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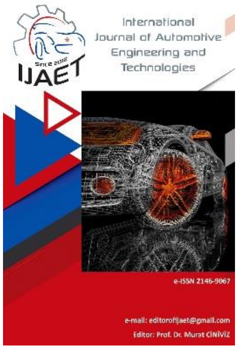

Original Research Article

Investigation of the pure use of microalg oil in diesel engines

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ABSTRACT

The effects of mixing pure vegetable oils with diesel fuels and using them in diesel engines were explored in this study. Due to its great production, Chorella protactes, a microalgae species, was employed as a vegetable oil. First, pure microalgae oil was combined with 5% (DSYK-5) and 10% (DSYK-10) diesel reference fuel (RDF) by volume for this experiment. The resulting blended fuels and diesel reference fuel were put to the test in a four-cylinder, four-stroke diesel engine at 1500 rpm and various loads. With the use of pure oil, the results showed a 4.64 percent rise in specific fuel consumption (SFC). CO emissions reduced by 9.05 percent on average when DSYK-5 fuel was used, while CO emissions increased when DSYK-10 fuel was used. HC emissions reduced by 4.6 percent on average when blended fuels were used, whereas NOx emissions increased by 3.13 percent on average. CO2 emissions were comparable to RDF fuel when DSYK-5 fuel was used. When comparing RDF fuel to DSYK-10 fuel, fewer CO2 emissions were found. Average gas temperatures, cumulative heat releases, and cylinder pressure values all reduced as the pure oil ratio in the mixture ratio increased.

Keywords: Chorella protactes, Diesel engines, Exhaust emissions, Pure Vegetable oil

1. Introduction

Oil is a critical factor in the economies of every country on the planet. Because oil accounts for the greatest proportion of total global energy use. The global consumption network is the most essential reason for the extensive usage of oil. It is now employed in a wide range of applications, from electricity generation to transportation. Because oil formation takes a long time, it is classified as a non-renewable (fossil) resource in the energy classification system [1]. This excessive consumption of fossil fuels causes global warming and the reduction of oil reserves day by day. One of the most important handicaps is that the biggest greenhouse gas source is motor vehicles. Therefore, the search for the new form of energy has become necessary for internal combustion engines. One of the most important of this new form of energy is vegetable oils. Vegetable oils are produced by processing agricultural products with a high oil content in several ways

[2]. Vegetable oils are non-harmful compounds that are biologically degradable easily and quickly [3]. They limit ash formation because of their lower carbon content compared to petroleum-derived oils [4]. Due to its low sulfur content, it almost eliminates the pollution generated by SO2 and shows major reductions in carbon monoxide. Vegetable oils can be used without any modification in the diesel engine, provided that they are pure in certain sizes [5]. However, during long-term use, some engine parts cause carbon deposits on their surfaces. These deposits grow with work time and cause adverse effects. Methods such as dilution, micro emulsion, pyrolysis, supercritical, and transesterification will mitigate high viscosity issues in order for vegetable oils to be used for a long time in diesel engines [6]. Among these vegetable oils, microalgae have come to the fore with their efficiency [7]. Some microalgae species have been reported to contain more than 70% (on dry weight basis) lipids [8]. There are biodiesel studies on microalgae in the literature, which has benefits like quick growth and high oil content. However, not enough research has been done on the utilization of these oils with pure diesel fuels. In order to learn more about the possibilities of these oils, pure microalgae oil was mixed with diesel fuel in this experiment. To begin with, Chorella protactes microalgae oil was combined with diesel fuel in proportions of 5% and 10% by volume. The combustion and emission characteristics of the blended fuels were investigated.

2. Microalgae

Microalgae are photosynthetic microorganisms capable of using sunlight, CO_2 and simple and readily accessible nutrients in the form of carbon-rich biomass to turn solar energy into chemical energy [9-10]. The release of O_2 from photosynthesis leads to the overall development of this vital gas for life on a large scale. With about 50 percent of its primary production on Earth, the metabolism of microalgae is derived from [11]. Microalgae are considered the most promising raw material for biofuels [12]. Microalgae can be grown in ponds or photo-bioreactors, in sea or brackish water, on non-fertile soils using N and P from wastewater sources [13,14]. Microalgae are capable of producing double biomass in a short span of about two days [15,16,17]. There is a high oil content of up to 80% in certain types of microalgae. The development of microalgae is an environmentally friendly process involving the atmospheric sequestering of CO_2 [18,19,20]. Comparison of microalgae oil ratios with other vegetable oil sources in Table 1. Oil contents of some microalgae species are given in Table 2.

Table 1. Comparison of some sources of biodiesel [20]

Crop	Oil yield (L/ha)	Land area needed (M ha)[a]	Percent of existing US cropping area[a]
Corn	172	1540	846
Soybean	446	594	326
Canola	1190	223	122
Jatropha	1892	140	77
Coconut	2689	99	54
Oil palm	5950	45	24
Microalgae[b]	136.900	2	1.1
Microalgae[c]	58.700	4.5	2.5

a: For meeting 50% of all transport fuel needs of the United States., b: 70% oil (by wt) in biomass., c: 30% oil (by wt) in biomass.

Table 2. Oil content of some microalgae [20]

Microalga	Oil Content (% dry wt)
Botryococcus braunii	25–75
Chlorella sp.	28–32
Crypthecodinium cohnii	20
Cylindrotheca sp.	16–37
Dunaliella primolecta	23
Isochrysis sp.	25–33
Monallanthus salina	>20
Nannochloris sp.	20–35
Nannochloropsis sp.	31–68
Neochloris oleoabundans	35–54
Nitzschia sp.	45–47
Phaeodactylum tricornutum	20–30
Schizochytrium sp.	50–77
Tetraselmis sueica	15–23

2.1. Chlorella protothecoides

Microalga Chlorella protothecoides can accumulate high proportion of lipids during the heterotrophic growth with glucose as the carbon source. However, its commercial application is restricted due to the high cost of the carbon source. Chlorella protothecoides is a valuable source of lipids that may be used for biodiesel production. Chlorella protothecoides (lipid content 14.6–57.8 %) is being investigated as the potential microalgae species owing to high oil content, less land area required for cultivation and faster growth rate [21]. Chlorella protothecoides is a microalga that can grow either photoautotrophically, mixotrophically or heterotrophically [22]. Properties of C. protothecoides microalgae oil are presented in Table 3.

Table 3. Properties of C. protothecoides microalgae oil [15].

Specifications	Value	Standard
Density (15 °C), kg/m^3	867	ISO 3675
Viscosity (40 °C), mm^2/s	3.8	ISO 3104
Flash Point, °C	124	ISO 15267
Caloric Value, MJ/kg	37.49	DIN 51900
Acid Value, mg.KOH/g	0,3	EN 14104
Iodine Value, mg.KOH/g	47	EN 14111
Water Content, Mg/kg	80	ENISO12937
Sulfur Content, Mg/kg	2	ISO 3987
Phosphorus Content, Mg/kg	3	ISO 10540

3.Material and Method

Experimental tests were carried out in Batman University Faculty of Engineering and Architecture Department of Mechanical Engineering Engine Test Laboratory. The moctoalga oil used in this study was obtained from soley biotechnology. Then the microalgae oil was mixed with the reference diesel fuel at a rate of 5% and 10% as pure. It was named DSYK-5 and DSYK-10. Experimental tests were carried out for each DSYK-5, DSYK-10 and RDF fuels at a fixed speed of 1500 rpm and engine loads of 3.52 kW, 7.04 kW and 10.56 kW. The schematic diagram of the experimental configuration can be seen in Figure 1. The characteristics of the diesel engine are shown in Table 4. In these experimental tests, gas emissions were evaluated using a gas analyzer called CAPELEC CAP 3200.

Table 4. The specification of the engine and generator.

Specifications	Descriptions
Standby power	17.5 kW/22 kVA
Prime power	16 kW/20 kVA
Power factor	0.8
Frequency & phase	50 Hz & 3 PH
Specifications of test engine	FAWDE
Engine brand	4DW81-23D
Model	1500 rpm
Number of cylinders	85 × 100 mm
Engine speed	17:1
Bore and stroke	18 kW/18.7 kVA
Compression ratio	19 kW/20.9 kVA
Rated power	1500 rpm
Standby power	85 × 100 mm

3. Results

3.1. Specific fuel consumption

The amount of fuel consumed per unit power is defined as the specific fuel consumption. The amount of power obtained in the specific fuel consumption map is proportional to the mass of fuel injected. [23]. When the specific fuel consumption curves of the test fuels are given in Figure 2. When examined, it is seen that the specific fuel values gradually decrease with the loading applied to the test engine. The reason for this decrease is that the load on the engine increases the turbulence in the cylinder, improving combustion and engine power. Increased engine power reduces specific fuel consumption. Compared to RDF fuel, DSYK-5: 3.4843 g/kWh, DSYK-10 showed 5.8072 g/kWh more consumption. The higher specific fuel consumption of pure oil-diesel blended fuels compared to RDF fuel is due to lower thermal values [24].

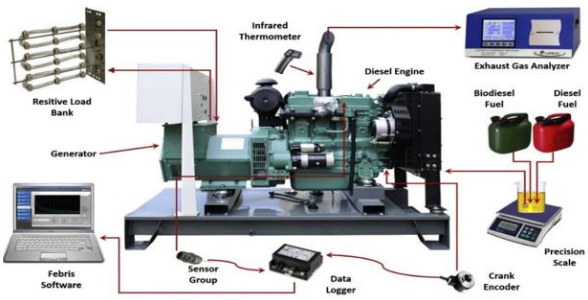

Figure 1. Schematic diagram of the test set-up [35].

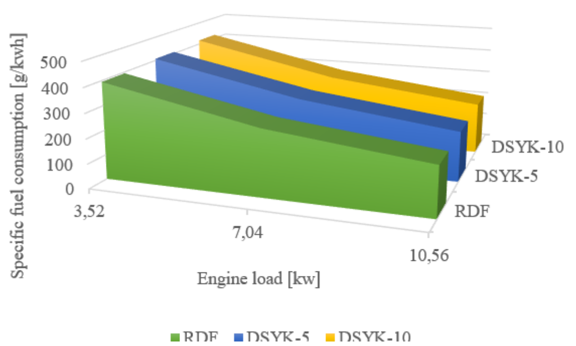

Figure 2. The relationship between engine load (kw) and SFC (g/kwh) for different blends.

4.2. Carbon monoxide (CO)

Formation of carbon monoxide, which is one of the emission types, is caused by the inhomogeneity of the mixture or insufficient oxygen in some areas in the cylinder [25]. When Figure 3 is examined, an average of 9.05% decrease was observed in the CO emission values obtained by using DSYK-5 fuel compared to diesel fuel. With the use of DSYK-10 fuel, increases in CO emission values compared to diesel fuel were determined. It has been determined in the literature studies that the increase in the pure oil ratio in RDF fuel content and the increase in density and viscosity increase the CO emission in DSYK-10 fuel use, as some researchers have worked in the same direction [26].

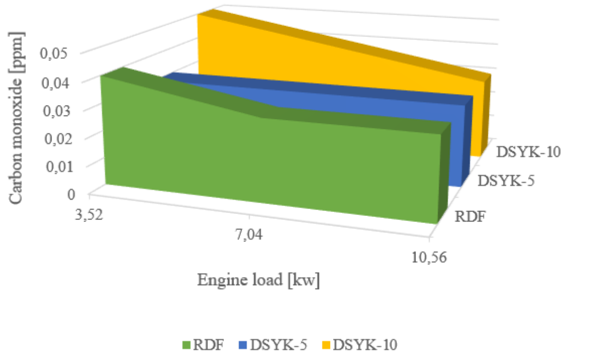

Figure 3. The relationship between engine load (kw) and CO (ppm) for different blends.

4.3. Carbon dioxide (CO_2)

The variation of CO_2 emission values according to the load is given in Figure 4. Emission values increased with the increase in load, which can be attributed to the improved combustion environment, for all of the test fuels. When the fuels were examined, it was seen that the CO_2 emission values of DSYK-5 fuel and RDF fuel were similar. In addition, with the use of DSYK-10 fuel, CO_2 values decreased compared to RDF fuel. When the amount of pure oil in the mixed fuel increases, it can be said that the combustion is adversely affected by high density and high viscosity.

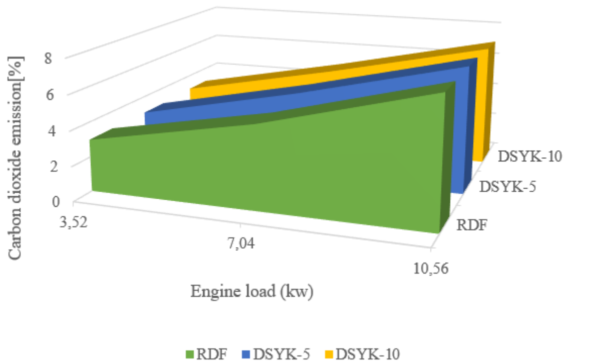

Figure 4. The relationship between engine load (kw) and CO_2 (%) for different blends.

4.4. HC emissions

Figure 5 depicts the differences in engine load and HC emission for diesel and pure oil blend fuels. For all fuels, HC emissions increased as they were loaded. Because incomplete combustion produces HC emissions, which is one of the organic molecules. HC emissions rise dramatically when the fuel-air ratio exceeds the stoichiometric ratio. When the experimental fuels were evaluated, it was discovered that the pure oil blended fuels emit 4.60 percent less HC than the RDF fuels on average. In the presence of vegetable oils, this reduction provides adequate oxidation in the oxygen-rich fuel-air mixture areas [28].

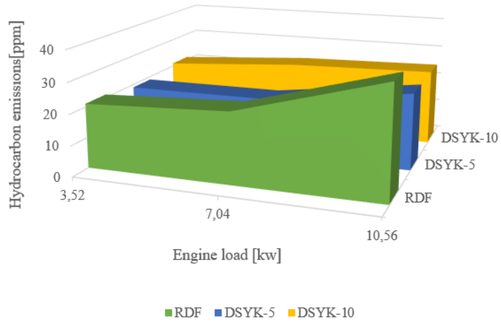

Figure 5. The relationship between engine load (kw) and HC (ppm) for different blends.

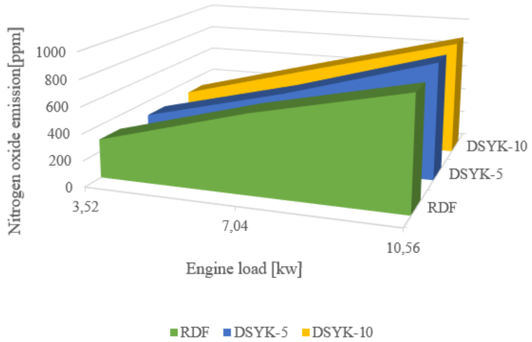

Figure 6. The relationship between engine load (kw) and NO_x (ppm) for different blends.

4.5. NO_x emissions

The NO_x emission variation of the test fuels depending on the load at constant engine speed is given in figure 6. When Figure 6 is examined, NO_x values for all of the experimental fuels increased in parallel with the increase in load. This increase can be attributed to the increase in temperature, which is a result of increased fuel consumption with loading. In addition, it was observed that the NO_x values increased partially with the increase in the pure oil ratio in the blended fuel. The total NOx values produced by the test fuels are RDF: 1814 ppm, DSYK-5: 1852 ppm, and finally dsyk-10: 1890 ppm. The combustion-improving effect of the oxygenated additives in the pure oil content and the long-term ignition delay resulting in faster premixed combustion result in higher combustion temperature and subsequently higher NO_x emissions [29].

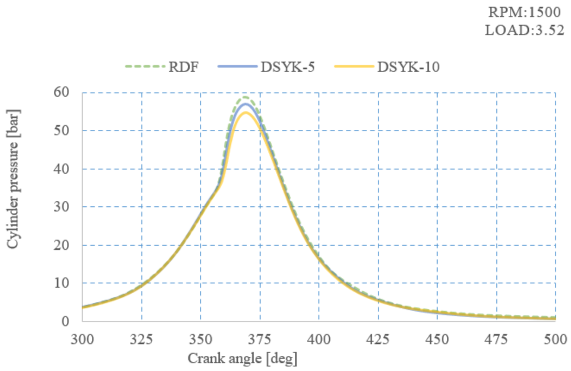

Figure 7.a. Cylinder pressure variations at 3.52 kW engine load

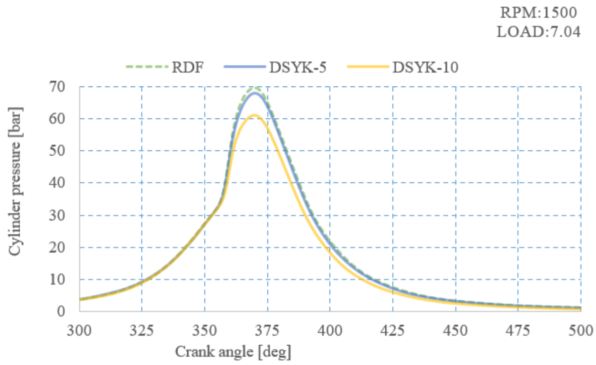

Figure 7.b. Cylinder pressure variations at 7.04 kW engine load

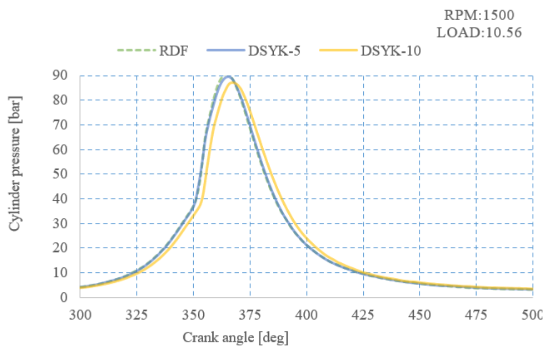

Figure 7.c. Cylinder pressure variations at 10.56 kW engine load

4.6. Cylinder pressure

The maximum cylinder pressure values for all of the test fuels occurred after the upper dead point (7.a.b.c.). As the engine load increased, the maximum cylinder pressure values for all experimental fuels also increased. The peak pressure of the blended fuels was found to be lower compared to the reference diesel. Because cylinder pressure is related to the energy content in the fuel [30]. In addition, when pure oil is added, the viscosity and density values of the blended fuels increase and the calorific energy amount decreases. In this case, the combustion characteristics are negatively affected and the engine performance may be reduced. In particular, the addition of pure oil worsens the injection characteristics and atomization of the fuel becomes difficult [31]. In this case, a homogeneous mixture cannot be achieved in the combustion chamber and the cylinder pressure peak values, which are one of the combustion parameters, decrease.

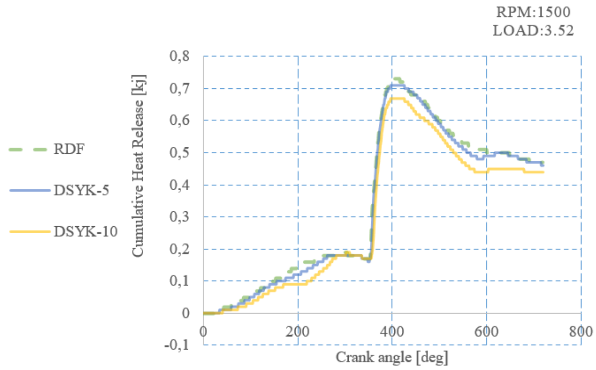

Figure 8.a. Change of cumulative heat release values at 3.52 kW motor load

4.7. Cumulative heat release

The sum of the heat energy released in the combustion chamber based on the crank angle is the cumulative heat dissipation. Cumulative heat values make it easier to examine combustion rates and, in particular, nitrogen oxide emissions. Ignition delay, burning rates, pre-mixed phase information, diffusion phase information, and phase burning durations can all be evaluated as a result of the curves' interpretation. Figure 8 (a.b.c.) The changes in the cumulative heat dissipation depending on the crank angle are shown. When the images were reviewed, it was discovered that under all load circumstances, RDF fuel produced more heat than blended fuels. Furthermore, it was discovered that as the amount of pure oil in the blend fuel grew, the cumulative values emitted dropped. The viscosity and density of the mixed fuel increase when a high percentage of pure oil is added, but the amount of calorific energy drops. The combustion properties are adversely influenced in this circumstance. When you use too much pure oil, the injection properties deteriorate and it becomes difficult to atomize the fuel. In this circumstance, the combustion rate is lowered because a homogenous mixture cannot be achieved in the combustion chamber. According to several studies, fuels with a low calorific value exhibit low cumulative heat release curves when injected at the same rate [31].

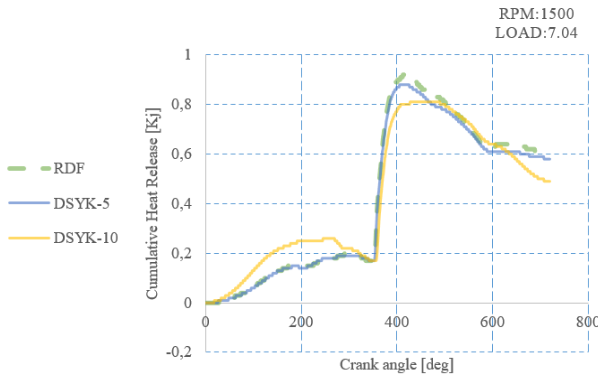

Figure 8.b. Change of cumulative heat release values at 7.04 kW motor load

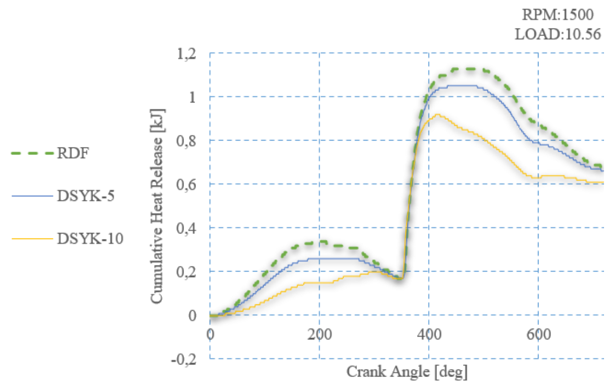

Figure 8.c. Change of cumulative heat release values at 10.56 kW motor load

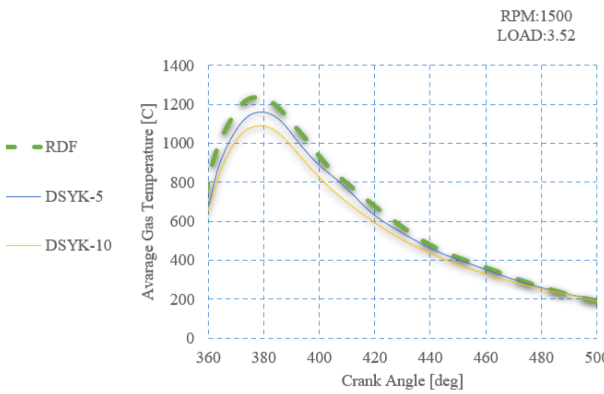

Figure 9.a. Change of average gas temperature values at 3.52 kW engine load

4.8. Average gas temperature

Figure. 9.a.b.c. When examining the variations of average gas temperatures due to the crank angle at 3.52, 7.04 and 10.56 kW engine load at 1500 fixed rpm, it was determined that both of the blended fuels formed lower values than RDF fuel. In addition, the average gas temperature value has decreased in parallel with the amount of pure oil in the mixing ratio. The explanation for the lower average gas temperatures of mixed fuel compared to RDF fuel was attributed to the short burning time and low lower heating value of pure vegetable oil [32, 33, 34].

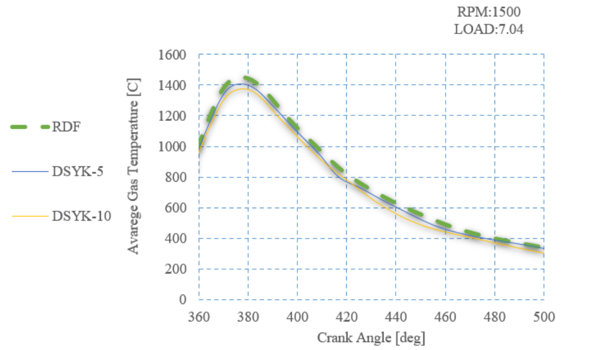

Figure 9.b. Change of average gas temperature values at 7.04 kW engine load

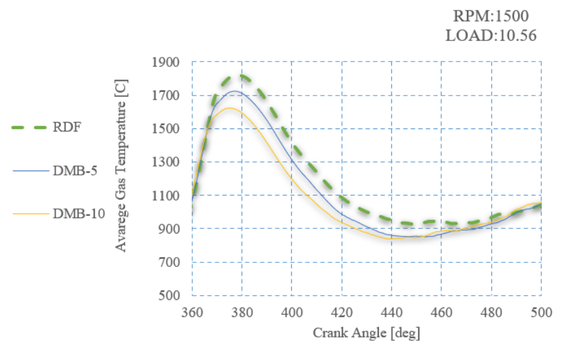

Figure 9.c. Change of average gas temperature values at 10.56 kW engine load

5. Conclusions

Pure microalgae oil was blended with reference diesel fuel at a rate of 5% and 10% in this investigation, and the resulting mixtures were evaluated in a diesel engine. The findings of the tests obtained are listed below. Due to the low heating value of blended fuel, increases in specific fuel consumption figures occurred. Compared to RDF fuel, CO emissions decreased with the use of DSYK-5 fuel, but were higher when DSYK-10 was used. The CO2 values of the blended fuels were lower than the RDF fuel when the CO2 change was assessed. When it came to NOX emissions, DSYK-5 and DSYK-10 fuels produced higher than RDF fuel. The NOx values increased as the amount of pure microalgae oil in diesel fuel increased. The usage of mixed fuels resulted in a reduction in HC emissions due to the oxygen content. When the combustion data was evaluated, it was discovered that using mixed fuel reduced cylinder pressures, cumulative heat release, and average gas temperature values. Based on the results of the experiments, pure algae oil at 5% by volume can readily be used in diesel engines.

CRediT authorship contribution statement

Erdal ÇILĞIN: Writing - original draft,

Investigation, Visualization, Supervision, Conceptualization, Methodology, Software, Formal analysis. Investigation, Supervision, Writing - review & editing. Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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