THE USE OF HIGH MOLECULAR ISO-AMYL ALCOHOL AS AN ALTERNATIVE FUEL FOR COMPRESSION IGNITION ENGINES

by

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Currently, many studies are being conducted to improve the emissions and combustion of diesel fuels of diesel vehicles. The majority of these studies consist of alcohol-derived fuels. Alcohol fuels are usually composed of butanol, methenol, and ethanol fuels. However, a high molecular alcohol such as iso-amyl with a high calorific value, which can be produced from sugar beet pulp, is the focus of more attention. Iso-amyl alcohol, chemical formula $(CH3)_2CH-CH_2CH_2-OH$, oxygen rich, can mix with solvents such as ether, photography, pharmaceutical industry, milk oil quantity determination and synthesis, used in a colorless, foul-smelling liquid. In this study, the effects of the addition of iso-amyl alcohol to diesel fuel in order to reduce Diesel engine emissions were examined. For this purpose, 5%, 10%, and 20% iso-amyl alcohol were added to the diesel fuel. The resulting mixtures were subjected to full fuel analysis, unlike other studies. After that, the fuel mixtures in a Diesel engine at different engine speeds at full load (1400 rpm, 1700 rpm, 2000 rpm, 2300 rpm, 2600 rpm, 2900 rpm. and 3200 rpm) were tried. As a result of the experiments, it was determined that the contribution of iso-amyl alcohol caused a 1% -3% reduction in cylinder pressure, 12-20% in power, and 8-25% in torque. Furthermore, when examined in terms of exhaust gas emissions, it decreased in NO_x emission by 1-10%, in smoke opacity by 9-36%, and in HC emission by 6-44%.

Key words: *Diesel engine, combustion, iso-amyl alcohol, engine performance, exhaust emissions.*

Introduction

Because of the danger of depletion of oil, which is an important source of motor vehicles, and the damage it causes to the environment, researchers are working on alternative fuels. When oil and its derivative fuels are burned, they cause the release of gases, which are described as greenhouse gases. Internal combustion engines are shown at the top of the emission sources of these GHG that cause global warming [1-3]. Diesel vehicles, commonly used in our society, are the most consumed of petroleum origin fuels. Diesel fuel contains more than forty toxic and environmental contaminants. The combustion of these substances in internal combustion engines causes pollution by releasing thousands of particles into the environment [4]. One of the most prominent studies of researchers to reduce emissions from diesel fuels is the use of alcohols and their derivatives as additives in diesel [5-7]. Alcohols are more advantageous for their ability to easily mix with conventional fuels than diesel fuel, as they have a high energy density, better ignition quality and high oxygen content. In addition, alcohols do

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not contain elements such as sulfur, phosphorus. All these factors are a huge advantage for alcohols and have therefore, been attracting the attention of researchers for the past decade [8-10]. One of these alcohols is amyl alcohol with an organic compound with the general formula $C_5H_{11}OH$, of which eight isomers are known. The most important of the eight known iso-mers is iso-amyl alcohol. Iso-amyl alcohol is usually obtained from the fermentation of potatoes and cereals and from fuel oil as a result of various processes (such as extraction, distillation and drying). They can also be synthesized by chemical methods. Iso-amyl alcohol of the chemical formula $(CH_3)_2CH\text{-}CH_2CH_2\text{-}OH)$, boiling point 131 °C density: 810 kg/m^3, molar mass: 88.148 g/mol is easily miscible with alcohol and ether, in photography, in the pharmaceutical industry, used in synthesis and in determining the amount of fat in milk, discolored, foul-smelling liquid. Iso-amyl alcohol has a high Corban ratio. As the number of carbon in alcohols increases they can be mixed more easily with fuels, as iso-amyl alcohol has good solvent properties, it can be easily mixed with diesel fuel. With the increase of carbons in alcohol, the number, density and calorific value of cetane increases, while the percentage of oxygen mass decreases. It is also a renewable additive with a straight-chain structure with the OH group in terminal carbon. Higher carbon alkoes such as iso-amyl have negative aspects such as lower evaporation temperature, high number of cetanes, high viscosity, low ignition temperature and corrosion. However, when mixed with diesel fuel with certain ratio to reduce emissions, improve performance, reduce the freezing point of the fuel, diesel fuel's viscosity decreases and provides a better fuel atomization features such as to stand out. Therefore, high alcohol-blended fuels are thought to offer significant contributions to the fuel potential of the next generation of diesel fuels [11, 12].

There are many studies that report that high molecule alcohols in general have an effect on motor performance with their use and change emissions [13-17]. In all of these studies, alcohol fuels are used directly in the engine. In general superficial fuel analyses were not performed and evaluated in studies with alcohols. In this study, detailed fuel analyses were made of the addition of pure iso-amyl alcohol to diesel fuel, the most important of the eight known iso-mers, and the effects of the resulting fuel mixtures on engine performance emission values were investigated. Thus, it is aimed to pave the way for the use of a biomass source that can be produced from wastes such as iso-amyl alcohol as fuel in engines and to eliminate the shortcoming in the literature.

Materials and methods

The diesel fuel used in the experiments was supplied from a local station selling in accordance with en 590 standards. Iso-amyl alcohol used for fuel mixtures is supplied from a company that sells chemical materials of >98% purity. The chemical properties of pure diesel fuel and iso-amyl alcohol are given in tab. 1. Fuel mixtures were mixed at 95% diesel fuel + 5% iso-amyl alcohol, 90% diesel fuel + 10% iso-amyl alcohol, and 80% diesel fuel + 20% iso-amyl alcohol. Of the prepared fuel mixtures, the abbreviation D5 is given for 5% doped, D10 for 10% doped and D20 for 20% doped. The physical and chemical properties of the mixtures obtained were realized at the Yakiz analysis center of the Turkish Scientific Research Center and at the fuel Analysis Laboratory of Malatya Inon-u University. The complete analyses of diesel fuel and iso-amyl alcohol mixed fuels used in the experiments are given in tab. 1.

The experiments were carried out in a direct-injection engine fired with single-cylinder compression. The schematic picture of the experiment assembly is shown in fig. 1, while the technical specifications of the experiment engine are given in tab. 2. Netfren brand electric dynamometer was used for engine experiments. The dynamometer has load absorption capability up to 26 kW en-

Table 1. Physical and technical properties of fuel mixtures

	Analysis method	D	Iso-amyl alcohol	D_5	D_{10}	D_{20}
Density [kgm^{-3}] 15 °C	ISO 12185	843	801.4	842.3	837	834
Viscosity [mm^{2}s^{-1}] 40 °C	ISO 3104	2.95	3.69	2.98	3.05	3.09
CFPP [°C]*	ISO 116	–17	–	–18	–20	–24
Sulfur [mgkg^{-1}]	ISO 20846	7	< 7	< 7	< 7	< 7
Mangan [mgL^{-1}]	EN 16576	0.2	–	0.2	0.2	0.1
Nitrogen [ppm]	ASTM D 5762	0.19	–	0.19	0.18	0.15
Carbon residue % [mm^{-1}]	EN ISO 10370	0.2	–	0.2	0.2	0.15
Water [ppm]	ISO 12937	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Copper strip corrosion	EN ISO 2160	1a	1a	1a	1a	1a
Ash content % [mm^{-1}]	EN ISO 6245	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Cetane number	EN ISO 4264	54.2	–	54	53.6	50.6
Oxidation stability [gm^{-3}]	EN1266	16	–	17	18	22
Sulfur determination [mgkg^{-1}]	EN ISO 20846	5	–	5	4	3
Flash point [°C]	EN ISO 2719	65	–	64	61	57
Calorific value [MJkg^{-1}]	ASTM D240	43.2	35.37	42.2	41.9	41

* CFPP – cold filter plugging point

gine power. The engine experiments were repeated three times for each fuel mixture, starting at 1400 rpm at full throttle position and increasing to 400 rpm at 3200 rpm. Graphs are created by averaging the data. The schematic picture of the experiment assembly is shown in fig. 1.

During the engine experiments, exhaust emission values for each engine speed, exhaust gas temperature value, fuel consumption value and in-cylinder pressure changes were measured and recorded. The brands and models of the measuring instruments used and the measurement uncertainties are given in tab. 3. Pressure change values have been recorded for the in-cylinder pressure values in accordance with the angle 0.1 crankshaft [°CA]. For the change in pressure values, the average of the pressure data in 100 cycles was taken.

The uncertainty calculations of the experiment mechanisms were calculated with No. 1 and 2.

Table 2. Technical feature of the test engine

Engine type	Four-stroke direct injection, air-cooled, naturally aspirated Diesel engine
Number of cylinders	1
Cylinder diameter [mm]	85
Stroke [mm]	90
Cylinder diameter [cm^3]	510
Compression ratio	17/1
Maximum power [kW]	8
Maximum torque [Nm]	22
Diesel injection pressure [MPa]	100
Maximum engine speed [rpm]	3200
Fuel consumption [g Hp.hour^{-1}]	185

Table 3. Precision and uncertainty of measuring instruments

Measurement	Measurement range	Sensitivity	Uncertainty [%]
CO [%Vol.]	0... 10.00	±0.06%	±0.1
CO_2 [%Vol.]	0... 20.00	±0.5%	±0.05
NO_x [ppm]	0... 5000	±5	±0.01
HC [ppm]	0... 50000 n-hexan	±12	±0.04
O_2 [% Vol.]	0...21	±0.1	±0.05
n [%Vol.]	0...100	Sensitivity to OIML 0 standard	±0.01
Cylinder pressure [bar]	0-250	≤ ±0.5	±0.01
Load [Nm]	0-80	±0.05	±0.05
Power [kW]	0-26	±0.05	±0.8
BSFC [$gkW^{-1}h^{-1}$]	–	–	±0.7
Speed [rpm]	0-5000	±5	±0.12
Temperatures [°C]	0-1000	±1	±0.1

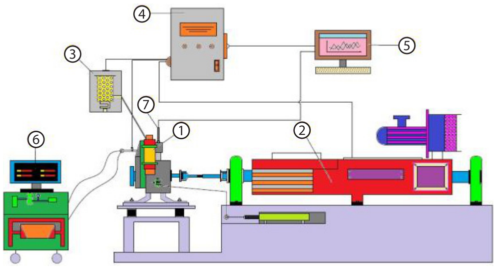

Figure 1. Engine test mechanism schematic view: *1 – Diesel test engine, 2 – dynamometer, 3 – diesel fuel tank, 4 – dynamometer control panel, 5 – control panel recording computer NF software, 6 – exhaust gas analyzer, and 7 – cylinder pressure sensor*

Results and discussion

Comparison of fuel characteristics

Combined with the mixing of iso-amyl alcohol into pure diesel fuel, the density value shows a decrease. The lowest density value was 834 kg/m^3 with D20 fuel mixture. With the addition of iso-amyl alcohol, the viskzoite value of the diesel fuel, which is 2.95 mm^2/s, increased to 3.09 mm^2/s. The number of cetanes is in decline along with the addition of iso-amyl alcohol. With the addition of 20% iso-amyl alcohol, a value of 50.7 was recorded, with a decrease of approximately 7% in the value of the number of cetanes. With the addition of iso-amyl alcohol to diesel fuel, the calorific value decreases. While the calorific value of D100 fuel was 42.6 MJ/kg, iso-amyl decreased to 42.2 MJ/kg, 41.9 MJ/kg, 41.5 MJ/kg, and 41.1 MJ/kg, respectively with the addition of alcohol.

Fuel analyses have shown that iso-amyl alcohol mixed into diesel fuel falls within EN590 standards. In this case, it is thought that the use of iso-amyl alcohol in diesel motor vehicles up to 20% will not pose a negative risk in terms of fuel characteristics.

In-cylinder pressure changes

In internal combustion engines, the combustion in the cylinder is recorded and the fuel in the cylinder can be understood how the combustion tends to be. In this study, pressure changes of low (1400 rpm), maximum torque speed (2600 rpm), and maximum speed (3200 rpm) were interpreted rather than pressure curves at all engine speeds. In fig. 2, in-cylinder pressure changes are given at 1400 rpm fig. 2(a), 2600 rpm fig. 2(b), and 3200 rpm fig. 2(c) engine speeds. The in-cylinder pressure was 34.7 bar with diesel fuel at 1400 rpm, while the D5 fuel was 34.4 with D10 fuel at 34.1 and D20 fuel at 33.9. The engine speed increased to 2600 rpm with diesel fuel 70.4 bar, D5 fuel with 69.5 bar, D10 fuel with 68.8 bar and D20 fuel with 68.5 values decreased. At 3200 rpm the engine speed decreased to 44 bar with diesel fuel, 43.7 bar with D5 fuel, 42.9 bar with D10 fuel and 42.1 bar with D20 fuel. In general, it is reported that low heat value fuels increase fuel consumption by reducing engine power and engine torque [18]. While the heat value of pure diesel fuel is 43.2 MJ/kg, with the addition of iso-amyl alcohol, the calorific value of fuel mixtures are reduced to 42.2 MJ/kg for D5, 41.9 MJ/kg for D10, and 41.1 MJ/kg for D20. On the other hand, the lowest in-cylinder pressure value was obtained at 2600 rpm. It is assumed that in-cylinder torque and power are reduced, along with pumping losses and increased friction mictair with further increase of engine speed [19]. In addition, with the increase in engine speed, the time required to burn the fuels taken into the cylinder decreases. Thus, a quantity of fuel is thought to be ejected from the exhaust without burning. All of these are caused by the increase in engine speed and the decrease in cylinder pressure values [20]. With the addition of iso-amyl alcohol, the highest amount of drop was found to be 2.7% at 2600 rpm as a result of the use of the D20 fuel mixture.

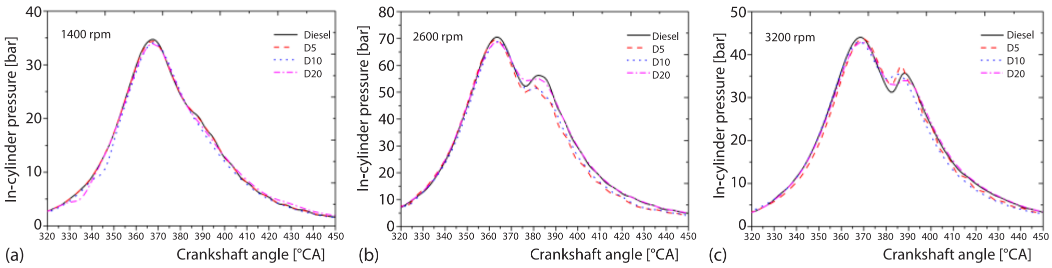

Figure 2. In-cylinder pressure changes in 1400 rpm (a), 2600 rpm (b), and 3200 rpm (c)

Engine performance

The effect of iso-amyl alcohol mixtures on motor torque, fig. 3(a), and motor power, fig. 3(b) is given. In Diesel engines, the engine speed is adjusted by the amount of fuel taken into the cylinder. In Diesel engines, the increase or decrease of engine speed is regulated by the change in the amount of fuel sent into the cylinder [21]. Engine torque is maximized at low engine speeds with a low engine speed of 2600 rpm. With the increase of the engine speed, the engine torque has fallen again. The maximum torque at 2600 rpm indicates an ideal combustion and maximum use of fuel. With the addition of iso-amyl alcohol to diesel fuel, engine torque has decreased at all engine speeds. There are many studies that report that engine torque decreases with the use of low heat-value fuels [22, 23]. With the addition of iso-amyl alcohol, it is evident in fig. 3 that the calorific value decreases by 2.7% compared to diesel fuel and decreases the pressure values in the cylinder. In this case, the engine torque is expected to drop. The same results have been reported in similar studies in [24]. With the addition of iso-amyl alcohol, the highest drop in engine torque was achieved with D20 fuel at 2600 rpm at an engine speed of about 30.4%. A decrease in engine power is observed along with the addition of iso-amyl alcohol to diesel fuel. Engine power increases at low engine speeds when less engine speed increases. The largest amount of decrease was with D20 fuel.

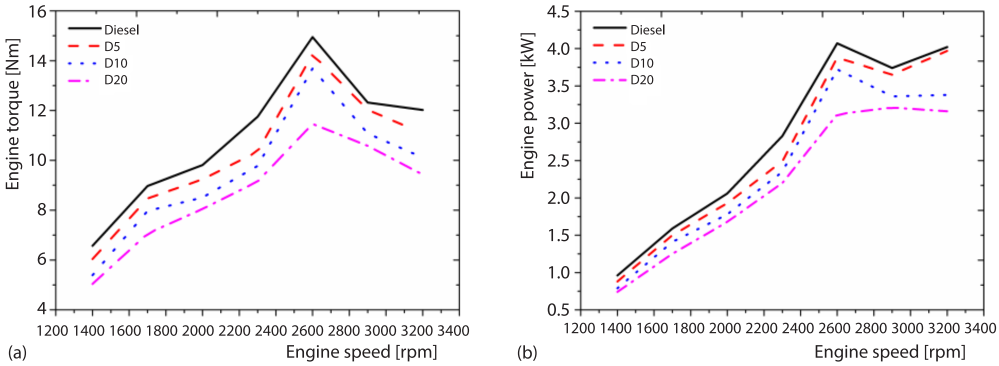

Figure 3. Changing of torque (a) and effective power (b) at various engine speeds for different fuel blends

The chart in fig. 4 shows the effect of iso-amyl alcohols on BSFC. This value represents the amount of fuel that must be spent in order to do one kilowatt per hour of work [25]. The amount of BSFC was found to be somewhat high at low engine speeds (1400 rpm, 1700 rpm, and 2000 rpm). However, with the output of the engine speed 2300 and 2600 rpm decreased towards the minimum values. The engine speed increased again with 2900 rpm and 3200 rpm output. The same conditions were also found with the addition of iso-amyl alcohol. The amount of BSFC increased with the addition of iso-amyl alcohol at all motor speeds. The highest rate of increase was formed by the D20 fuel mixture. This situation is directly related to the reduction of calorific value of the fuel mixture. As it is known, less fuel is required to burn more fuel in order to obtain the same engine power. In this case it increases the amount of BSFC. The highest rate of increase in the amount of BSFC combined with the addition of iso-amyl alcohol was determined by D20 fuel at 2600 rpm engine speed with an increase of about 35%.

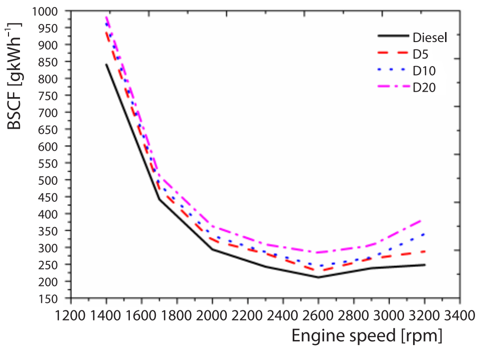

Figure 4. Changing of BSCF at various engine speeds for different fuel blends

Exhaust emission

The graph in fig. 5 shows the effect of iso-amyl alcohols on HC emissions. Hydrogen and carbon are the main components of fuels. The HC emissions are the amount of unburned fuel in the combustion chamber as a result of partial combustion [26]. Speed appears to be effective on HC emissions. At low engine speeds, HC emissions tend to decrease with increased engine speed. The lowest HC emission value was determined at 3200 rpm engine speed. With the addition of iso-amyl alcohol, HC emissions tend to decrease at all engine speeds and fuel mixtures.

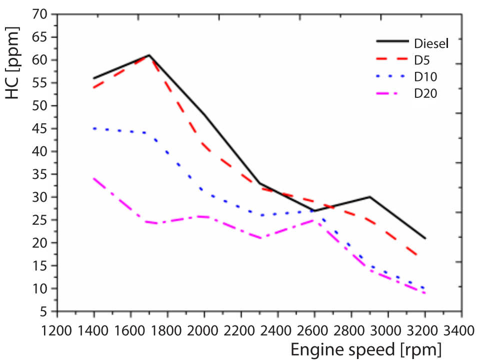

Figure 5. Changing of HC emission at various engine speeds for different fuel blends

It has been mentioned in many studies that the oxygen content of alcohol fuels partially improves combustion and reduces HC emissions [27-29]. Therefore, the oxygen content of iso-amyl alcohol is thought to reduce HC emissions. The lowest HC emission was measured as 9 ppm with D20 fuel at 3200 rpm engine speed. The highest HC emission was found at 1400 rpm with the use of D fuel at 34 ppm.

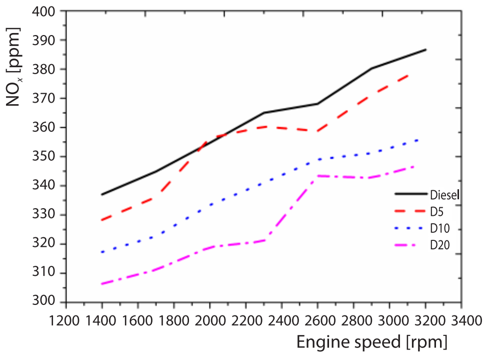

Figure 6. Changing of NO_x emission at various engine speeds for different fuel blends

The graph in fig. 6 shows the effect of iso-amyl alcohols on NO emissions. The factors affecting NO_x emission in Diesel engines are end-of-combustion temperature, reaction temperature, heat dissipation rate, stoichiometric combustion, ignition delay time, residual mixture from previous engine cycles and excess oxygen ratio. The increase in NO_x emission depends on the temperatures in the cylinder, increasing in direct proportion the increase in temperature [29]. The higher the combustion temperature of diesel fuel, the higher the emissions of NO_x than other fuels during all cycles. The amount of NO_x decreases as the rate of iso-amyl alcohol increases. The lower heat value of iso-amyl alcohol [MJkg^{-1}] is lower than that of diesel fuel. Therefore, because iso-amyl alcohol has lower calories and lower burn-end energy, NO_x emissions decrease as the ratio of iso-amyl alcohol increases. The study obtained the lowest NO_x emission value with D20 fuel. The NO_x emissions increase in all fuel mixtures as engine speed increases. This can be explained by the increase in the amount of air and fuel taken into the cylinder. Because as the engine speed increases, the amount of fuel taken into the cylinder increases with the resulting NO_x emission values are also increasing.

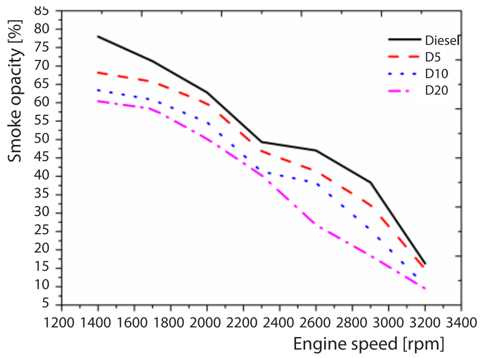

Figure 7. Changing of smoke opacity emission at various engine speeds for different fuel blends

The graph in fig. 7 shows the effect of iso-amyl alcohols on smoke opacity emissions. In Diesel engines, H_2 molecules in the fuel drop, which are liquid in the cylinder, react quickly by merging with oxygen and the remaining C cannot find enough oxygen, cannot burn out as soot particles. Therefore, the main reason for smoke opacity formation is that diesel fuel cannot find enough air in the cylinder, cannot mix with air quickly from time to time, and cannot evaporate [26-29]. Because iso-amyl alcohol has more oxygen content than diesel fuel, it has less smoke opacity than diesel fuel. In addition, because the fuel density decreases with iso-amyl alcohol, it is thought that separating the injected fuel particles into smaller diameters causes the fuel to mix better with the air, thus reducing smoke opacity.

Conclusions

In this study, the effects of iso-amyl alcohol addition on emissions and engine performance in a Diesel engine were examined. For experimental fuels, iso-amyl alcohol is added to diesel fuel by 5%, 10%, and 20% weight. The characteristics of the performance, combustion and emissions of the engine at different engine speeds were analyzed. The analyses were compared with standard diesel fuel and the results were obtained as follows.

- With the addition of amyl alcohol, fuel density decreases. The lowest density value was obtained with D20 fuel. Compared to diesel fuel, D20 fuel was reduced by 1.07%.
- The viscosity value of diesel fuel increases with the addition of iso-amyl alcohol. The highest increase value was seen with a 4.7% increase in D20 fuel.
- In-cylinder pressure measurements; 1400 rpm engine speed (D5 → 0.86%, D10 → 1.75%, D20 → 2.03%), 2600 rpm engine speed (D5 → 1.27%, D10 → 2.27%, D20 → 2.69%), and 3200 rpm engine speed (D5 →%0.68, D10 →%2.5, D20 → %4.31) rates decreased.
- In addition, the D5 fuel; 12.79% reduction in engine power, 8.54% reduction in engine torque, BSFC 16.15% increase was found. Emissions were reduced by 6.51% in HC, 1.75% in NO_x, and 9.68% in smoke opacity.
- The D10 fuel; 15.19% reduction in engine power, 14.86% reduction in engine torque, BSFC 20.33% increase was determined. Emissions were reduced by HC 28.25%, NO_x 7.2%, and smoke opacity 22.45%.
- The D20 fuel; 20.55% reduction in engine power, 25.8% reduction in engine torque, BSFC 24.63% increase was determined. Emissions were reduced by 44.57% HC, 10.81% NO_x, and 36.5% smoke opacity.

As a result of the experimental study, it was determined that iso-amyl alcohol can be used as fuel in Diesel engines. As the ratio of iso-amyl alcohol in diesel fuel increases, there have also been linear reductions in engine performance. However, there have also been significant reductions in HC, NO_x and smoke opacity emissions as the ratio of iso-amyl alcohol in diesel fuel increases.

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