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Çift Yakıtlı Dizel Bir Motorda BD35 (Biyodizel/Dizel Karışımı) ve Propanol Kullanımının Yanma Karakteristiklerine Etkisinin İncelenmesi

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Öz

Bu çalışma, reaktivite kontrollü sıkıştırma ateşleme modunda çalışacak şekilde modifiye edilmiş dizel bir motorda düşük reaktiviteli yakıt olarak propanol ve yüksek reaktiviteli yakıt olarak BD35 yakıtlarının kullanımının motorun yanma karakteristiklerindeki değişimini incelemektedir. Araştırmada, %35 biyodizel ve %65 petrol kökenli dizel karışımından oluşan BD35 yakıtı, yüksek reaktiviteli yakıt olarak doğrudan silindire püskürtülürken, reaktivite kontrollü sıkıştırma ateşleme için düşük reaktiviteli yakıt olarak propanol düşük basınçta emme kanalına püskürtülmüştür. Deneylerde propanol %0, %15, %30 ve %45 olmak üzere dört farklı ön karışım oranında kullanılmıştır. Deneyler %60 motor yükü ve 2400 (d/d) sabit motor hız şartları altında gerçekleştirilmiştir. Elde edilen verilere göre, karışım oranının artmasıyla birlikte silindir içi maksimum basınç değerinin arttığı ve özellikle %45 karışım oranı kullanımında önemli bir artış meydana geldiği tespit edilmiştir. Reaktivite kontrollü sıkıştırma ateşleme konsepti altında test motorunda propanolun düşük reaktiviteli yakıt olarak kullanılmasının ortalama indike basınç değerinde azalmaya neden olduğu gözlemlenmiş olmasına rağmen, karışım oranının artmasıyla birlikte ortalama indike basınçtaki azalma hızının yavaşladığı belirlenmiştir. Son olarak, karışım oranının artmasıyla birlikte silindir içi sıcaklığın önemli ölçüde azaldığı belirlenmiştir. Tüm bulgular analiz edildiğinde, reaktivite kontrollü sıkıştırma ateşleme modunda çalışacak şekilde modifiye edilmiş dizel motorlarda düşük reaktiviteli yakıt olarak propanol ve yüksek reaktiviteli yakıt olarak BD35 kullanımının yüksek yükte motor performansı üzerindeki etkilerini anlamak adına önemli bir yol göstermiştir.

Anahtar Kelimeler: RCCI, Biyodizel, Propanol, Yanma, BD35

*Yazışılan Yazar

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Investigation of The Effects of BD35 (Biodiesel/Diesel Blend) and Propanol Usage in Combustion Characteristics in A Dual Fuel Diesel Engine

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Abstract

This study investigates the changes in the combustion characteristics of a diesel engine modified to operate in reactivity controlled compression ignition mode using propanol as low reactivity fuel and BD35 as high reactivity fuel. In the study, BD35 fuel, a blend of 35% biodiesel and 65% petroleum-derived diesel, was sprayed directly into the cylinder as a high reactivity fuel, while propanol was sprayed into the intake manifold at low pressure as a low reactivity fuel for reactivity controlled compression ignition. Four different low reactivity fuel premixed ratios of 0%, 15%, 30% and 45% propanol were used in the experiments. The experiments were carried out under 60% engine load and 2400 (rpm) constant engine speed conditions. According to the data obtained, it was found that the maximum in-cylinder pressure value increased with the increase in the premixed ratio and a significant increase occurred especially when 45% premixed ratio was used. Although the use of propanol as low reactivity fuel in the test engine under the reactivity controlled compression ignition concept was observed to cause a decrease in the indicated mean effective pressure, the rate of decrease in the indicated mean effective pressure was found to slow down as the premixed ratio increased. Finally, it was found that the in-cylinder gas temperature decreased significantly with increasing the propanol premixed ratio. When all the findings are analyzed, it has shown an important way to understand the effects of propanol as low reactivity fuel and BD35 as high reactivity fuel on engine performance at high load in diesel engines modified to operate in reactivity controlled compression ignition mode.

Keywords: RCCI, Biodiesel, Propanol, Combustion, BD35

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1. Introduction

In a wide range of operations, including energy generation via generators and transportation operations such as land, sea, and rail travel, diesel engines are used as a power source A major disadvantage of diesel engines is that they produce high amounts of pollutants such as NOx and soot, which are harmful to the environment and human health. Therefore, many studies are carried out by researchers and engine manufacturers to reduce these pollutant emissions from diesel engines. Although there are different studies to reduce these emissions, today researchers mostly focus on in-cylinder combustion strategies and alternative fuel applications due to the problems of exhaust systems such as high cost, maintenance and fuel consumption [1]. In studies on diesel engines in the literature, low-temperature in-cylinder (LTC) combustion techniques were designated as RCCI (Reactivity Controlled Compression Ignition), PCCI (Premixed Charge Compression Ignition), and HCCI (Homogeneous Charge Compression Ignition) [2-4]. HCCI is based on the self-ignition of a homogeneous mixture by compression [5]. According to Demirci and Çınar, [6] utilizing premixed CNG in an HCCI-DI engine reduced CO and soot emissions by 90% as compared to using diesel fuel, but dramatically increased unburned HC and NOx emissions. Due to these drawbacks of HCCI mode, researchers have begun to look into PCCI mode, which functions similarly to HCCI and traditional diesel burning. In this concept, NOx and soot emissions are reduced due to low flame temperatures and less rich fuel mixture areas in the combustion chamber [7, 8]. To overcome some of the disadvantages of the HCCI and PCCI concepts, the RCCI concept has become more popular in recent years [9].

By using at least two fuels with different reactivity in RCCI, it is aimed to better control the combustion phases while maintaining low soot and NOx emissions and high thermal efficiency. Low cetane or low reactivity fuel in RCCI is often injected into the engine through a port during the intake stroke, whereas high cetane or high reactivity fuel is injected directly into the cylinder during the compression stroke. The RCCI concept is claimed to work in a larger load range with extremely low NOx and soot emissions, an acceptable pressure increase rate, and high indicated efficiency, according to previous studies [9-11]. According to Li et al. [12], RCCI provides better fuel efficiency, a lower ringing index, lower emission values, and more stable operation across a larger load and speed range than HCCI due to its optimum premixed ratio. Curran et al. [13] stated that the RCCI concept significantly reduced NOx emissions while increasing HC and CO emissions. It also increased thermal efficiency by 7% when compared to traditional diesel combustion. In their study [14], Uyumaz and Solmaz examined the RCCI concept. In this study, they emphasized that RCCI caused high unburned HC and CO emissions and very high maximum pressure rise rates at low engine loads. They also noted that other challenges needed to be resolved, such as in-cylinder maximum pressure peaks at high loads. Due to these challenges, researchers believe that the RCCI concept still has some problems to be solved and they are continuing their work in this field.

Alternative fuels are widely utilized in internal combustion engines to lower the amount of petroleum-based fuels and the pollution-causing exhaust emissions that result from their combustion. In this context, the most researched alternative fuels used in diesel engines are biofuels such as biodiesel and bio alcohols [15]. Biodiesel has important features such as being renewable, having properties close to petroleum diesel, and creating low pollutants. Despite these advantages, high viscosity, poor low flow characteristics, and high NOx emissions may be demonstrated as some problems that still need to be solved [16]. In the literature, it was been seen that alcohols such as butanol and propanol, which have better fuel characteristics, were suitable for use in internal combustion engines [17]. As mentioned in the previous section, RCCI can achieve a wider load range thanks to fuel and injection management among low-temperature combustion strategies. However, RCCI still has difficulties with high unburned HC and CO emissions under low load conditions, as well as pressure increase rates and maximum pressure values at high loads [18-20]. Also, Imtenan et al. reported that HC and CO emissions can be reduced by using biodiesel [21]. Because of its high viscosity and low calorific value, biodiesel is often employed in diesel engines by blending it with petroleum-based fuel. Certain mixing ratios are chosen in practice, although several alternative mixing ratios ranging from 0% to 100% have been investigated in experimental investigations. The most common and well-liked biodiesel fuel mixes in the US are BD20 and BD35, although a 7% biodiesel blend is commonly utilized in Europe. Additionally, it has been said that some diesel vehicles may run on a blend of 30% biodiesel (BD30) [22], [23].

Taking into account all of these data, biodiesel (BD35, or 35% biodiesel and 65% petroleum diesel by volume) was selected as the high reactivity fuel (HRF), and alcohol-based propanol as the low reactivity fuel (LRF) in this investigation. It is anticipated that employing both BD35 and propanol in the RCCI concept diesel engine will provide benefits such as high cetane numbers and oxygen content, besides negating some drawbacks such as high viscosities and poor heating values. Due to these effects, it is aimed to lower HC and CO emissions, which are the main drawbacks of the RCCI concept.

2. Materials and Method

In the engine laboratory of the Frat University Technology Faculty's Automotive Engineering Department, experiments were conducted. A single-cylinder, four-stroke diesel engine with common rail direct injection (CRDI) that had been adapted to run in the RCCI concept was used for the tests. Table 1 lists the specifications of the engine used in the experiment. In this research, a port fuel injection system was used to inject propanol into the intake channel at 0.5 MPa pressure to ensure the RCCI concept. LRF was injected into the port after the opening of the intake valve at the intake stroke (25^o CA aTDC), while HRF was injected directly into the cylinder via the CRDI at the compression stroke (21^o CA bTDC). The fuel management mechanism on the control panel was used to determine how much fuel was used. Fuel consumption was calculated with the help of a volumetric scaled fuel tank and verified with precision balances. The volumetric fuel consumption of the engine was determined during the experiments, and it was determined based on the time. BD35, which is used as HRF, was obtained by mixing petroleum-based commercial diesel fuel and commercial biodiesel fuels at 65% and 35% volumetric ratios. The propanol used as LRF was 99.5% pure and was obtained from a commercial company.

Table 1. Technical specifications of the engine

Parameters	**Value**
Engine type	1 cylinder and 4 stroke
Cylinder Bore x Stroke	86 mm x 70 mm
Cylinder volume	406 cm^3
Compression ratio	18.1
Maximum torque	25.7 Nm @ 2400 rpm
HRF injection type	Common-Rail Direct Injection (CRDI)
HRF injection pressure and time	300 bar @21 ^{o}CA (bTDC)
Intake valve open and close (IVO and IVC)	9^{o}CA (bTDC)-93^{o}CA (bTDC)
Exhaust valve open and close (EVO and EVC)	145^{o}CA (aTDC) / 2^{o}CA (aTDC)
E_{total} (J/cycle)	590@60% load

The engine was connected to an electric dynamometer with the Gensan GSA 271 S/4 type to carry out the loading. The tests were conducted under load conditions of 60% of the highest power of the engine and at a stable engine speed of 2400 rpm. The load amount was determined using a Zemic L6W load cell. Figure 1 depicts the overall perspective of the experimental apparatus.

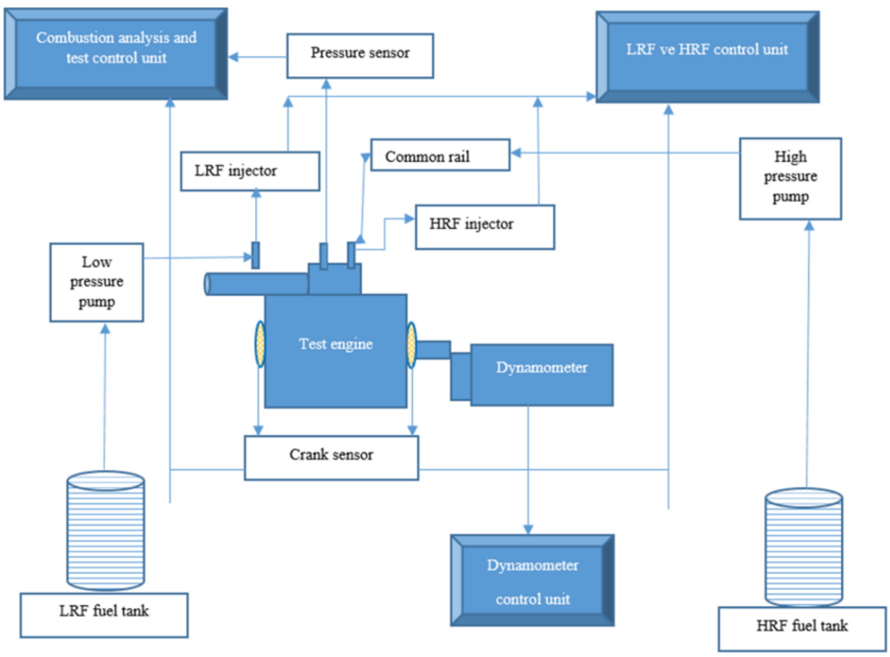

Figure 1. Schematic view of the experimental setup

An Optrand sensor and a Kübler encoder were used as pressure sensors. FebriS was used to examine the data after it was transferred to a data collecting card. For every operating position, the in-cylinder gas pressure was averaged over an average of 200 cycles. The program used the in-cylinder pressure and volume measurements along with the first law of thermodynamics to compute the heat release rate. The knock intensity was determined by the second derivative method. According to the total amount of energy consumed by the conventional diesel engine at 60% load, the amount of energy at 60% engine load in the case of RCCI was calculated for this study. Additionally, the low reactivity fuel premixed ratio (Rp) for the engine's total energy input each cycle was calculated. The Rp (premixed ratio) was determined from the consistent amount of energy provided to the conventional diesel engine per cycle. For this, the product of mass flow rate and lower calorific value of LRF is divided by the sum of the product of mass flow rate and lower calorific value of low and high reactivity fuels. Rp value was determined as 0%, 15%, 30%, and 45%. For instance, it was founded that using high reactivity fuel (BD35) at 60% engine load provided the engine with a total energy of 590 J/cycle. 15% of the 590 J/cycle total energy delivered to the engine in the conventional diesel mode for 15% Rp at this load is delivered to the engine using low reactivity fuel (propanol), and the remaining 85% is delivered to the engine using high reactivity fuel, as previously described. In this case, the experiment was carried out with a premixed ratio of 15% at 60% engine load. This method was used to determine all premixed ratios (Rp).

3. Results and Discussions

Figure 2 illustrates how changes in the LRF premixed ratio affect the in-cylinder pressure and heat release rate (HRR) for both conventional diesel engines (BD35) and RCCI (Rp 15%, 30%, and 45%) at 60% engine load. Examining the data, it was found that, in comparison to BD35, the rise in Rp raised the pressure and HRR. Increasing the Rp up to 45% gradually increased both the pressure and the HRR and the peak values were formed at this Rp. In addition, the increase in the Rp extended the ignition delay and the peak value of the pressure and HRR gradually moved away from the TDC in parallel with the increase in the Rp. Propanol's characteristics, including its low viscosity, high oxygen concentration, and high octane number, were very effective in beginning combustion reactions. Due to the high octane number of propanol and the increasing Rp, the ignition delay was prolonged in all experiments [24]. As a result, there was an effect that increased the pressure velocity and HRR values. In summary, it was determined that the use of propanol as LRF increased the in-cylinder pressure and HRR rate, and the greatest increase occurred with the use of 45% Rp.

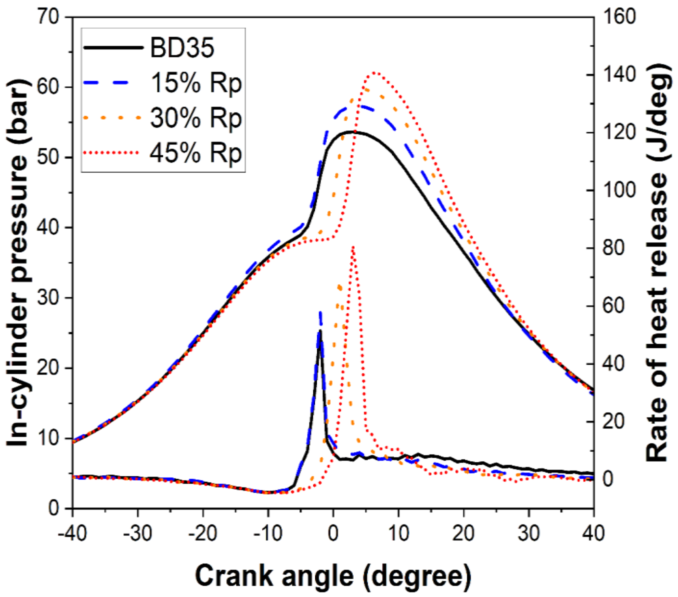

Figure 2. Variation of in-cylinder pressure and heat release rate (HRR) depending on the Rp

The effects of LRF premixed ratio change on indicated mean effective pressure (IMEP) at 60% engine load for conventional diesel engines (BD35) and RCCI (Rp 15%, 30%, and 45%) are shown in Figure 3. According to the data, when the RCCI method was used, the IMEP decreased and the greatest decrease in the IMEP was realized with the 15% premixed ratio. Although IMEP increased again as the premixed ratio increased, the decrease in IMEP continued compared to HRF. As it is known, IMEP directly or indirectly affects many different parameters such as combustion reaction efficiency, in-cylinder pressure, air/fuel ratio and ignition delay. In addition, IMEP is a parameter that is directly related to the amount of energy and pressure in the cylinder and the crank angle at which this energy and pressure of the cylinder occur. The formation of the maximum in-cylinder pressure value at an angle close to the TDC is decisive in the increase or decrease of IMEP. In previous sections, it was stated that the ignition delay rises depending on the increase in the premixed ratio. Although the pressure peak value in the cylinder increased, the crank angle at which this value occurred gradually moved away from the TDC. At the end of this change, negative work increased while positive work decreased with the use of LRF. It is thought that IMEP decreases due to this decrease in positive work. Considering all the data, in the experiments where the Rp was 15%, the maximum decrease in IMEP was realized by approximately 13%.

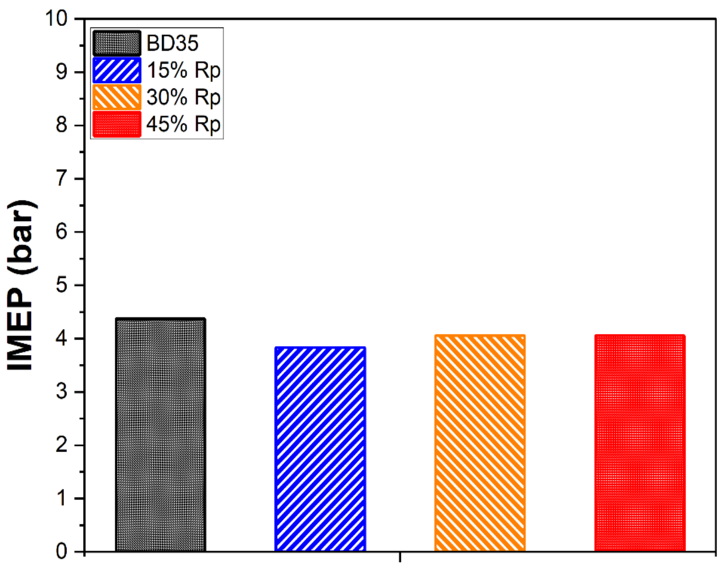

Figure 3. Variation of IMEP depending on the Rp

The impact of a premixed ratio on the maximum pressure increase and knock intensity in an engine using the RCCI concept is seen in Figure 4. When the data were examined, it was determined that the maximum pressure rise increased as the premixed ratio increased. As the premixed ratio increased up to 45%, the pressure rise rate reached its highest level. This change in pressure is due to the prolongation of the ignition delay (result from the premixed ratio), accordingly, the homogeneity level of the charge in the cylinder and the local reactive regions in the cylinder. In addition, with the increase of the premixed ratio, it was observed that the homogeneity of the charge in the cylinder decreased, the number of local reactive zones increased, and the ignition delay was prolonged. Taking these factors into account, at high premixed ratios, the combustion reactions become uncontrollable, and at very short crank angles, the pressure change achieves its maximum value. According to the graphs, a parameter directly affected by the change in the maximum pressure rise value is the engine knock intensity. The effects similar to the change in pressure are also in the values of the knock intensity. It was observed that the knock density reached the maximum level with the use of the premixed ratio of 45%. When all these data were evaluated, it was determined that the increase in the Rp, which caused the maximum pressure to occur, also brought the knock density to the maximum level.

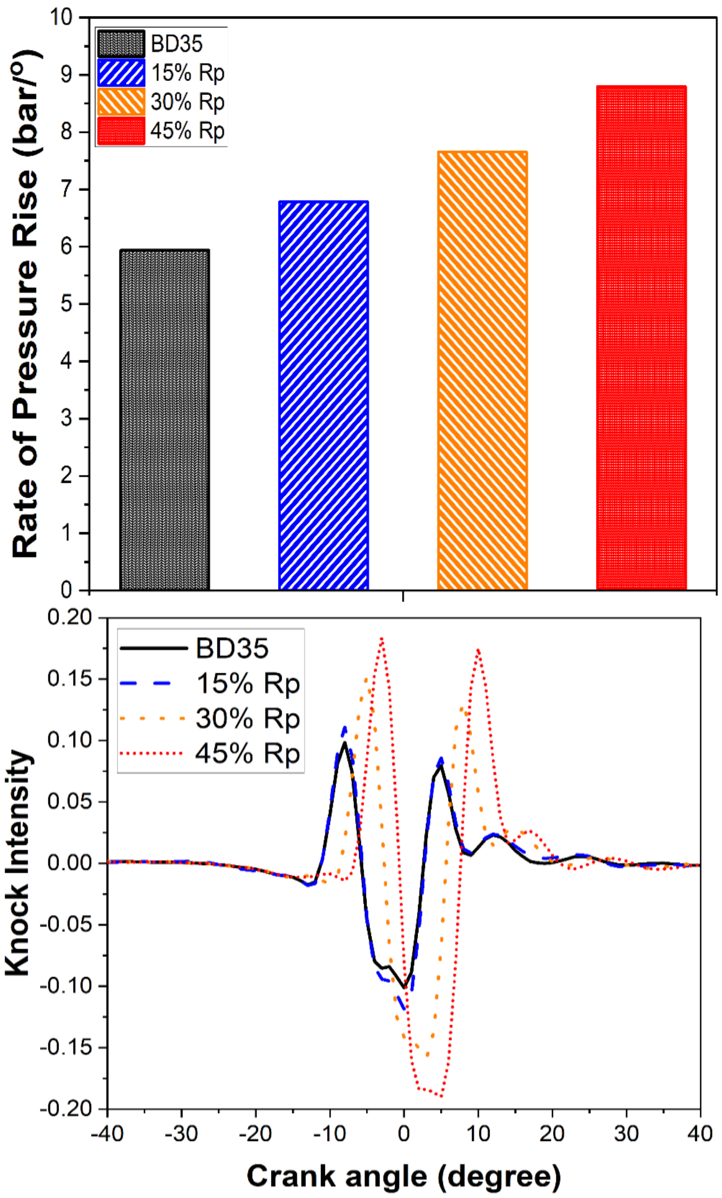

Figure 4. Variation of Rate of Pressure Rise (PRR) and knock density depending on the Rp and CA.

The effect of premixed ratio on cylinder temperature in an engine using the RCCI concept is seen in Figure 5. The results showed that the in-cylinder temperature dropped as Rp increased until the combustion processes started. As the premixed ratio increased, the effect's intensity increased and the temperature value dropped even more. After the start of combustion reactions, the temperature value suddenly increased at very short crank angles but remained below the temperature peak value according to BD35. Propanol used as LRF is an alcohol with a high heat of vaporization, oxygen content and high octane number. While the high oxygen content of propanol causes the ignition process to be shortened, the ignition delay wants to be prolonged due to its high octane content. This situation caused instability in the temperature change at 30% Rp. In this context, as the premixed ratio increased, the heat of evaporation increased and therefore cold zones were formed in the cylinder. Combustion reactions that started under these conditions caused sudden temperature changes in the cylinder and caused the reactions to be completed at a lower temperature than HRF. Despite the combustion reactions that start and continue at a lower temperature, it is thought that there is not a great decrease in combustion performance since propanol contains higher oxygen and hydrogen compared to BD35. This situation is also seen in the IMEP graph given in Figure 3. This decrease in temperature is thought to be due to the high heat of evaporation of the LRF used.

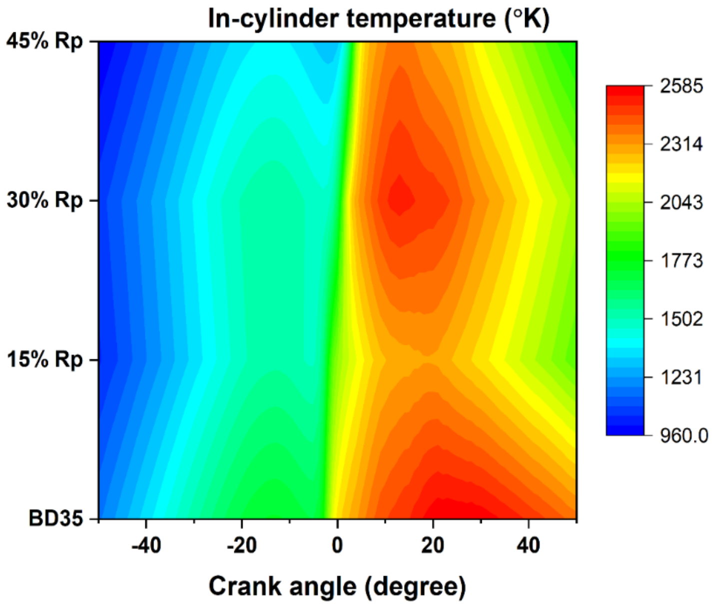

Figure 5. Variation of in-cylinder temperature depending on the Rp and CA.

4. Conclusions

The study investigated the effects of applying the RCCI concept to a single cylinder diesel engine fueled with BD35 and propanol. The results obtained in the above section are presented in detail. Some of the highlights of the study are highlighted below:

- The use of propanol as LRF increased the in-cylinder pressure and heat release rate. The largest increase in pressure was realized by approximately 16% with the use of 45% Rp.
- In the RCCI concept engine, IMEP decreased as Rp increased. The greatest reduction in IMEP was 13% when using a 15% Rp. However, as the Rp increased, this decrease rate decreased and the reduction rate in IMEP was realized as 7% at 45% Rp.
- Knock intensity increased with increasing LRF premixed ratio.
- The increase in Rp had a decreasing effect on the in-cylinder temperature. In the experiment using LRF, although the peak in-cylinder temperature increased abruptly during the rest of the combustion process, it was still a small increase compared to the use of BD35.

As a result, it has been observed that the in-cylinder temperature decreases with the RCCI concept applied to the conventional diesel engine with BD35 fuel. The greater oxygen content in the structure of the low-reactivity fuel compared to the high-reactivity fuel resulted in high pressure and heat release rates during the combustion reactions despite this drop.

5. Acknowledgment

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6. Author Contribution Statement

Mutlu Okcu: Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. Müjdat Fırat: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition. Yasin Varol: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition.

7. Ethics Committee Approval and Statement of Conflict of Interest

There is no conflict of interest with any person/institution in the prepared article.

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