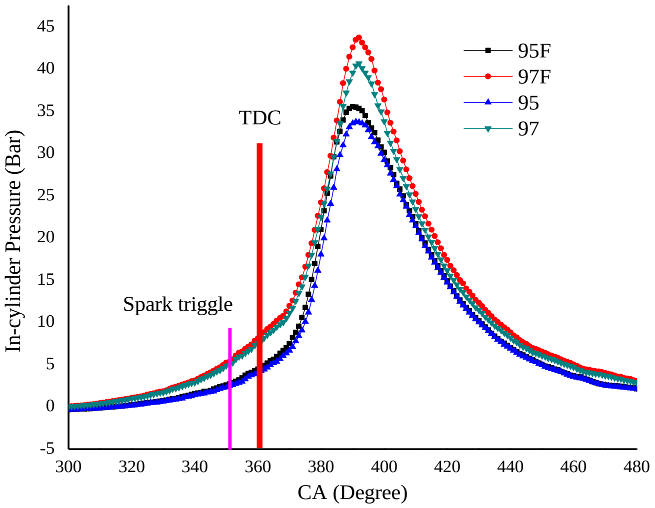

Fig. 2 - In-cylinder pressure for 2000 RPM engine speed

3.2 Coefficient of Variation

Figure 3 displays the COV result variations that used commercial fuels (A) RON95 and RON97, (B) RON95F and RON97F with an engine speed of 2000 RPM and a 30% throttle load. The data engine was recorded at 200 consecutive engine cycles. The standard deviation of RON95, RON97, RON95F and RON97F are 4.0, 3.9, 5.2 and 4.8, respectively. The values are based on calculations. It shows how the COV increases when commercial fuel blends are used. Despite becoming unstable, the combustion is still contained inside a secure perimeter. Heywood asserts that COV should not be more than about 10% to produce enjoyable driving experience [14]. In the case of fusel oil blends, when the COV increases, the air fuel ratio burning becomes a lean mixture operation, and the misfire or partial burning cycle appears. According to Kocakulak et al.[2], increasing the amount of fusel oil in the pure fuel increases the COV value. They described that the amount of water in the fuel blends contributes to the ignition delay and increased flame speed. Furthermore, Wang et al. [22] reports that an evaporation process during combustion may be accelerated by an increase in COV caused by the occurrence of micro explosions.

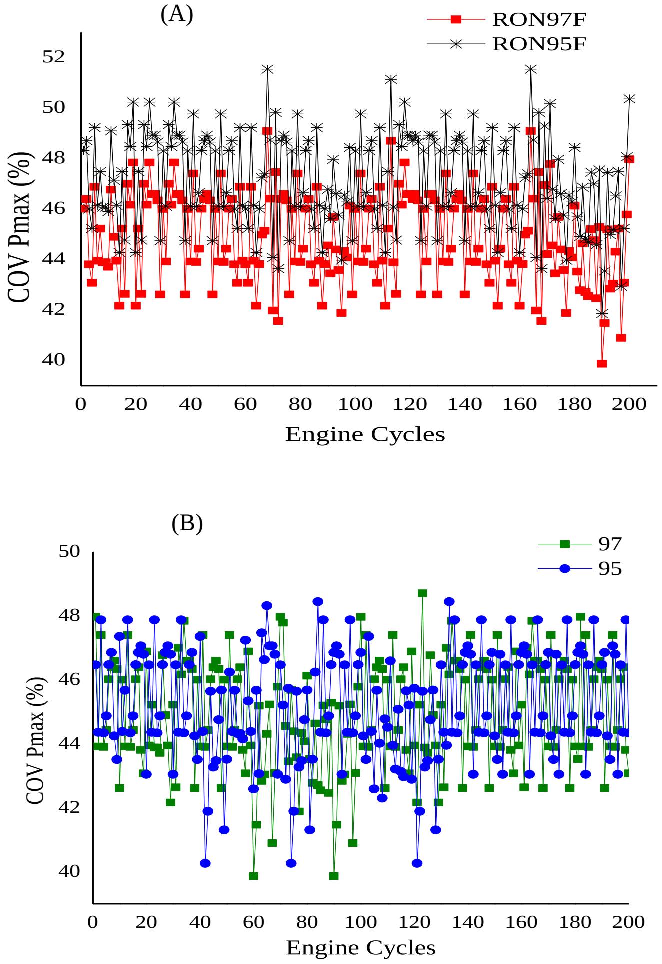

Fig. 3 - COVpmax for 200 cycles. A with fusel oil blends and B without fusel oil blends

3.3 Rate of Pressure Rise

Figure 4 shows the ROPR variations for the RON95, RON97, RON95F, and RON97F using constant engine speed at 2000 rpm and 30% throttle load. For all fuels, the peak of pressure rises at a rate of about 4 to 4.3 Bar/deg. However, the curve for RON95F and RON97F are showing up slightly earlier than without blending fuel. It occurs due to higher flame speed of combustion. One of the main factors that controls the combustion process is laminar flame speed. Understanding burning behavior, air/fuel combination, and the reliability of kinetic systems are necessary [23].

The rate of pressure increase brought on by compression provides information on the degrees of charge cooling. It occurs when fusel oil blends are used in commercial fuel. The right design and technology enables the control of ROPR and prevents excessive combustion noise [24]. It means that combustion occurs rapidly after the ignition spark is triggered at 10 degrees before Top Dead Center (TDC). The molecular structure and reaction kinetic characteristics of alcohol fuel occur during propagation due to advance combustion [7]. Then there is a slight short of fuel blend end combustion pressure due to the presence of the hydroxyl moiety in fusel oil that weakens the C-H bond [25].

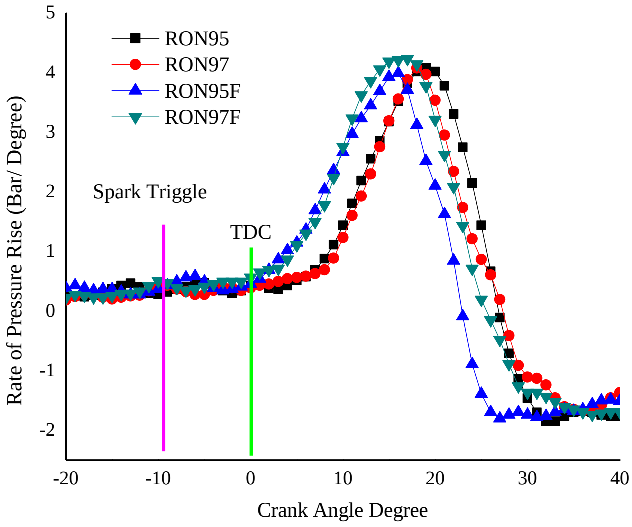

Fig. 4 - ROPR for 2000 RPM engine speed

3.4 Rate of Heat Release

Figure 5 shows the variation of ROHR using fuel RON95, RON97, RON95F, and RON97F at a constant speed of 2000 rpm and 30% throttle load. The peaks of ROHR for both fuels are 50 J/deg by RON97F. ROHR for RON 95, RON95F and RON97 are 35J/deg, 36J/deg and 42J/deg, respectively. The peak of curve for RON95F and RON97F is 20–30% higher compared to RON95 and RON97. In comparison to all fuels, the RON97 curve shows a somewhat advanced kinetic combustion phase. The main reason for this is that the in-cylinder turbulence intensity is important because it affects the mixture of air and fuel, in-cylinder heat release rate, flame stretch, and other variables. The same reason was described by Liu et al. [26] that shows their study using alcohol fuel in an SI engine. With more oxygen, the family of isoamyl alcohols has a faster laminar flame than gasoline, which raises the value of the cylinder gas pressure. This could make a region in SI engines that is better suited for combustion and increase work output compared to gasoline [17].

3.5 Mass Fraction Burn

Figure 6 shows the variation of MFB using variable fuels which are RON95, RON97, RON95F, and RON97F at a constant speed of 2000 rpm and 30% throttle load. The MFB of 0–10% for fuel blends show early progress in increasing burning rate. Then, the MFB 50% shows that RON97 is higher compared to blend fuels. This time, the blend fuels slightly reduce the MFB due to the disturbance of the flame by the water content. The air-fuel ratios of RON95F and RON97F has a slight lean due to combustion disturbance. The flame speed of RON97F occurs slightly earlier due to aggressive of combustion. During start of combustion (SOC) and end of combustion (EOC), fuel blends show slight advance. In-cylinder turbulence, intensity is less intense at low speeds than it is at high speeds, which is the main cause of this. The MFB 50–100% shows that fuel blends have a slightly earlier finish progress. According to Liu et al. [26] because in-cylinder heat release rate, flame stretch, and other factors influence the combination of air and fuel, the strength of the turbulence is crucial to edge the MFB result.

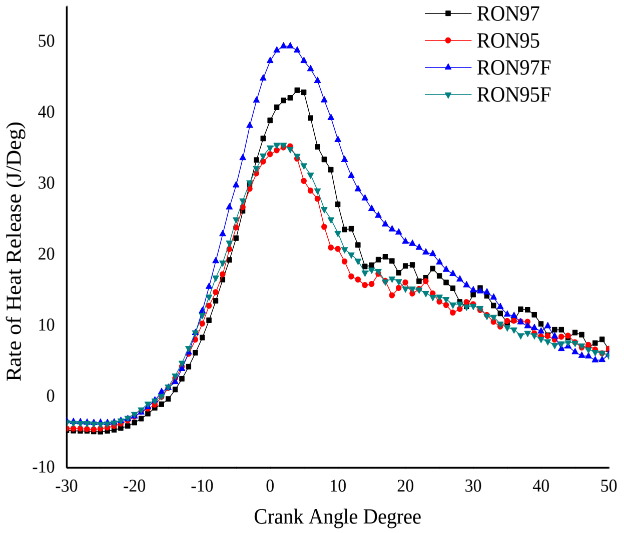

Fig. 5 - ROHR for 2000 RPM engine speed

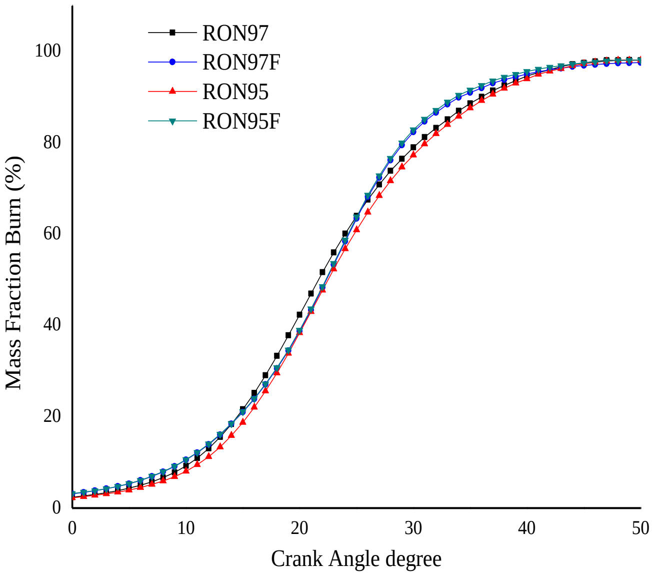

Fig. 6 - MFB for 2000 RPM engine speed

4. Conclusion

At 2000 rpm and 30% throttle load, the engine performance and emission characteristics of a 1.8L turbocharged engine test bed with RON95, RON97, RON95F and RON97F were evaluated. The study yielded the following results:

i. The in-cylinder pressure rises by 8% in comparison to the original fuel because of the high octane number and latent heat vaporisation of fusel oil up to 10% of blends in both commercial fuels.

ii. The cycle-by-cycle fluctuations are evaluated by COVpmax using data from in-cylinder pressure for 200 consecutive engine cycles. The lower energy content and higher density of RON95F and RON97F increase 0.25% and 0.18% respectively the value of COVpmax. The number of COVpmax is valuable in the limitation.

iii. Fuel blends show advance combustion and advance peak pressure compared to commercial fuel for rate of pressure rise and heat release. It occurs because fusel oil has higher octane number and higher oxygen content that produces higher flame speed during combustion.

iv. The MFB of blends fuel show that the flame speed of combustion terminates early by 0.5% as compared to commercial fuel at SOC and EOC. It means that the oxygen content helps the progress during combustion.

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