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AN EXPERIMENTAL STUDY ON THE EFFECTS OF DIESEL AND JET-A1 FUEL BLENDS ON COMBUSTION, ENGINE PERFORMANCE AND EXHAUST EMISSIONS IN A DIRECT INJECTION DIESEL ENGINE

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Abstract: In this study, an experimental investigation was performed in order to determine the effects of Jet-A1(A100), diesel fuel and Jet-A1/diesel fuel blends (A25, A50, A75) including 25% Jet-A1/75% diesel, 50% Jet-A1/50% diesel and 75% Jet-A1/25% diesel by volume respectively on combustion and engine performance in a single cylinder, direct injection diesel engine. For this purpose, the test engine was run at four different brake torques (7.5, 11.25, 15 and 18.75 Nm) at maximum brake torque engine speed (2200 rpm). The variation of cylinder pressure, heat release rate, ignition delay, combustion duration and exhaust emission were investigated in a naturally aspirated direct injection diesel engine fueled with diesel-Jet-A1 fuel blends. The test results showed that ignition delay time decreased with the increase of brake torque. Maximum in-cylinder pressure was retarded versus crank angle with the increase of brake torque. NO_x emissions decreased with the increase of amount of Jet-A1 in the test fuels, but CO and soot emissions increased. It was also found that combustion duration increased when Jet-A1 (A100) fuel was used compared to A25, A50, A75 test fuels. In conclusion, Jet-A1 aviation fuel can be utilized via mixing with diesel fuel in diesel engines.
Keywords: Jet A1, Cetane number, Biodiesel, Brake torque, Exhaust emission

DİREKT ENJEKSİYONLU BİR DİZEL MOTORUNDA DİZEL VE JET-A1 YAKIT KARIŞIMLARININ YANMA, MOTOR PERFORMANSI VE EGZOZ EMİSYONLARINA ETKİLERİ ÜZERİNE DENEYSEL BİR ÇALIŞMA

Özet: Bu çalışmada Jet-A1 (A100), dizel ve sırasıyla %25 Jet-A1/%75 dizel, %50 Jet-A1/%50 dizel ve %75 Jet-A1/%25 dizel hacimsel oranlarda karıştırılarak elde edilen yakıt karışımlarının (A25, A50, A75) tek silindirli, direkt enjeksiyonlu bir dizel motorunda yanma ve motor performansı üzerindeki etkilerini belirleyebilmek için deneysel çalışma gerçekleştirilmiştir. Bu amaçla, test motoru dört farklı motor torkunda (7.5, 11.25, 15 ve 18.75 Nm) ve maksimum motor tork devrinde (2200 d/d) çalıştırılmıştır. Silindir içi basınç, ısı dağılım oranı, tutuşma gecikmesi, yanma süresi ve egzoz emisyonlarının değişimi Jet- A1 ve dizel yakıt karışımları ile çalışan doğal emişli direkt enjeksiyonlu dizel motorunda incelenmiştir. Deney sonuçları motor yükü arttıkça tutuşma gecikmesi süresinin azaldığını göstermiştir. Motor yükü arttıkça maksimum silindir içi basıncın elde edildiği nokta krank açısın cinsinden rötara alınmıştır. Karışım yakıtlardaki Jet-A1 yakıt oranı arttıkça NO_x emisyonları azalmış, CO ve duman emisyonları artmıştır. Bununla birlikte A25, A50 ve A75 yakıtları ile karşılaştırıldığında Jet-A1(A100) yakıtı ile yanma süresinin arttığı görülmüştür. Sonuçta, Jet A1 yakıtının dizel yakıtı ile karıştırılarak kullanılabileceği görülmüştür.
Anahtar Kelimeler: Jet-A1, Setan sayısı, Biyodizel, Motor momenti, Egzoz emisyonu

NOMENCLATURE

ASTM	American society for testing and materials
BTDC	Before top dead center
CA	Crank angle
CO	Carbon monoxide
CO_2	Carbon dioxide
DAQ	Data acquisition
HC	Hydrocarbon
Imep	Indicated mean effective pressure
O_2	Oxygen
PM	Particulate matter
NO_x	Nitrogen oxides
W_{net}	Net work
V_k	Swept volume
dQ	Heat release rate

$d\theta$	Variation of crank angle
k	The ratio of specific heat values
P	In-cylinder pressure
V	Cylinder volume
dP	The variation of in-cylinder pressure
dV	The variation of cylinder volume
dQ_{heat}	Heat transferred to the cylinder walls
COV_{imep}	Cyclic variations of imep
σ_{imep}	The standard deviation of the consecutive 50 cycles
X	The average of indicated mean effective pressures

INTRODUCTION

Global warming, reduction of oil reserves and increasing energy demand caused to considerable interest on renewable energy in motored vehicles. Because road vehicles fuelled with petroleum emit CO, HC, NO_x and PM which pollute the environment and damage the human health (Marsh, 2008, Sgouridis, 2012, Moraes et al., 2014, Uyumaz et al., 2014). Among the alternative renewable fuels aviation fuels have a big attractiveness on reduction exhaust emissions from internal combustion engines. When aviation fuels are considered, Jet-A1 and JP-8 are the most commonly used in the aircraft and diesel engines. One of the significant property of the Jet-A1 is the cooling effects on hot engine parts. Because internal combustion engine is warmed up especially at full engine load. So, engine is needed to be cooled (Papagiannakis et al., 2006, Jinwoo et al., 2011, Lestz and LePera, 1992, Yamık et al., 2013). Kerosene consisting of complex hydrocarbon is widely used in aircraft engines. It has boiling point between 145-300°C (Hubet et al., 2010, Tesseraux and Toxicoll, 2004). NATO decided to use a single aviation fuel in order to eliminate the logistic problems in the war. At this point, Jet-A1 aviation fuel was selected as a single fuel (Mosses et al., 1993, Kouremenos et al., 1997). When JP-8 was used in the internal combustion engines, specific fuel consumption increased. Moreover, Jet-A1 has lower cetane number. But Jet A1 aviation fuel can be used via mixing with diesel fuel in both aircraft and diesel engines (Uyumaz et al., 2014, Yamık et al., 2013, Kouremenos et al., 1997, Arkoudeas et al., 2002, Owens et al., 1989, Lee and Bae, 2011). Jet A1 which has lower freezing point can be used in military vehicles at cold operation conditions (Kouremenos et al., 1997, Arkoudeas et al., 2002, Owens et al., 1989, Lee and Bae, 2011, Çelikten et al., 2011, Çelikten et al., 2012). It was also mentioned that some additives intended to be used with Jet-A1 in order to improve its properties. Chuck et al (2014) investigated the compatibility of biofuels with Jet-A1 aviation fuel. They determined the viscosity of the test fuels. They showed that limonene became the best fuel as an alternative aviation fuel. It is clear to say that Jet-A1 has good properties such as good atomization, rapid evoporation on the ground, lower explosion risk, lower freezing point, non-toxic and availability. Jet-A1 is economically competitive to diesel fuel. Besides, Jet-A1 is compatible and blendable with standard fuels. In view of the chemical properties, Jet-A1 has lower viscosity and high volatility which promotes vaporisation. As boiling point temperature of Jet-A is lower, better mixture quality can be obtained during evaporation compared that diesel. Apart from these advantages, Jet-A1 fuel can be utilized as good corrosion inhibitor, lubricity enhancer and fuel system icing inhibitor. Furthermore, Jet-A1 can be easily mixtured and used with diesel fuel and important reductions can be observed on NO_x emissions (Blakey et al., 2011, Armstrong et al., 1997, Gardner and Whyte 1990, Chuck et al., 2014, Lefebvre AH., 1999, Chong and Hochgreb, 2014, Chiaramonti et al., 2014, Solmaz et al., 2014). Chong and Hochgreb (2014) compared the spray combustion characteristics rapseed methyl esters with Jet-A1 using a gas turbine. They performed a study in order to determine the flame chemiluminescence. They saw small droplets near the centreline region. It was also implied that rapseed methyl esters showed the similar spray characteristics compared to Jet-A1. Jing et al. (2015) researched the spray combustion of Jet-A fuel. The test results showed that Jet-A fuel showed the similar flame development like diesel. They also determined that soot cloud was oxidized rapidly for Jet-A compared to diesel. It was also reported that lower OH^*emission area was obtained for Jet-A than diesel due to faster reaction rate of Jet-A. Lower soot level was obtained for Jet-A (Nargunde et al., 2010). Abu Talib et al. (2014) analyzed the effects of biodiesel based on palm oil methyl ester and the blends of biodiesel-Jet A1 in a turbojet engine. They found that B20 gave the notable results according to Jet-A1. It was also reported that combustor efficiency improved with the addition of biodiesel. The test results showed that palm oil methyl ester should be used as anadditive fuel to Jet-A1. French (2003) conducted an experiment in turbojet gas turbine fueled with canola oil biodiesel. He found that maximum thrust was achieved with Jet-A fuel compared to biodiesel at maximum speed. Habib et al. (2009) investigated the effects of biodiesels and biodiesel-Jet A1 fuel belnds. They concluded that turbine inlet temperature was lower than Jet-A1 when biofuels were used. However, similar exhaust gas temperatures were obtained for all test fuels. Solmaz et al. (2014) investigated the effects of civil aviation fuel Jet-A1 blends on engine performance and emissions in a diesel engine. They determined that engine brake torque decreased by about 5.85 %. Furthermore, it was seen that specific fuel consumption increased 8.77 % using Jet-A1. In contrast, NO_x emissions decreased by 29 %. Lee and Bae (2011) performed an experimental study to evaluate the effects of JP-8 and diesel fuel in a single cylinder heavy-duty diesel engine. They noticed that JP-8 provided shorter spray penetration than diesel owing to faster vaporization characteristics of JP-8. It was also showed that longer ignition delay was observed with JP-8 due to the lower cetane number. Kouremenos and Rakopoulos (1997) investigated the usage of JP-8 as an alternative fuel in case diesel fuel in a Ricardo high-speed engine. They reported that combustion pressures and combustion intensity increased with JP-8. It was also found that there was a slight difference on exhaust emissions for both fuels. Uyumaz et al. (2014) performed an experimental study to evaluate the effects of JP-8-biodiesel fuel blends in a direct injection single cylinder diesel engine. It was determined that specific fuel consumption decreased as the brake torque increased for all test fuels. They have seen that NO_x emissions increased with the increase of the amount of biodiesel in the test fuels. On the other hand, CO emissions decreased with the increase of biodiesel in the test fuels. Rakopoulos et al. (2004) burned the diesel and JP-8 fuels in order to see the variation of emissions. They demonstrated that emissions were affected by the combustor type. When two fuels were burned in the same combustor, comparable results were obtained both fuels.

As seen in the literature survey, there is no enough study on the usage of Jet-A1 aviation fuels in the internal combustion engines. Good atomization and vaporisation, lower freezing point and mixing properties of Jet-A1 attract attention on the usage in the internal combustion engines. Moreover, lower NO emissions are obtained compared that püre diesel fuel in case jet-A1 and diesel fuel blends are used diesel engines. In this study, it was aimed to see the effects of Jet-A1 aviation fuel addition into diesel fuel on combustion, engine performance and exhaust emissions. For this purpose, a direct injection, single cylinder diesel engine was operated with diesel and diesel/Jet-A1 aviation fuel blends (A25, A50, A75 and A100) at four different brake torques (7.5, 11.25, 15 and 18.75 Nm) and maximum brake torque (2200 rpm) engine speed. The variation of cylinder pressure, heat release rate, combustion duration (CA10-90), cyclic variations of indicated mean effective pressure and CO, NO_x and soot emissions were investigated in order to evaluate the effects of Jet-A1 aviation fuel.

EXPERIMENTAL SETUP AND PROCEDURE

A single cylinder, four stroke, naturally aspirated, direct injection diesel engine was used in the experiments. The technical specifications of the test engine are given in Table 1.

Table 1. The technical specifications of the test engine

Engine type	Four stroke, direct injection
Number of cylinder	1
Cylinder bore [mm]	86
Stroke [mm]	68
Displacement [cc]	395
compression ratio	18/1
Maximum brake torque at 2200 rpm [Nm]	19
Injection pressure [bar]	180
Injection advance [°CA, BTDC]	24
Maximum power at 3000 rpm [kW]	5.4

The schematic view of the experimental set-up is seen in Figure 1.The experiments were conducted at four different brake torques including 7.5, 11.25, 15 and 18.75 Nm and 2200 rpm engine speed. As seen in Table 1, maximum brake torque is obtained as 19 Nm at 2200 rpm. The test engine can be loaded with 75 N force by dinamometer. The load cell is placed 0.25 m away from dynamometer shaft axis. So, maximum brake torque is obtained 18.75 Nm at full load. For this reason, brake torques were determined intervals of 3.75 Nm as 7.5, 11.25, 15 and 18.75 Nm in order to analyze performance, combustion and emissions accurately. In addition, four different brake torques are sufficient in order to determine performance and emission characteristics. Before the each experiment, the test engine was heated in order to stable combustion and avoiding incomparability. Thus, engine oil and coolant oil temperatures were fixed at 75°C and 85°C during the experiments.

The test engine was coupled with DC dynamometer. In addition, load cell was used in order to measure the brake torque. Cussons P8160 DC dynamometer that is rated 10 kW at 4000 rpm engine speed was used to load the engine. Brake torque and speed were controlled via dynamometer control panel. Water-cooled AVL 8QP500c piezoelectric in-cylinder pressure sensor was mounted in the cylinder head in order to measure the in-cylinder pressure. The specifications of the cylinder pressure sensor are given in Table 2.

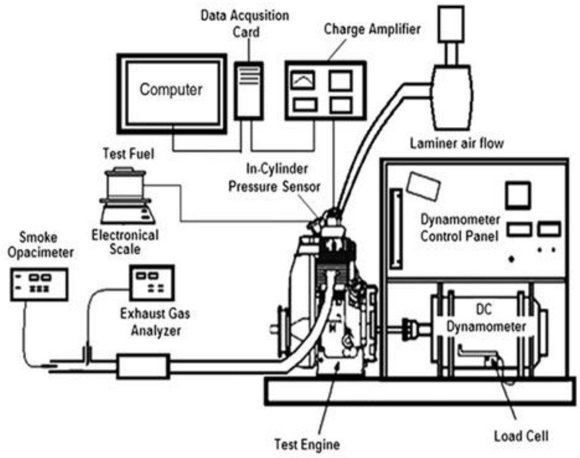

Figure 1. The schematic view of the experimental set-up

Table 2. The specifications of the cylinder pressure sensor

Model	AVL 8QP500c
Operating range [bar]	0-150
Measurement precision [pC/bar]	11.96
Linearity [%]	±0.6
Natural frequency [kHz]	>100

In addition, incremental shaft encoder which gives 1000 pulses per rotation was adapted in the crank shaft to determine the top dead center and engine speed. In-cylinder pressure datas were delivered to the combustion analyzer in order to amplify the raw digital cylinder pressure signals. National Instruments USB 6259 data acquisition card (DAQ) with 0.36° crank angle interval was used to record the pressure signals to the computer. Cyclic variations were intended to be reduced via the averaging the consecutive 50 cycles. VLT 2600 S opacimeter and Testo exhaust gas analyzer were used to measure the exhaust emissions. The specifications of the VLT 2600 S opacimeter and Testo exhaust gas analyzer are given in Table 3 and Table 4 respectively.

Table 3. The specifications of the VLT 2600 S opacimeter

Parameter	Operating range	Accuracy
Soot intensity [%]	0–99	0.01
k soot factor [m−1]	0–10	0.01
Engine speed [rpm]	0–9999	1

Table 4. The specifications of the Testo exhaust gas analyzer

Combustion products	Operating range	Accuracy
O_2 [vol.%]	0–25	±2 mV
CO [ppm]	0–10000	5 ppm (0–99 ppm)
CO_2 [vol.%]	0–50	±0.3 vol.% +1 mV.% (0–25) vol.%) (0–25 vol.%)
HC [%]	0.01–4	<400 ppm (100–4000 ppm)
NO_x [ppm]	0–3000	5 ppm (0–99 ppm)

Five different test fuels were used in the experiments. The abbreviations and the percentages of test fuels are given in Table 5. Jet-A1 aviation fuel has lower cetane number and calorific value compared to diesel fuel. But, lower freezing point of Jet-A1 has significant advantage at cold conditions. The properties of the test fuels are shown in Table 6. As mentioned above, there are very few experimental investigations with Jet-A1 on the effects of combustion, performance and emissions in a diesel engines. Test fuels were selected according to stable opereating conditions. In order to see the effects of Jet-A1 addition into diesel fuel on combustion, performance and emissions, the fraction of Jet-A1 has been increased by 25 % vol. periodically in the test fuel. It was seen that the test engine could run with Jet-A1/diesel fuel blends smoothly at very different mixing ratios. The test engine is even run with 100 % Jet-A1 (A100). Test fuel selection has been also based on research that performed by Solmaz et al. (Solmaz et al., 2014). So, five different test fuels were determined as diesel, A25, A50, A75 and A100.

Table 5. Percentage of fuels and abbreviations

Abbreviation	Percentage of fuels
A25	25 % Jet-A1 and 75% Diesel
A50	50 % Jet-A1 and 50% Diesel
A75	75 % Jet-A1 and 25% Diesel
A100	100 % Jet-A1

Table 6. The properties of the test fuels

Fuel	Diesel	Jet-A1	Method
Density [g/cm3, at 15°C]	0.8372	0.775	ASTM D 1298
Viscosity [cSt]	2.8 (40°C)	3.87 (-20°C)	ASTM D 445
Freezing point [°C]	-5	-47	ASTM D 2386
Flash point [°C]	73	38	ASTM D 93
Lower heating value [kcal/kg]	10450	10200	ASTM D2015

During the experiments fuel consumption was measured using electronic scale for each test. Moreover, exhaust gas temperature was measured K-type thermocouple placed in the exhaust line. In order to measure the air consumption Meriam Z50MC2-4F model laminar air flow meter was used. Equivalence ratio was determined using fuel and air consumption. Imep was calculated using the Eq. (1) as below. Four different brake torques were selected in the experiments. Imep values were calculated for each brake torque (Heywood, 1988).

$$imep = \frac{W_{net}}{V_k} \tag{1}$$

In addition cylinder pressure was used in order to determine the heat release rate. Hence, heat release rate was determined according to the first law of thermodynamics. It was assumed to be ideal gas in the cylinder. Gas leakages and some frictions were neglected (Heywood, 1988, Zhao,2007).

$$\frac{dQ}{d\theta} = \frac{k}{k-1} P \frac{dV}{d\theta} + \frac{1}{k-1} V \frac{dP}{d\theta} + \frac{dQ_{heat}}{d\theta} \tag{2}$$

In Eq. (2), k defines the ratio of specific heat values. dQ and dQ_{heat} are expressed as heat release rate and transferred heat from the cylinder walls respectively. $d\theta$ defines the variation of crank angle. Cyclic variations are seen in the internal combustion engines. Because, mixture composition, pressure-temperature history in the combustion chamber, heat losses and leakages vary in each cycle. So, it should be determined the coefficient of variation in the test engine. In the present study, coefficient of variation of indicated mean effective pressure COV_{imep} was calculated as in Eq. (3).

$$COV_{imep} = \frac{\sigma_{imep}}{X} x100 \tag{3}$$

σ_{imep} and X refer the standard deviation of the consecutive 50 cycles and the average of indicated mean effective pressures respectively (Heywood 1988, Zhao 2007).

RESULTS AND DISCUSSION

The experiments were conducted at four different brake torques and 2200 rpm engine speed. To analyze the combustion, the variation of cylinder pressure and heat release rate were examined. Hence, detailed analysis of experimental findings was conducted in order to understand the role of Jet-A1 aviation fuel. Figure 2 shows the variation of cylinder pressure and heat release rates versus crank angle with diesel and Jet-A1-diesel fuel blends at different brake torques including 7.5, 11.25, 15 and 18.75 Nm. It can be first said that combustion occured later due to increase of Jet-A1 aviation fuel in the test fuel. In addition, it is possible to mention that the increase of brake torque causes the combustion duration to increase. Because, more charge mixture should be burned with the increase of brake torque. Imep values could be also seen in Figure 1 according to brake torque. Maximum imep was calculated as 3.43 bar. It was found that diesel fuel started to burn earlier than mixture test fuels due to higher cetane number. Cetane number directly influences the start of combustion. As the amount of Jet-A1 aviation fuel increased in the test fuels, combustion occured later. Furthermore, lower heat release rate was obtained with diesel fuel compared to Jet-A1 aviation fuel blends. It can be also concluded from Figure 2 that maximum cylinder pressure was obtained later as the brake torque increased. As can be seen in Figure 2, higher heat reelase rate were obtained with the fuel blends. When the variations of cylinder pressure are examined, there is no remarkable difference between the Jet-A1 fuel blends except for pure diesel.

The composition of the charge mixture, initial conditions, heat losses, gas leakages and turbulance cause to variations in each cycle in the engines. The cyclic variations should not be exceed 10 % in the internal combustion engines (Heywood 1988). Figure 3-a illustrates the variation of COV_{imep} versus brake torque with test fuels. It is concluded from Figure 3-a that COV_{imep} decreases with the increase of brake torque.

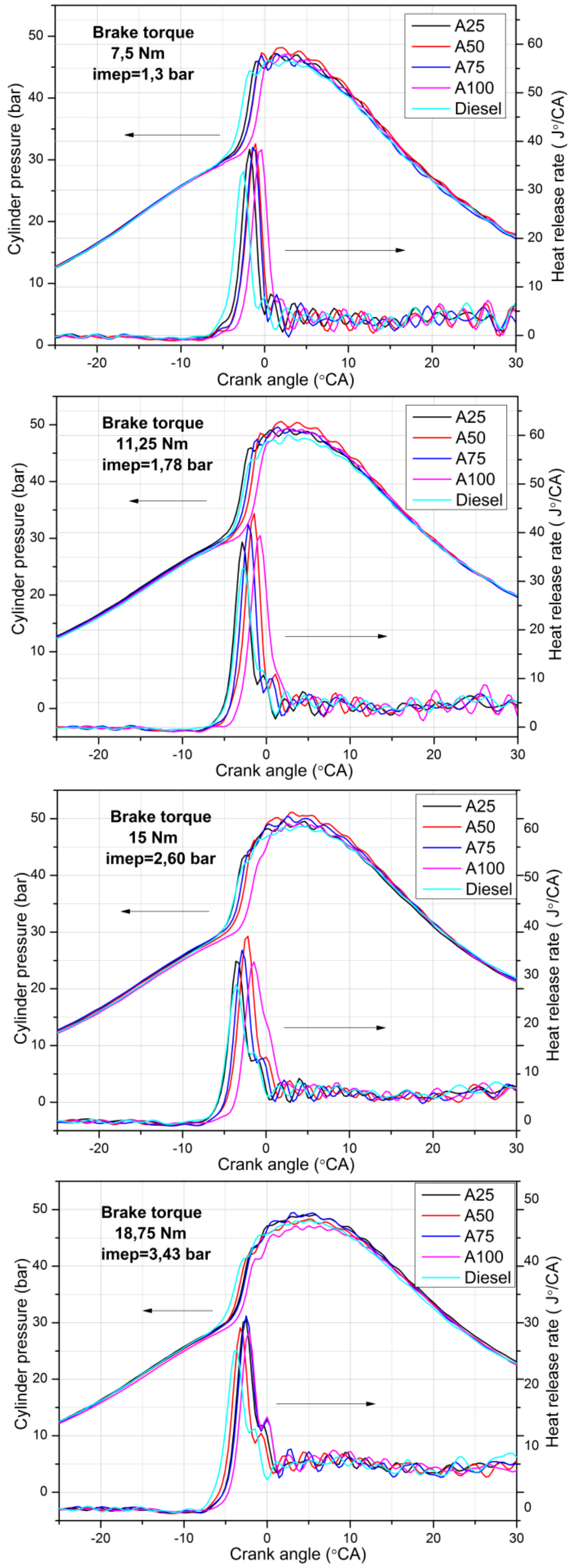

Figure 2. The effects of Jet-A1 and diesel fuel blends on cylinder pressure and heat release rate

As the brake torque increases, more charge mixture is delivered into the cylinder. It causes to higher cylinder temperature and oxidation reactions are improved. It results more regular combustion. Thus, COV_{imep} decreases. It was also seen that COV_{imep} decreased with the increase of the amount of Jet-A1 in the test fuel due to lower cetane number. It was seen that COV_{imep} exceeds the 10 % at 7.5 Nm brake torque for all test fuels.

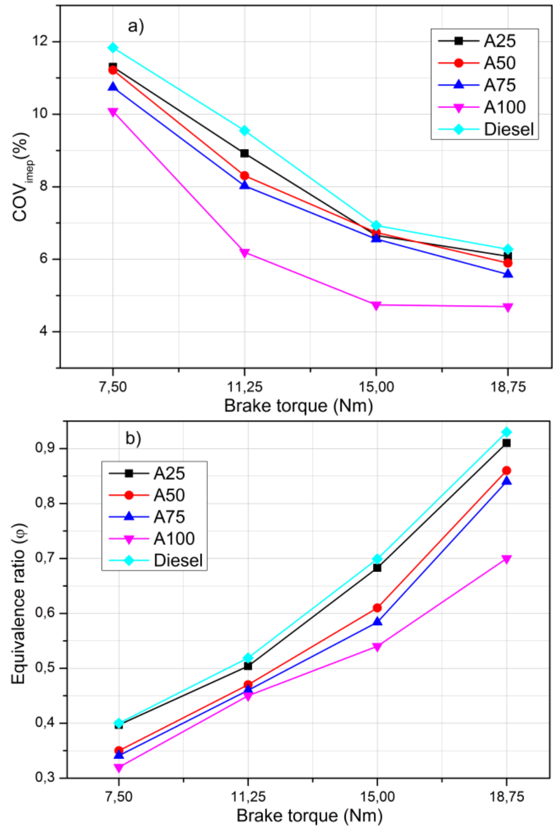

Figure 3. The variation of COV_{imep} and equivalence ratio

Figure 3-b depicts the variation of calculated equivalence ratios for all test fuels versus brake torque. Highest equivalence ratio was obtained with diesel fuel due to higher density. Lower density of Jet-A1 caused to deliver less fuel into the cylinder. On the other hand, equivalence ratio increased when diesel fuel was used owing to higher density compared to Jet-A1. It is also clear that equivalence ratio decreased with the increase of the amount of Jet-A1 in the test fuel.

Ignition delay is one of the most significant parameters affecting the combustion process in diesel engines. If the ignition delay time is prolonged, the amount of charge mixture which ready to be burned increases. Once the ignition starts, whole charge mixture intends to participate into the combustion. As a result, higher pressure rise rate and knocking combustion occur in the diesel engines. It can be also heard owing to loud metal noise (Yao et al., 2009). Figure 4 demonstrates the variation of ignition delay times versus brake torque with test fuels. It is seen that ignition delay times decrease with the increase of brake torque. Because, in-cylinder temperature increases and higher cylinder temperatures help to start the combustion earlier. It was also obtained that ignition delay time increased with the increase of amount of Jet-A1 aviation fuel in the test fuel. The reason of this issue is lower cetane number of Jet-A1 aviation fuel. Shorter ignition delay also leads to obtain pressure trace earlier. However, it should be also mentioned that longer duration is required in order to complete whole charge mixture with the increase of brake torque, because more charge mixture should attend to the oxidation reactions. Moreover, the more test fuel which has low cetane number increases with the increase of brake torque. This low cetane number test fuel causes to obtain maximum in-cylinder pressure later at the end of combustion.

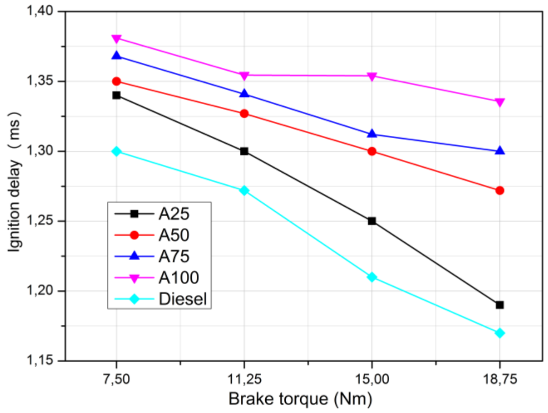

Figure 4. The variation of ignition delay times

Figure 5 expresses the definiton of combustion duration versus crank angle. CA50 defines the crank angle when the half of charge mixture completed to burn in the combustion chamber. CA10 refers the time when the 10 % percentage of charge mixture has combusted depending on the crank angle. Similarly, CA90 is defined as the time 90 % percentage of mixture has completed to combust.

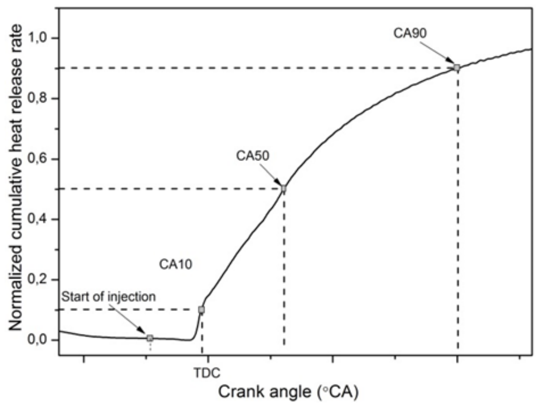

Figure 5. The definition of combustion duration

Combustion duration is generally determined between CA10 and CA90 depending on the crank angle. To determine the these mentioned values, cumulative heat release is normalized between 0 and 1. Moreover, the start of combustion is determined as the heat release rate reaches to the positive value. In contrast, the end of combustion can not be exactly determined due to heat transfer, gas leakages and continuous combustion. For this reason, combustion duration was accepted as CA10-90 in this study (Heywood 1988, Zhao 2007, Yao et al., 2009, Çınar et al., 2015).

Figure 6 shows the variation of CA 50 and CA10-90 versus crank angle with different test fuels. When Figure 6-a is examined, CA50 increased with the increase of brake torque due to more charge mixture. CA50 is defined as after top dead center in Figure 6-a. It can be clearly said that CA50 increases with the increase of Jet-A1 aviation fuel in the test fuel. Because cetane number of Jet-A1 is lower than diesel. It causes to prolong the combustion. It was also found that maximum in-cylinder pressure was obtained later with the increase of brake torque. This situation can be also observed that CA50 is obtained after top dead center as seen in Figure 6-a.

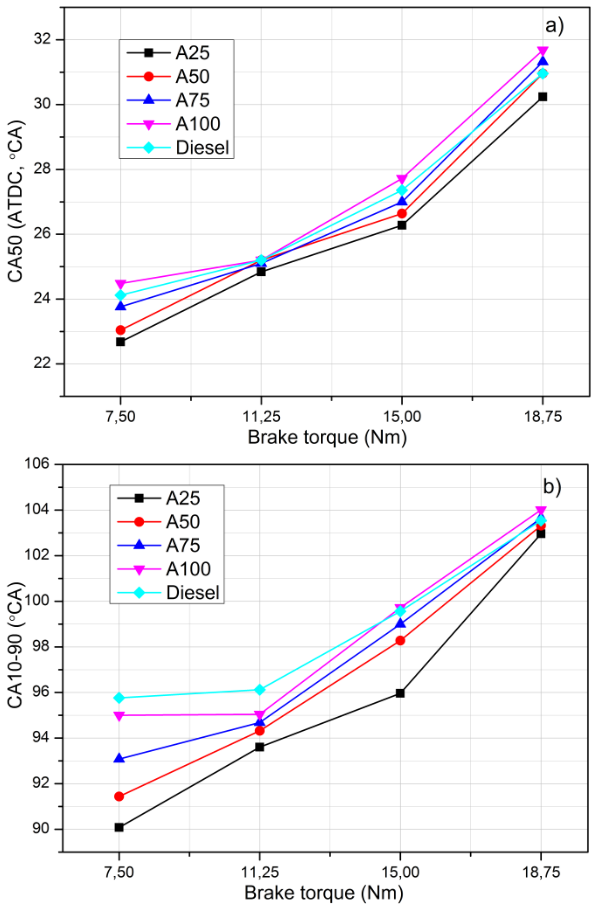

Figure 6. The variation of CA 50 and CA10-90 versus crank angle

Figure 6-b shows the variation of CA10-90 versus brake torque. Similar effect was seen with CA10-90 like CA50. It was found that combustion is prolonged with the usage of Jet-A1. Lower heating value and cetane number of Jet-A1 led to longer combustion. It may be mentioned that the highest combustion duration was observed with diesel because of the higher density. Combustion duration increases as the more charge mixture is delivered into the cylinder. It takes more time in order to complete the combustion at higher brake torques. Minimum combustion duration was obtained with A25 test fuel.

The variation of specific fuel consumption is depicted from Figure 7. It can be stated that specific fuel consumption decreases with the increase of brake torque. It can be said that higher amount of charge mixture causes to increase the in-cylinder temperature at the end of combustion. It was also shown that specific fuel consumption increased with the increase of the amount of Jet-A1 aviation fuel in the test fuel. Because the lower calorific value and density of Jet-A1 causes to increase the specific fuel consumption resulting in lower released heat. The test engine has to consume more fuel in order to produce the same engine power output. So, maximum specific fuel consumption was determined with A100 test fuel. Specific fuel consumption decreased by 45.20 % with diesel compared to A100 test fuel at full load.

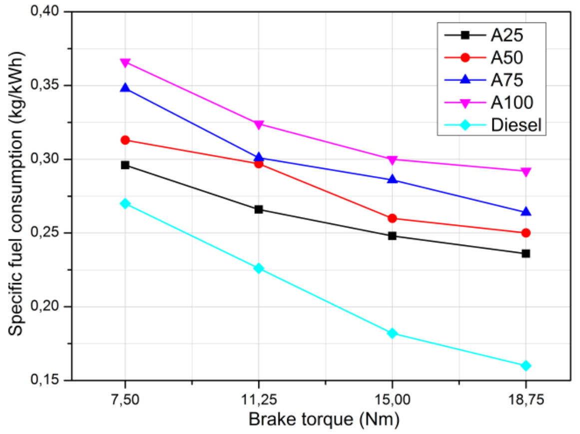

Figure 7. The variation of specific fuel consumption

Figure 8 demonstrates the variation of exhaust gas temperatures versus brake torque with test fuels.

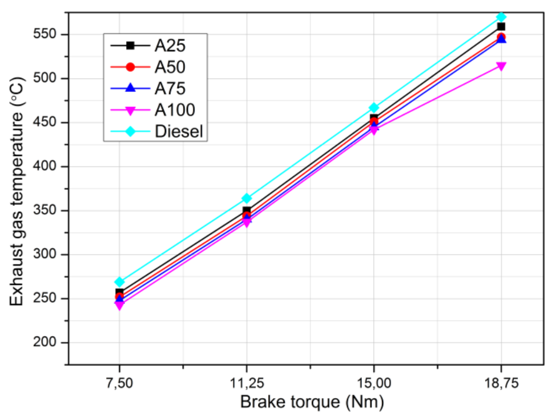

Figure 8. The variation of exhaust gas temperatures versus brake torque

When figure 8 is examined, exhaust gas temperature increases with the increase of brake torque. Because in-cylinder temperature increases when more charge mixture is burned. It causes to increase the exhaust gas temperature. Moreover, exhaust gas temperature decreases with the increase of amount of Jet-A1 aviation fuel in the test fuel due to lower heating value. Thus, minimum exhaust gas temperature was measured with A100 test fuel. Lower density of Jet-A1 also affects the in-cylinder temperature at the end of combustion. Because it can be said that less Jet-A1 aviation fuel is injected owing to lower density into the combustion chamber. It reduces the in-cylinder temperature and exhaust gas temperature.

CO emission is a product of incomplete combustion in the internal combustion engines. The most important factors causing CO formation are unsufficient oxygen and lower temperature in the combustion chamber. Figure 9 shows the variation of CO and soot emissions versus brake torque with different test fuels. CO emissions increase with the increase of brake torque. The reason of that is unsufficient oxygen content in the combustion chamber during combustion. Chemical reactions can not occur between oxygen and hydrocarbon molecules in case of unsufficient oxygen. So, CO_2 formation is prevented (Heywood 1988, Zhao 2007, Çınar et al., 2015, Stone 1999). At higher brake torques, oxygen content of charge mixture decreases by percentage in the combustion chamber. It was also concluded from Figure 9 that CO emission increased with the increase of amount of Jet-A1 in the test fuel. The in-cylinder temperature decreased when the Jet-A1 was used in the test fuel due to lower heating value of Jet-A1. Soot emissions increased with the increase of brake torque like CO emissions. Solid particles from the internal combustion engines are called soot emissions. Soot emissions increased with the increase of Jet-A1 in the test fuel. At full load, it was seen that CO and soot emission increased by about 11 %, 8 % with A100 test fuel compared to diesel respectively.

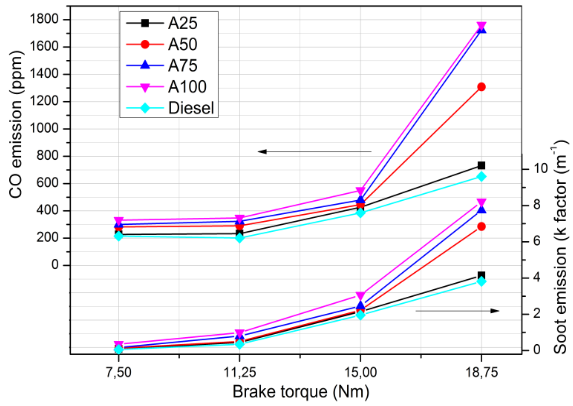

Figure 9. The variation of CO and soot emissions

Nitrogen oxides are generated at higher cylinder temperature at the end of combustion. Because oxygen and nitrogen can react at higher cylinder temperature. So, NO formation mechanism is improved. Figure 10 illustrates the variation of NO_x emissions versus brake torque. It was depicted from Figure 10 that NO_x emissions increased with the increase of brake torque owing to higher cylinder temperature as a result of combustion.

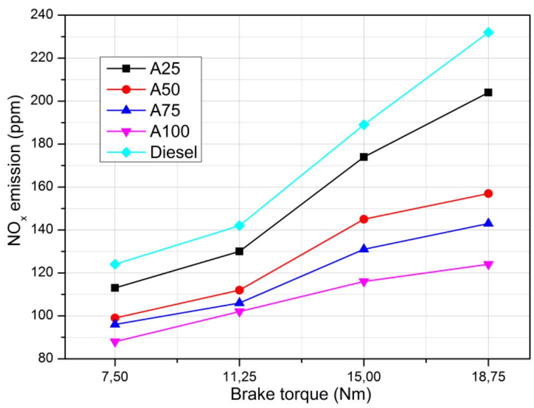

Figure 10. The variation of NO_x emissions

The most attractive effect of the usage Jet-A1 was seen on NO_x emissions. NO_x emissions decreased with the increase of the amount of Jet-A1 in the test fuel. It can be stated that NO_x emissions decreases due to lower heating value and density of Jet-A1. Because, cylinder temperature decreases with the usage of Jet-A1 aviation fuel. So, NO_x formation mechanisms are prevented. Minimum NO_x emissions were measured with A100 test fuel. In contrast, maximum NO_x emissions were obtained with diesel fuel. At full load, NO_x emissions decreased by about 47 % with A100 compared to diesel fuel.

CONCLUSIONS

It is hoped that this experimental study contributes to see the effects and the usage of Jet-A1 aviation fuel in diesel engines. In this way, Jet-A1 seems to be supportive fuel with diesel fuel. However very few publications are available on the usage of Jet-A1 in diesel engines. The scope of this study is to investigate the effects of Jet-A1 addition into diesel fuel on combustion, engine performance, and exhaust emissions in a direct injection diesel engine. Thus, the test engine was run at four different brake torques (7.5, 11.25, 15 and 18.75 Nm) and maximum brake torque (2200 rpm). Five different test fuels (A25, A50, A75, A100 and diesel) were used in order to see the variations on cylinder pressure, heat release rate, combustion duration, ignition delay, performance and exhaust emissions. The test results showed that combustion duration increased with the usage of Jet-A1 in the test fuel due to lower cetane number. Ignition delay was prolonged when Jet-A1 was used in the experiments. It was pointed that specific fuel consumption increased with the usage of Jet-A1 in the test fuel. Indicated thermal efficiency decreased with the addition of Jet-A1 in the test fuel due to lower calorific value. This situation can be realized via the variation of specific fuel consumption. Indicated thermal efficiency was computed as 28.5 % and 27.8 % with diesel and Jet-A1 (A100) test fuels respectively at full load. It was also found that CO and soot emissions increased with the increase of Jet-A1 in the test fuels. But NO_x emissions decreased with the usage of Jet-A1 aviation fuel. It is clear to mention that the most important influence of Jet-A1 was seen on NO_x emission. It can be concluded that Jet-A1 aviation fuel can be used via mixing with diesel fuel.

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