THE EFFECT OF USING ACTIVATED CARBON OBTAINED FROM SEWAGE SLUDGE AS A FUEL ADDITIVE ON ENGINE PERFORMANCE AND EMISSIONS

by

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The increasing need for clean water depending on the world's population has accelerated efforts to re-evaluate the use of water. This has led to the spread of wastewater treatment plants (WWTP). Sewage sludge (SS), which is the waste of WWTP, is increasing due to the increase in the number of plants. As a result, the disposal and evaluation of SS, which is waste, has accelerated. In this study, researches were carried out on different usage areas of SS, which is WWTP waste. The SS was first dried. After the drying process, the SS was subjected to physical and chemical activation processes and turned into activated carbon. Activated carbons were obtained at different operating temperatures. The FT-IR, XRD, ICP-MS, TG-DTA, CHNS, SEM-EDX analyzes were performed for the obtained activated carbons. According to the results of the analysis, the selected activated carbons were mixed with diesel fuel at 50 ppm and 100 ppm ratios. The effects of fuel mixtures prepared with diesel fuel in terms of engine performance, combustion and emissions are investigated. Engine performance and exhaust emission measurements were made in a 6-cylinder Diesel engine at a constant speed of 600 rpm and under five different loads (0 Nm, 50 Nm, 100 Nm, 150 Nm, and 200 Nm). Emission values were measured as CO, HC, CO_2, O_2, and NO_x and comparative assessments were made. In this study, the positive effects of SS-derived activated carbons on the engine were determined by using it as a diesel fuel additive.

Key words: *carbonization, activation, activated carbon, pyrolysis, Diesel engine, emission, sewage sludge*

Introduction

The scarcity of clean water resources in the world necessitates more active and efficient use of drinking and utility water. At the beginning of these works is the treatment of wastewater from the wastewater networks of the cities, in the WWTP. Purified water after wastewater treatment is discharged to the relevant areas within acceptable limits. After the treatment process, a waste called SS comes out from the plant. Different studies are carried

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out to reduce the environmental impact values of these wastes and bring them into the economy [1, 2]. Carbonization of SS by pyrolysis method is at the forefront of the studies. In a study by Gao *et al.* [3] they found that the gas products released because of the pyrolysis process of dried SS at different temperatures showed differences in terms of quantity and quality. In the pyrolysis of SS, it was observed that the amount of gas released increased as the temperature increased [4, 5]. The moisture content of SS is another factor affecting pyrolysis and pyrolysis products [6, 7]. Organic and inorganic substances contained in SS also affect the pyrolysis products [8]. Heavy metals are at the forefront of the inorganic content of SS. The environmental impact values of these heavy metals were investigated and the analyzes of the carbonized solid material obtained by pyrolysis were made [9]. One of the evaluation studies of SS is its conversion into activated carbon by pyrolysis method [10]. Studies on the conversion of SS to activated carbon and the determination of the properties of the obtained activated carbons have gained momentum [11]. Since activated carbons obtained by physical and chemical activation methods are generally a good adsorbent, research and trials have been conducted for their use in different filtration studies. One of the first studies was to investigate the use of activated carbon obtained from SS in water treatment in WWTP [12, 13]. To obtain high quality activated carbon from SS, high temperature chemical activation method is preferred [14, 15]. The pore structures and adsorption abilities were compared using H_2O and CO_2 gases in the process of producing activated carbon by physical activation [16, 17]. Positive results have been obtained from studies on the use of activated carbons obtained from chemical activation with KOH from SS raw material in water treatment and energy storage [18, 19].

So far, we have talked about SS, activated carbon and the methods of obtaining it. The reason for this is that many studies have been made with SS and activated carbon as a result of our literature searches and researches, but studies on the use of activated carbon obtained from SS as a fuel additive have not been reached. In our study, activated carbons obtained from SS by different methods were mixed with diesel fuel in nanoparticle sizes. By using the fuel mixtures prepared in different ratios in a heavy-duty diesel engine, the mixtures were experimentally investigated in terms of engine performance and emissions.

Recently, due to the increase in environmental awareness, studies have accelerated especially in order to increase the efficiency of Diesel engines and reduce their environmental impacts. Due to its large surface area and high heat transfer coefficient, studies are carried out to use metal nanoparticles as diesel fuel additives [20]. Soudagar *et al.* [21] in their study, determined that nanoparticle diesel fuel mixtures increase engine performance and reduce emissions. It has been observed that the proportions of the mixtures made directly affect the performance indicators [22]. Most of the studies have focused on biodiesel fuel because it is a more environmentally friendly fuel [23]. Chandrasekaran *et al.* [24] have studied metal nanoparticle fuel additives to convert crude oil into clean diesel fuel and increase efficiency. When alumina nanoparticle is used as a fuel additive, it has been determined that it has a reducing effect on emission values [25].

Materials and methods

Activated carbons were obtained from SS. The 85% dry SS was obtained from the Avdan Energy of Samsun. The dried SS was first carbonized in the reactor in the Inonu University Chemical Engineering Department Laboratories. Carbonized SS was converted into activated carbon by physical and chemical activation methods. Physical activation was conducted at a reactor temperature of 850 °C and a temperature increase rate of 10 °C per minute in N_2 environment for 1 hour using water vapor. The KOH was used for chemical activation and the process was conducted at 900 °C for 1 hour. The resulting activated carbons were ground into powder. Powdered activated carbons were mixed with diesel fuel at 50 ppm and 100 ppm ratios, and comparisons were made with unmixed diesel fuel. Nanoparticles added to diesel fuel in certain amounts have a direct effect on engine efficiency, combustion characteristics and emission values [20]. The addition of metal nanoparticles to diesel fuels has contributions such as increasing engine efficiency and improving combustion reactions. However, the amount of additives added to the fuel is important [26].

Activated carbon preparation

Activated carbon is a product with many different uses due to its porous structure and superior adsorption ability. Since there is a lot of usage area, the need is also more on the same scale. With the increase in the need for activated carbon, the efforts to produce activated carbon from different raw materials have accelerated [27]. Activated carbon coconut shell, charcoal, sawdust, *etc.* It is produced from biomass [28]. Especially, the surface areas of activated carbons produced by chemical activation are higher [29]. This allows use in different areas [30-32]. Activated carbon, which has many uses, is also used in the automotive industry. Gas adsorption is one of the main uses of activated carbon in the automotive industry. It provides vaporization of the fuel with the heat in the fuel tanks of gasoline engines and eliminates the risk of explosion. Another use is in pollen filters. Activated carbon filters increase the air quality by filtering the air taken into the vehicle.

In this study, physical and chemical activation methods, among the activated carbon preparation methods, were used. The SACK12 and SACK24 were selected among the activated carbons obtained at different temperatures and different temperature rise rates. The SACK12 is produced from raw sludge by chemical activation method with KOH. The SACK24, on the other hand, was produced by physical activation method using H_2O.

Activated carbon analysis

When the elemental analysis results of the activated carbon samples produced by chemical and physical activation methods were examined, the carbon ratio was found to be higher in KOH (W/W 1:3) activation. Low carbon content in physical activation is associated with high ash content. When the surface areas of both samples were examined, a very high value in chemical activation with KOH was obtained. In physical activation, low surface area is an expected result since water vapor interacts with the organic fraction and inorganic components. In the activated carbon sample obtained by KOH activation, iron, titanium, nickel, copper, and zinc, which are structurally difficult to dissolve and remain in the ash composition, remained in the inorganic structure. In the activated carbon sample obtained by physical activation, it is seen that it is rich in phosphorus as the main component (due to the structure of the SS), sodium, calcium, aluminum, magnesium, iron, and potassium components.

Fuel mixture preparation

Studies have shown that many different products can be used as fuels and fuel additives. It has been determined that the use of multi-layered carbon nanotubes and alumina nano additives as diesel fuel additives both increases fuel combustion efficiency and reduces emission values [33]. Studies show that activated carbon is mostly used for desulfurization in vehicles [34]. The sulfur in the diesel fuel turns into sulfur oxide compounds because of combustion. These compounds have harmful effects on the environment. For this reason, there are different desulfurization methods [35]. It has been demonstrated by experimental studies that the pore structure of activated carbon is important in desulfurization processes from diesel fuel. It has been determined that micropores increase the sulfur adsorbent ability, while mesopores tend to hold other components of the fuel [36-38]. Filtering studies were also carried out by impregnating different chemicals with activated carbon [39-42]. When activated carbon is used as a fuel additive, its contribution to engine fuel consumption and emission values has been examined. The SACK12 and SACK24 activated carbons were added to diesel fuel at 50 ppm and 100 ppm ratios. Fuel and activated carbons were mixed homogeneously by means of an ultrasonic mixer. The mixtures were prepared in a Bandelin brand sonopuls model 20 kHz uniform wavelength ultrasonic homogenizer. Each mixture was mixed in the homogenizer for 45 minutes at 85% capacity.

Experimental set-up

The study was conducted at Erciyes University Engines Laboratory. Experiments were conducted in an experimental set-up with a six-cylinder, water-cooled Diesel engine connected to a temperature sensor, pressure sensor, dynamometer, and emission measuring devices. Engine technical specifacations is 2300 rpm, 814 torque, 169 kW maximum power, 6 cylinders, 11670 cc. Cylinder pressure, temperature, exhaust emissions, fuel consumption data were obtained with the experimental set-up. The hydraulic dynamometer uses the NF150 model dynamometer, which can measure 0-6500 rpm engine speed and 0-450 Nm torque.

Emission measurements

Exhaust emission measurement was made with Bosch brand BEA60 model device. The emission device is dying of excess air coefficient, HC, CO, CO_2, NO_x, and O_2, emissions.

Combustion parameters

Cylinder pressure

One of the methods used to analyze the combustion occurring in the cylinder is the in-cylinder pressure variation graphs. The pressure changes graphs, which are usually measured by piezoelectric pressure sensors and drawn according to the crankshaft angle (CA), provide information about many parameters such as fuel ignition delay, combustion speed, peak pressure value and angle. Pressure changes at maximum load of fuels with 50 ppm and 100 ppm nanoparticle concentrations and pure diesel fuel used in the experiments *e. g.* Figure 1 has also been given. Figure 2 shows the peak pressures at all loads. In the graphs, it is seen that the fuel injection starts at the TDC and combustion starts after approximately 2 KMA ignition delays for all fuels. Peak pressure was measured at 41.3 bar for diesel fuel, 42 bar for CA50 and 42.4 bar for PA50. The highest peak pressure is 42.6 bar for PA100. Fuel mixtures with nanoparticles provided a slight increase in peak pressures compared to diesel. While the angles of formation of the peak pressures were measured for diesel, CA50 and PA50 fuels, bTDC 7 CAD was measured, while TDC was 6 CAD for CA100 and bTDC was 8 CAD measured for PA100. According to these results, it can be said that nanoparticles slightly increase the combustion quality of diesel.

Exhaust gas temperature

Since the temperature of the exhaust gases expelled in internal combustion engines is strongly dependent on the combustion state, the exhaust gas temperature graphs are also

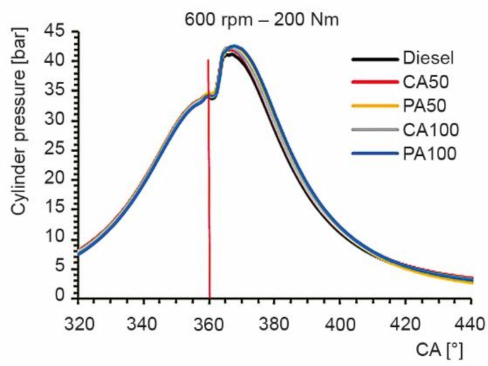

Figure 1. Variation of cylinder pressure with CA of fuel blends

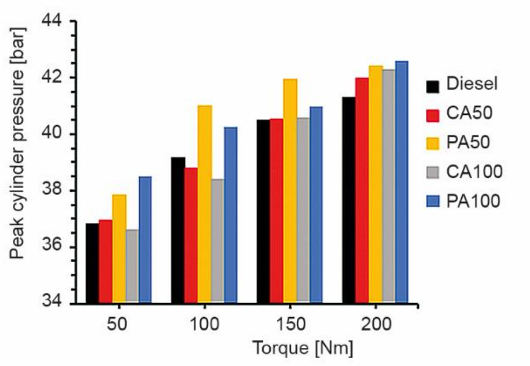

Figure 2. Variation of peak cylinder pressure with engine load of fuel blends

important in terms of supporting the interpretations made in the combustion analysis. For this reason, it would be appropriate to evaluate it together with the cylinder pressure. The variation of exhaust gas temperatures according to engine load for all fuels used is given in *e.g.* fig. 3. The temperature of the exhaust gases is measured at the exhaust manifold outlet. According to the measurement results, while the temperature for CA50, CA100, and PA100 fuels was higher than diesel fuel at partial loads, it was observed that the temperature was lower for PA50 fuel at all loads.

Brake thermal efficiency

Thermal efficiency is the ratio of the power taken from the engine crank to the power of the fuel used in the engine. Figure 4 shows the brake thermal efficiencies (BTE) obtained for pure diesel fuel and 50-100 ppm nanoparticle mixtures at 600 rpm constant engine speed and different load values (0 Nm, 50 Nm, 100 Nm, 150 Nm, 200 Nm). In these graphs, it is observed that PA50 and PA100 mixtures produced by physical activation cause a decrease in the thermal efficiency of diesel fuel at low loads (50 Nm and 100 Nm), while it tends to increase at high loads. The mixtures of CA50 and CA100 with activated carbon obtained by chemical activation have better thermal efficiency especially at low loads. It is known that as the load increases in internal combustion engines, the in-cylinder temperature rises. In this

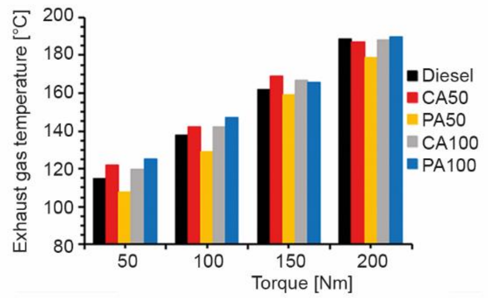

Figure 3. Variation of exhaust gas temperature with engine load of fuel blends

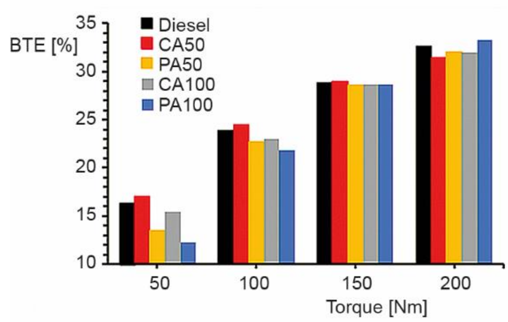

Figure 4. Variation of BTE with engine load of fuel blends

case, it can be concluded that nanoparticles obtained by physical activation in the fuel increase the reactivity of diesel fuel at high temperatures. On the other hand, it is possible for the physical activation nanoparticle, which has a very high amount of basic components (Na_2O, K_2O, MgO, CaO, *etc.*) compared to the chemical activation nanoparticle, to increase the thermal efficiency by converting the aliphatic hydrocarbons that make up the diesel fuel into smaller units with the effect of increasing in-cylinder temperature.

Emissions

The rapid increase in the number of vehicles in our country and in the world and the increasing number of vehicles predominantly using petroleum-derived fuels have caused environmental problems. Due to the increase in land and sea transportation and the effects of the emission values of diesel fuel vehicles used in this sector on the environment, many studies are carried out to reduce the emission values [43, 44]. Studies have focused on examining the parameters (coolant temperature, engine speed, *etc.*) affecting the engine and fuel additives in order to reduce the emission value [45, 46]. In this study, the use of activated carbon obtained from AC as a diesel fuel additive and the effects of fuel mixtures on CO, CO_2, HC, NO_x emissions in Diesel engines were investigated.

The CO emission

Figure 5 shows the variation of CO emissions according to engine load. In addition to being a very toxic gas for living life, CO emission is a fuel with a calorific value of 10.112 kJ/kg [47]. Usually, HC are produced as a result of burning fuel with insufficient air. Since Diesel engines always work with excess air, CO emissions are very low. However, there is some CO emission in the exhaust gases due to the very short time allocated for combustion, the very poor and rich regions formed in the cylinder, and many other reasons. Due to the low in-cylinder temperature at 50 Nm load, CO emissions were high in all fuels. On the other hand, the addition of nanoparticles to diesel increased CO emissions at 50 Nm load for all fuel mixtures. While the lowest CO emission was obtained with PA50 at 100 Nm, 150 Nm, and 200 Nm loads, the highest CO emission was measured in CA100 fuel at all loads.

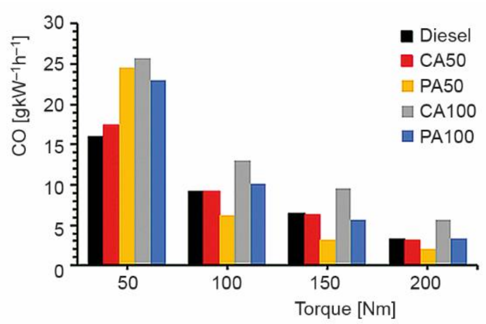

Figure 5. Variation of CO emission with engine load of fuel blends

The CO_2 emission

The graph of change of CO_2 emission, which is the product of complete combustion of HC fuels, according to engine load is given in *e.g.* fig. 6. Although CO_2 gas is not directly harmful to the environment, it is not desirable because it increases global warming since it is in the GHG class. The most effective way to reduce CO_2 emissions in Diesel engines is to increase thermal efficiency. The low thermal efficiency of PA50 and PA100 fuels at 50 Nm load compared to other fuels increased CO_2 emissions. The CO_2 emissions measured in other experiments are close to each other. According to the measurements obtained from the experiments, the addition of carbon nanoparticles to the diesel fuel did not affect the CO_2 emissions.

The HC emission

The HC emissions are harmful emissions that form photochemical fog by reacting with atmospheric gases, especially produced as a result of incomplete combustion. Figure 7 shows the variation of HC emissions of the fuels used in the experiments carried out according to the load. It is seen in the graph that the lowest HC emission values were obtained in experiments using PA50 and PA100 fuel mixtures at all operating loads except 50 Nm load. It is observed that the HC emission values measured in the CA50 fuel mixture increase for all operating conditions when the nanoparticle concentration in the mixture is increased to 100 ppm. This shows how important the particle concentration in fuel mixtures is, depending on the composition of the nanoparticle used. Because nanoparticles change many physical properties of the fuel they are mixed with, such as density, viscosity and flash point, as well as affect the chemical reactions that occur during combustion.

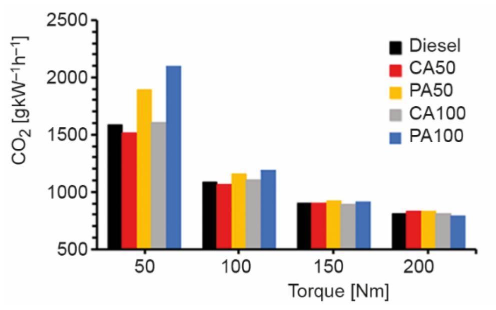

Figure 6. Variation of CO_2 emission with engine load of fuel blends

The NO_x emission

The NO_x emissions are formed when the neutral nitrogen molecule reacts with oxygen gas at high temperatures. Most of the NO_x emissions in Diesel engines are NO [44]. Figure 8 It shows the change of NO emission according to engine load. As the engine load increases, the NO emission will naturally increase as the in-cylinder temperatures will increase. The CA50 and PA50 generate lower NO emissions than diesel fuel at all loads. While CA100 and PA100 increase NO emission especially at 50 Nm load, they generate lower NO emissions than diesel fuel under other operating conditions. The lower levels of NO emission in fuel mixtures may be since nanoparticles provide a more homogeneous temperature distribution in the cylinder.

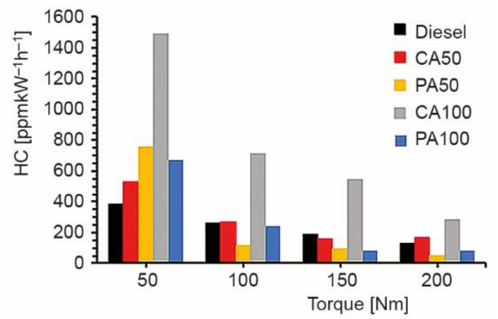

Figure 7. Variation of HC emission with engine load of fuel blends

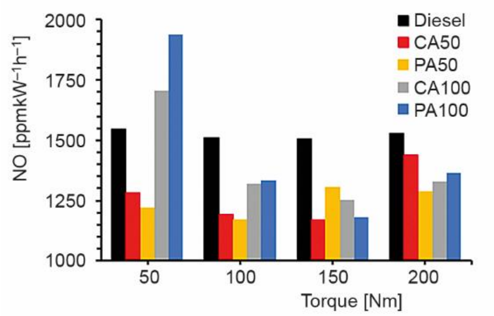

Figure 8. Variation of NO emission with engine load of fuel blends

Conclusions

In this article, the effects of the addition of activated carbon nanoparticles obtained from SS by chemical and physical production methods to diesel fuel on the performance and emissions of a Diesel engine were investigated experimentally. The results obtained from the experiments are summarized below. It was observed that the peak pressures obtained in PA50 and PA100 fuel mixtures were higher than other fuels at all loads. The lowest exhaust temperature at all loads was also measured in PA50 fuel. The CA50 fuel mixture increased the thermal efficiency of diesel at low loads but decreased it slightly at full load. The importance of the concentration of nanoparticles in the fuel obtained by chemical activation is clearly observed in CO and HC emissions. The CO and HC emissions measured for the CA50 fuel mixture increased for all load conditions in the CA100 fuel mixture. Nanoparticles mixed with diesel fuel generally reduce NO emissions under all operating conditions. When the test results were evaluated in general, it was observed that 50 ppm mixtures of carbon nanoparticles produced by chemical and physical activation method reduced exhaust emissions.

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