Isı Bilimi ve Tekniği Dergisi, 39, 2, 51-58, 2019
J. of Thermal Science and Technology

ISSN 1300-3615

ATIK POLİETİLEN PİROLİZİNİN DİZEL MOTOR ve EMİSYON PARAMETRELERİNE ETKİSİNİN İNCELENMESİ

İbrahim BİLİCİ*, Metin Gürü ve Ali KESKİN *****
*Engineering Faculty, Chemical Engineering Dep., Hitit University, Çorum, ibrahimbilici@hitit.edu.tr
**Engineering Faculty, Chemical Engineering Dep., Gazi University, Ankara, Turkey, mguru@gazi.edu.tr
***Tarsus Technical Education Faculty, Automotive Division,
Mersin University, Mersin, Turkey, akeskin@cu.edu.tr

(Geliş Tarihi: 28.06.2018, Kabul Tarihi: 11.02.2019)

Özet: Plastik malzemelerin kullanılmasının artışıyla birlikte Polietilen (PE) nin de kullanımı da bütün dünyada artmıştır. Bu yüksek miktardaki PE doğal bozulmama özelliğinden dolayı çevresel problemleri de beraberinde getirmektedir. Fakat bu PE sıvı yakıtlara dönüştürülebildiği için çevresel ve ekonomik olarak fayda sağlayabilir. Bu deneysel çalışmada PE dizel yakıt katkısına dönüştürülerek polimer bazlı yakıtların dizel motorlarda eksoz emisyonu ve performans paramatereleri incelenmiştir. PE atıklar termal piroliz yöntemiyle yakıta dönüştürülmüştür. PE atık katkılı yakıt %5, %10 ve %20 oranlarında dizel yakıt ile karıştırılarak herhangi bir modifikasyon gerçekleştrilmeden test edilmiştir. Genel olarak motor performans ve eksoz emisyon değerleri dizel yakıtlar ile benzer özellikler göstermiştir. Spesifik yakıt tüketimi (SFC) değeri PE oranının artmasıyla hafif düzeyde artış göstermiştir. Karbonmonoksit (CO) ve azot oksit (NOx) değerleri de dizel yakıt ile karşılaştırıldığında artma eğilimi göstermiştir.
Anahtar Kelimeler: Polietilen atık, Geri dönüşüm, Termal piroliz, Alternatif yakıt, Dizel motor, Emisyon

INVESTIGATION OF PYROLYSIS OF WASTE POLYETHYLENE (PE) AND EFFECTS ON DIESEL ENGINE AND EMISSION PARAMETERS

Abstract: With the increment of usage of plastic materials, the use of polyethylene (PE) all over the world is also increasing. The great amount of PE usage results in a huge amount of PE waste. These huge amounts of PE wastes are generating environmental problems due to their non-degradable properties. But, PE wastes can be converted into liquid fuels for both economic and environmental benefits. In this experimental study, the conversion of PE wastes into diesel fuel and influence of the polymer-based fuels on the performance and exhaust emission of diesel engine was investigated. The conversion of PE wastes was carried out by utilizing the thermal pyrolysis process. The blends of the PE waste based fuel with diesel fuel were tested with three different ratios (5%, 10%, and 20%) in an unmodified direct injection diesel engine at full load condition. In general, engine performance and exhaust emission values of the blend fuels were similar to that of diesel fuel. Specific fuel consumption (SFC) values of the blend fuels slightly increased depending on the ratio of PE based fuel in the test fuels. The carbon monoxide (CO) and oxides of nitrogen (NO)x emissions of the blended fuels values showed an increasing trend as compared to the values of diesel fuel
Keywords: Polyethylene waste, Recycle, Thermal pyrolysis, Alternative fuel, Diesel engine, Emission

NOMENCLATURE

Kd Power correction coefficient for diesel engine
Pa Atmospheric pressure of the laboratory [kPa]
Pst Atmospheric pressure accepted as standard [101,325 kPa]
Ta Atmospheric tempreture of the laboratory [K]
Tst Standard ambient temperature [273,15+25 oC=298,15 K]

INTRODUCTION

Due to the environmental concerns, international attention has been drawn on the research of alternative energy sources to compensate the depletion of fossil fuels (Horvat et al., 1999; Keskin et al., 2008; Guru et al., 2009). A great deal of research has been conducted on alternative fuel from waste materials. One of them is the production of alternative liquid fuels from the polyethylene wastes for internal combustion engines (Prakash et al., 2013;Panda et al., 2012; Mohammedi et al., 2013;Kumar et al., 2013;Jan et al., 2010;Akpanudoh et al., 2005;Gulab et al., 2010).

The production of plastics in the world has been increasing, and this has been dependent on economic growth, changing consumption, and production patterns. The production of plastics has increased by an average of almost 10% every year since the 1950. Nowadays, it is known that about 300 million tons waste is generated per year and polyethylene was found to have the highest share of production of any polymer type, which is about 29.1% of them. These plastics are widely used in the productions of many important daily applications, such as clothing, house holding, automotive components, and etc.. (Kim et al., 2002;Al Salem et al., 2009). As a result, the growing production of polymer-based materials had increased the waste streams (Kanterelis et al., 2009; Panda et al., 2010; Gobin et al., 2004). The huge amount of waste polymer-based materials are causing more and more environmental problems worldwide due to non-biodegradable and extremely troublesome components for landfilling (Miskolczi et al., 2004; Siddiqui et al., 2009; Meng et al., 2015). The problem of waste plastics can be solved with the conversion of the waste polymer-based materials into liquid fuels with different uses (Huang et al., 2010; Ali et al., 2011; Meng et al., 2015).

In general, pyrolysis processes areused to convertwaste plastics as a tertiary recycling (Lin et al., 2008; Breyer et al., 2016). It is classified into low, medium, and high temperatures. Low-temperature processes generally produce liquid products and high-temperature processes produce gaseous products. The properties of the products obtained from pyrolysis processes depend on the type of plastic, feeding arrangement, residence time, temperature, reactor type, condensation arrangement, and the catalysts used (Walendziewski, 2002; Puente et al., 2002; Elordi et al., 2009; Coelho et al., 2012;Elordi et al., 2012; Bockhorn et al., 1999; Ceamanos et al., 2002; Huang et al 2010;Elordi et al., 2007; Arabiourritia et al., 2012; Gonzales et al., 2011). Biodiesel and its additives are also one of the overemphasized research objects. Due to being an alternative fuel for diesel engines, wide variety of biological waste and vegetable could be evaluated as a biodiesel or additives (Can, 2014; Oliveira et al., 2010; Al dawody et al., 2014; Luu et al., 2014; İlkılıç et al., 2015; Rashedul et al., 2015).
The purpose of this study was to investigate the influence of the polymer-based fuel (P)-diesel fuel (D) blends on the diesel engine performance and exhaust emissions. The ratio of PE waste-based additive in the test blend was selected as main parameter. Thermal pyrolysis process was used to convert the waste polymers to PE waste based fuel. Blends of the PE based fuel and diesel fuel were tested at full load condition of the test engine.

MATERIALS AND METHOD

The study consisted of two phases. Firstly, polyethylene-based alternative fuel was produced, and secondly, the engine performance and exhaust emission tests were carried out.

Production of polymer-based fuel

The mixture of PE waste polymer used in this study was obtained from a post-consumer plastic waste stream in the Ankara Municipality. It was characterized by using Mettler – Toledo / DSC 1 / 700 within 10 C°/min Differential scanning calorimetry (DSC) and Thermo Scientific / Nicolet IS1 Fourier transform infrared spectroscopy (FTIR) . In addition, collected and purged PE was cut by a shredder into small pieces the size of a flake under a 10 mm sieve. The pyrolysis was carried out a ceramic core (50 mm inside diameter, 350 mm height) that housed a removable quartz reactor whose inner diameter and volume were 35 mm and 250 cm3, respectively. A waste polyethylene and reactor were heated slightly to 400 °C and held at this temperature for a period of 60 minutes. Due to the exothermic reaction, the temperature in the reactor reached up to 500 °C and was stabilized at atmospheric conditions, and, in this process, the products were cooled and collected. The schematic diagram of thermal pyrolysis system is illustrated in Fig. 1.

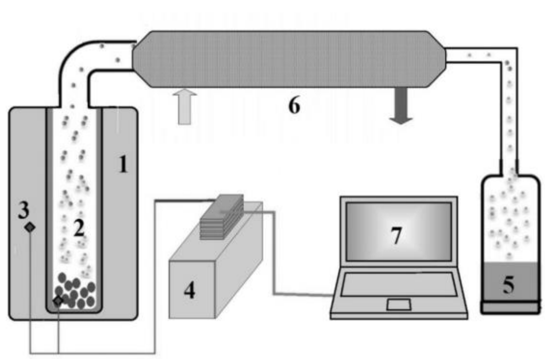

Figure 1. Schematic diagram of the thermal pyrolysis system (1. Ceramic core, 2. Reactor, 3. Thermocouple, 4. PID Control device, 5. Liquid product, 6. Condenser, 7. Computer).

Test Engine and Other Equipment

As shown in Fig. 2. the engine test system consists of nine pieces of equipment. The engine performance and emission tests were performed on a single-cylinder, direct-injection Antor 4LD 640 compression ignition (diesel) engine.

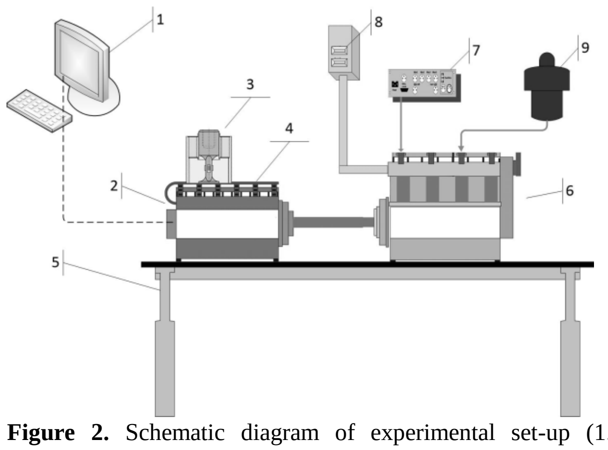

Figure 2. Schematic diagram of experimental set-up (1. Control panel, 2. Hydraulic dynamometer, 3. S-type load cell, 4. Magnetic pick-up, 5. Platform, 6. Test engine, 7. Smoke meter, 8. Fuel tank, 9. Diesel emission analyzer)

Table 1. Technical specifications of the test engine

Items	Specification
Manufacturer/type	Antor Diesel 4 LD 640
Cylinders number	1
Swept volume (cc)	638
Bore (mm)	95
Stroke (mm)	90
Compression ratio	17:1
Maximum speed (rpm)	3000
Maximum power (kW)	9.694
Maximum brake torque (Nm at 1800 rpm)	43
Cooling system	Air-cooled

The basic specifications of the test engine were given in Table 1. The test fuels were tested at the full load condition of the engine between the engine speeds of 1200 and 3000 rpm. Before conducting the tests, the engine was run to reach a normal working temperature. Each sample was tested three times, and the average of values was calculated.A hydraulic dynamometer was used for the determination of torque and power output. Technical specifications of the hydraulic dynamometer was given in Table 2.

Table 2. Technical specifications of hydraulic dynamometer

Items	**Specification**
Maximum torque	1000 Nm
Maximum speed	7500 rpm
Capacity of load cell	2500 N
Length of torque rod	350 mm
Trunk diameter	350 mm
Total weight	110 N

The test of smoke emission was carried out by measuring the opacity of the exhaust gasses with CAP 3200. The accuracy of the CAP 3200 device is 0.01 m-1 for k factor and measurement capacity is 0–10 m-1. Gas analyzer (Testo 350-S) was used to measure CO and NOx. The measurement accuracy of the Testo 350-S is 1 ppm for CO and 1 ppm for NOx. Measurement capacity of the device is 0–10,000 ppm for CO and 0–3,000 ppm for NOx. The experimental uncertainties are given in Table 3.

Correction coefficient was used in order to determine effects of atmospheric pressure and tempreture on power, torque and specific fuel consumption valuese. Power correction coefficient was calculated with Equation 1 (Çetinkaya et al., 2014).

$$k_d = \left(\frac{Pst}{Pa}\right)^{0.65} \cdot \left(\frac{Ta}{Tst}\right)^{0.5} \quad \text{Equation 1.}$$

Table 3. Uncertainties of measurements

Measurements	Unit	Uncertainty ±%
Torque	Nm	0.29
Power	kW	0.32
BSFC	g/kWh	0.97
Engine speed	rpm	0.13
NOx	ppm	2.76
CO	ppm	2.36
HC	ppm	1.93
Smoke	m-1	2.27

Three different blends of polymer-based fuels (P) and diesel fuels (D) were evaluated as an alternative to diesel fuel. These fuels are 5% P/95% D, 10% P/90% D, and 20% P/80% D, which are called P5, P10, and P20, respectively. Test fuels were mixed based on volume.

RESULTS AND DISCUSSION

Characterization Of Collected Polyethylene

Polyethylene could be classified as high or low density polyethylene according to polymerization from 0.92 to 0.96 g/cm3 (Hitachi 2017) . In Fig. 3., it is clear that collected and pyrolyzed polyethylene is high density polyethylene (HDPE).

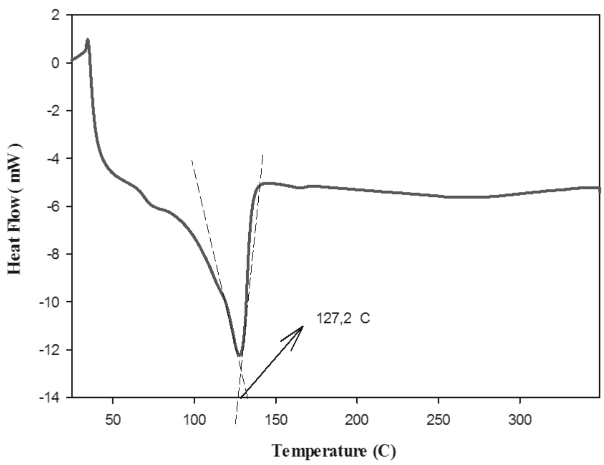

Figure 3.. DSC Thermogram of collected PE

Fig. 4. reveals that characteristic absorption peaks are around 3000 cm-1, 1500 cm-1 and between 700 and 750 cm-1 as an HDPE (Wang et al., 2016; Mehmood et al., 2016).

Cooled and collected pyrolysis products were not dissociated in this study, because in this study the main aim was to investigate the performance and emission characteristics of PE based fuel-diesel fuel blends. Additionally, a large number of study has been done about the pyrolysis product types of polyethylene mixtures and its modeling in the literature reviews (Levine et al., 2009; Kannan et al., 2014; Wang et al., 2013; Liu et al 2014; Santella et al., 2016).

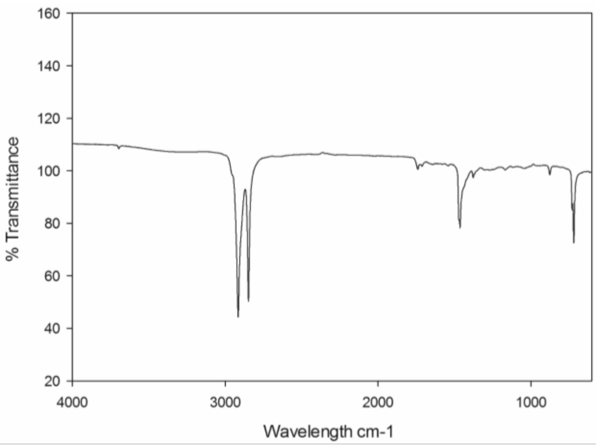

Figure 4. FTIR spectrum of collected PE

Results of Dynamometer

The fuel properties of the test fuels are shown in Table 4. In general, the fuel properties of blended fuels were close to that of diesel fuel. The heating value of the blended fuel was slightly lower than that of diesel fuel because of higher carbon content. In addition, the flash point of the blended fuel was lower than the diesel fuel. The test results concluded that the flash point value is not directly related to engine performance and exhaust emissions. Furthermore, the flash point value is used to determine fire risk during normal storage and handling.

Table 4. Chemical and physical properties of test fuels

	P5	P10	P20	D
Density at 15 ºC (kg/m³)	0,828	0,827	0,8235	0.830
Viscosity at 40ºC (SAYBOLT)	2.51	2.55	2.58	2.51
Calorific value (kJ/kg)	42307.14	41841.31	41033,82	42824,63
Cetane number	56,887	57,021	57,187	56,824
Sulphur content (wt%)	0.0826	0.0825	0.0826	0.0827
Flash Point (ºC)	38	35.5	35,5	62
Cloud point (ºC)	-20	-20	-21	-20
Water content (mg/kg)	84	88	88	85
Copper strip corrosion (3 h, 50 ºC)	1	1	1	1

The variations of torque and power values are shown in Fig. 5. and Fig. 6. The characteristics of the torque and power curve did not change significantly with the PE waste based fuel blended fuels. In general, both the torque and power values of the blended fuels were similar to the diesel fuel. The results may be result of the similar fuel properties of the test fuels. In comparison with the diesel fuel, the torque and power values of the P20 slightly increased between 1400 and 2800rpm. The average of the increment was 1.98% with the P20. The maximum reduction and increment ratio was 4.11% with P10 at 3000 rpm and 4.39% with the P20 at 2800 rpm respectively. Decrease in engine power and torque value may be caused from higher viscosity, lower calorific values and density of blend fuels

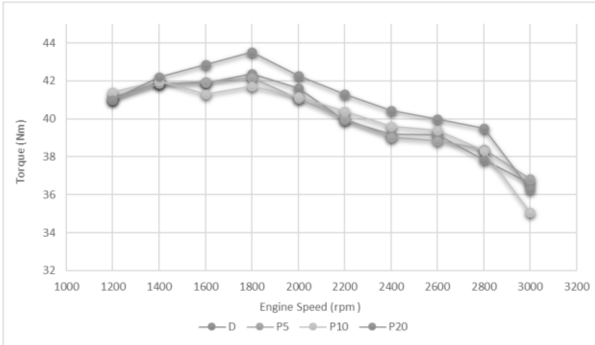

Figure 5. Torque values at full load condition

The maximum torque values for all test fuels were measured at 1800 rpm. The maximum power values for both D and P5 were measured at 3000 rpm. However, the maximum power values for both P10 and P20 were measured at 2800 rpm.

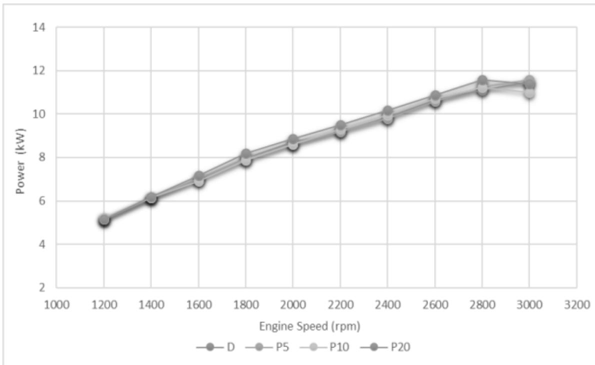

Figure 6. Power values at full load condition

The SFC values of the test fuel are given in Fig. 7. The SFC values of each of the blended fuels increased slightly when compared with the diesel fuel values. The increasing maximum ratios of the P5, the P10, and the P20 were 4.93% with the P5 at 2400 1/m and 6.44%, the P10 at 2400 1/m and 4.70%, and the P20 at 1200 1/m. The higher SFC values were measured with both the P10 and the P20 at all engine speeds. The average rates of increase in SFC values with both the P10 and the P20 were 2.51% and 1.80%, respectively. At both low and high engine speeds, the lower SFC values were measured with the P5 when compared with D. The maximum reduction ratio was 6.29% with the P5 at 3000 rpm. The increase in SFC with the blend fuels may be caused by the lower heating values of the blend fuels that lead to higher fuel consumption which decrease SFC values of diesel engine.

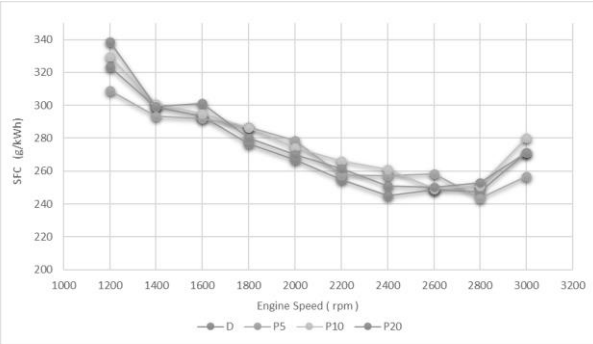

Figure 7.SFC values at full load condition.

As seen in Fig. 8., in comparison with diesel fuel, the CO emission showed a trend of increasing with both the P10 and the P20. The results may be caused by the higher viscosity, lower density and different volatility properties of the polymer-based fuel. Injection and combustion characteristic of the test engine may be changed depending on the different fuel properties. The CO emissions for both the P10 and the P20 increased up to 64.97% at 2400 rpm, and 82.08% at 2600 rpm, respectively. The average of the increment in CO emissions with the P10 and the P20 were 18.17% and 28.77%, respectively. The increment ratios of all blended fuels were lower at higher engine speeds. As can be seen in Fig. 8., the lower CO emissions were measured with P5 at low engine speeds. The maximum reduction ratio was 11.21% at 1400/m with the P5. These results are similar to a study done by pristine study (Mani et al., 2009).

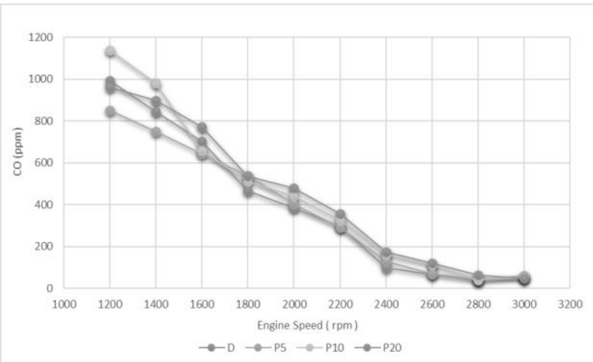

Figure 8. CO emission values at full load condition.

The variation of the NOx emission is shown in Fig. 9. The NOx emissions changed depending on the in-cylinder temperature and the availability of oxygen and combustion time. In general, the NOx emissions showed a trend of increment with the usage of blend fuels. These results may be caused from regional temperature increases in the combustion chamber because of different fuel properties of blend fuels such as viscosity, calorific values and density. In comparison with D, the higher NOx emissions values were measured between 1200 and 2600 rpm with the all blend fuels. The maximum ratio of the increment of the blend fuels were 15.76% with the P5 at 2400 rpm, 28.3% with the P10 at 2200 rpm, and 10.36% with the P10 at 1200 rpm. The maximum reduction of the NOx emission was observed as 18.2% with the P20 usage at 2800 rpm. In addition, the NOx emission values of both D and the P20 were similar between 1600 and 3000 rpm. Similar results were also obtained by other researchers [48].

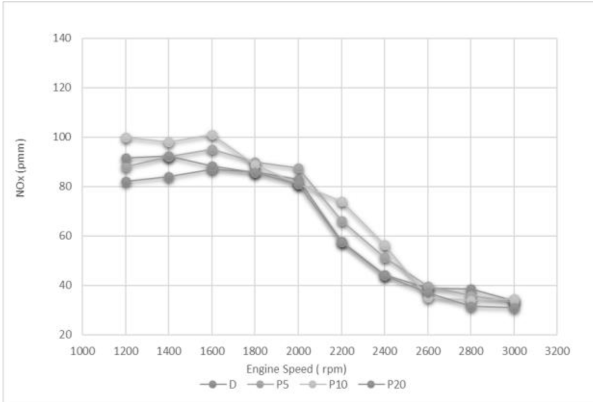

Figure 9. NOx emission values at full load condition.

The opacity of the exhaust gas that was measured is in fact an indication of the particulate matter (PM), or smoke emission. The smoke opacity values of the test fuels are shown in Fig. 10. The smoke opacity values of the P5 were similar to that of D. The smoke opacity values with the P10 showed a decreasing trend in general. The lower smoke opacity values were measured to be between 1200 and 2400 rpm with the P10. The maximum decrement ratios was 13.45% with the P10 usage at 1800 rpm. The higher smoke opacity values were usually obtained with the P20, in comparison with the D. The maximum incerement ratio was 18.2% with P20 at 2600 rpm.

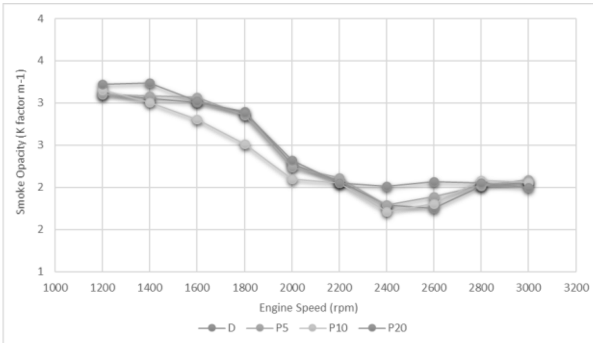

Figure 10. Smoke opacity values at full load condition.

CONCLUSION

The following results are concluded from the experimental study:

• In general, the blended fuels had similar fuel properties to the diesel fuel according to experimental results. However, the flash point of the blended fuels was lower than the value of the diesel fuel. The low flash point of the blended fuels increases the risk of fire during both storage and handling procedures. Further investigation needs to solve the issue with different additives or treatments.

• The characteristics of the torque and power curves of the blended fuels did not change significantly. In general, the torque and power values of the blended fuels were similar to that of the diesel fuel.
• The specific fuel consumption values slightly increased with the blended fuels in comparison with the diesel fuel values. This is because of the lower heating value of blended fuels.
• In general, both the CO and NOx emissions showed a trend of increment with the usage of blended fuels. In comparison with diesel fuel, both the CO and NOx emissions of the blended fuels increased up to 82.08% and 28.30%, respectively.
• According to the experimental study, the blended fuels, especially P5 and P10, can be used as alternative fuels within conventional diesel engines without any major modificaions by considering the CO and NOx emissions.

REFERENCES

Akpanudoh, N.S., Gobin, K., Manos, G., 2005, Catalytic degradation of plastic waste to liquid fuel over commercial cracking catalysts - Effect of polymer to catalyst ratio/acidity content, *Journal of Molecular Catalysis a-Chemical*, 235(1-2), 67-73.

Al Dawody, M.F., Bhatti, S.K.,2014, Experimental and Computational Investigations for Combustion, Performance and Emission Parameters of a Diesel Engine Fueled with Soybean Biodiesel-Diesel Blends. In: Othong, S., Waewsak, J. (eds.) 2013 International Conference on Alternative Energy in Developing Countries and Emerging Economies, *Energy Procedia*, 52,421-430.

Ali, M.F., Ahmed, S., Qureshi, M.S., 2011, Catalytic coprocessing of coal and petroleum residues with waste plastics to produce transportation fuels, *Fuel Processing Technology*, 92(5), 1109-1120.

Al-Salem, S.M., Lettieri, P., Baeyens, J., 2009, Recycling and recovery routes of plastic solid waste (PSW): A review, *Waste Management*, 29(10), 2625-2643.

Arabiourrutia, M., Elordi, G., Lopez, G., Borsella, E., Bilbao, J., Olazar, M., 2012, Characterization of the waxes obtained by the pyrolysis of polyolefin plastics in a conical spouted bed reactor, *Journal of Analytical and Applied Pyrolysis*, 94, 230-237.

Bockhorn, H., Hornung, A., Hornung, U., Schwaller, D., 1999, Kinetic study on the thermal degradation of polypropylene and polyethylene, *Journal of Analytical and Applied Pyrolysis*, 48(2), 93-109.

Breyer, S., Mekhitarian, L., Rimez, B., Haut, B., 2017, Production of an alternative fuel by the co-pyrolysis of landfill recovered plastic wastes and used lubrication oils, *Waste Management*, 60, 363-374.

Can, O., 2014, Combustion characteristics, performance and exhaust emissions of a diesel engine fueled with a waste cooking oil biodiesel mixture, *Energy Conversion and Management*, 87, 676-686.

Ceamanos, J., Mastral, J.F., Millera, A., Aldea, M.E., 2002, Kinetics of pyrolysis of high density polyethylene. Comparison of isothermal and dynamic experiments, *Journal of Analytical and Applied Pyrolysis*, 65(2), 93-110.

Çetinkaya, S., Salman S., 2014, *Motor ve Taşıt Test Tekniği Ders Notları*, Gazi Üniversitesi, Sayfa 81.

Coelho, A., Costa, L., Marques, M.M., Fonseca, I.M., Lemos, M., Lemos, F., 2012, The effect of ZSM-5 zeolite acidity on the catalytic degradation of high-density polyethylene using simultaneous DSC/TG analysis, *Applied Catalysis a-General*, 413, 183-191.

Elordi, G., Lopez, G., Olazar, M., Aguado, R., Bilbao, J., Product distribution modelling in the thermal pyrolysis of high density polyethylene, *Journal of Hazardous Materials*, 144(3), 708-714.

Elordi, G., Olazar, M., Castano, P., Artetxe, M., Bilbao, J., 2012, Polyethylene Cracking on a Spent FCC Catalyst in a Conical Spouted Bed, *Industrial & Engineering Chemistry Research*, 51(43), 14008-14017.

Elordi, G., Olazar, M., Lopez, G., Amutio, M., Artetxe, M., Aguado, R., Bilbao, J., 2009, Catalytic pyrolysis of HDPE in continuous mode over zeolite catalysts in a conical spouted bed reactor, *Journal of Analytical and Applied Pyrolysis*, 85(1–2), 345-351.

Gobin, K., Manos, G., 2004, Polymer degradation to fuels over microporous catalysts as a novel tertiary plastic recycling method, *Polymer Degradation and Stability*, 83(2), 267-279.

Gonzalez, Y.S., Costa, C., Marquez, M.C., Ramos, P., 2011, Thermal and catalytic degradation of polyethylene wastes in the presence of silica gel, 5A molecular sieve and activated carbon, *Journal of Hazardous Materials*, 187(1-3), 101-112.

Gulab, H., Jan, M.R., Shah, J., Manos, G.,2010, Plastic catalytic pyrolysis to fuels as tertiary polymer recycling method: Effect of process conditions, *Journal of Environmental Science and Health Part a-Toxic/Hazardous Substances & Environmental Engineering*, 45(7), 908-915.

Guru, M., Artukoglu, B.D., Keskin, A., Koca, A., 2009, Biodiesel production from waste animal fat and improvement of its characteristics by synthesized nickel and magnesium additive, *Energy Conversion and Management* 50(3), 498-502.

Hitachi: DSC Measurement of Polyethlene. In., vol. 1. (2017)

Horvat, N., Ng, F.T.T., 1999, Tertiary polymer recycling: study of polyethylene thermolysis as a first step to synthetic diesel fuel. *Fuel* 78(4), 459-470

Huang, W.C., Huang, M.S., Huang, C.F., Chen, C.C., Ou, K.L., 2010, Thermochemical conversion of polymer wastes into hydrocarbon fuels over various fluidizing cracking catalysts, *Fuel*, 89(9), 2305-2316.

İlkılıç, C., Cilgin, E., Aydin, H., 2015, Terebinth oil for biodiesel production and its diesel engine application, *Journal of the Energy Institute*, 88(3), 292-303.

Jan, M.R., Shah, J., Gulab, H., 2010, Catalytic degradation of waste high-density polyethylene into fuel products using BaCO3 as a catalyst, *Fuel Processing Technology*, 91(11), 1428-1437.

Kannan, P., Ibrahim, S., Reddy, K.S.K., Al Shoaibi, A., Srinivasakannan, C., 2014, A Comparative Analysis of the Kinetic Experiments in Polyethylene Pyrolysis, *Journal of Energy Resources Technology-Transactions of the Asme*, 136(2).

Kantarelis, E., Donaj, P., Yang, W., Zabaniotou, A., 2009, Sustainable valorization of plastic wastes for energy with environmental safety via High-Temperature Pyrolysis (HTP) and High-Temperature Steam Gasification (HTSG), *Journal of Hazardous Materials*, 167(1–3), 675-684.

Keskin, A., Guru, M., Altiparmak, D., Aydin, K., 2008, Using of cotton oil soapstock biodiesel-diesel fuel blends as an alternative diesel fuel, *Renewable Energy* 33(4), 553-557 (2008).

Kim, D., Shin, S., Sohn, S., Choi, J., Ban, B., 2002, Waste plastics as supplemental fuel in the blast furnace process: improving combustion efficiencies, *Journal of Hazardous Materials*, 94(3), 213-222.

Kumar, S., Prakash, R., Murugan, S., Singh, R.K., 2013, Performance and emission analysis of blends of waste plastic oil obtained by catalytic pyrolysis of waste HDPE with diesel in a CI engine, *Energy Conversion and Management*, 74, 323-331.

Levine, S.E., Broadbelt, L.J., 2009, Detailed mechanistic modeling of high-density polyethylene pyrolysis: Low molecular weight product evolution, *Polymer Degradation and Stability*, 94(5), 810-822.

Lin, Y.H., Yang, M.H., 2008, Tertiary recycling of polyethylene waste by fluidised-bed reactions in the presence of various cracking catalysts, *Journal of Analytical and Applied Pyrolysis*, 83(1), 101-109.

Liu, X.L., Li, X.X., Liu, J., Wang, Z., Kong, B., Gong, X.M., Yang, X.Z., Lin, W.G., Guo, L.,2014, Study of high density polyethylene (HDPE) pyrolysis with reactive molecular dynamics, *Polymer Degradation and Stability*, 104, 62-70.

Luu, P.D., Truong, H.T., Luu, B.V., Pham, L.N., Imamura, K., Takenaka, N., Maeda, Y., 2014, Production of biodiesel from Vietnamese Jatropha curcas oil by a co-solvent method, *Bioresource Technology*, 173, 309-316.

Mani, M., Subash, C., Nagarajan, G., 2009, Performance, emission and combustion characteristics of a DI diesel engine using waste plastic oil, *Applied Thermal Engineering*, 29(13), 2738-2744.

Mehmood, C.T., Qazi, I.A., Hashmi, I., Bhargava, S., Deepa, S., 2016, Biodegradation of low density polyethylene (LDPE) modified with dye sensitized titania and starch blend using Stenotrophomonas pavanii, *International Biodeterioration & Biodegradation*, 113, 276-286.

Meng, A., Chen, S., Long, Y., Zhou, H., Zhang, Y., Li, Q., 2015, Pyrolysis and gasification of typical components in wastes with macro-TGA, *Waste Management*, 46, 247-256.

Miskolczi, N., Bartha, L., Deák, G., Jóver, B., 2004, Thermal degradation of municipal plastic waste for production of fuel-like hydrocarbons, *Polymer Degradation and Stability*, 86(2), 357-366.

Mohammadi, P., Tabatabaei, M., Nikbakht, A.M., Farhadi, K., Far, M.K., Castaldi, M.J., 2013, Simultaneous Energy Recovery from Waste Polymers in Biodiesel and Improving Fuel Properties, *Waste and Biomass Valorization*, 4(1), 105-116.

Oliveira, J.F.G., Lucena, I.L., Saboya, R.M.A., Rodrigues, M.L., Torres, A.E.B., Fernandes, F.A.N., Cavalcante, C.L., Parente, E.J.S.,2010, Biodiesel production from waste coconut oil by esterification with ethanol: The effect of water removal by adsorption, *Renewable Energy*, 35(11), 2581-2584.

Panda, A.K., Singh, R.K., Mishra, D.K., 2010, Thermolysis of waste plastics to liquid fuel A suitable method for plastic waste management and manufacture of value added products-A world prospective, *Renewable & Sustainable Energy Reviews*, 14(1), 233-248.

Panda, A.K., Singh, R.K., Mishra, D.K., 2012, Thermo-catalytic Degradation of Thermocol Waste to Value Added Liquid Products, *Asian Journal of Chemistry*, 24(12), 5539-5542.

Prakash, R., Singh, R.K., Murugan, S., 2013, Experimental investigation on a diesel engine fueled with bio-oil derived from waste wood-biodiesel emulsions, *Energy,* 55, 610-618.

Puente de la , G., Klocker, C., Sedran, U., 2002, Conversion of waste plastics into fuels - Recycling polyethylene in FCC, *Applied Catalysis B-Environmental,* 36(4), 279-285.

Rashedul, H.K., Masjuki, H.H., Kalam, M.A., Ashraful, A.M., Rahman, S.M.A., Shahir, S.A., 2014, The effect of additives on properties, performance and emission of biodiesel fuelled compression ignition engine, *Energy Conversion and Management,* 88, 348-364.

Santella, C., Cafiero, L., De Angelis, D., La Marca, F., Tuffi, R., Vecchio Ciprioti, S.2016, Thermal and catalytic pyrolysis of a mixture of plastics from small waste electrical and electronic equipment (WEEE), *Waste Management*, 54, 143-152.

Siddiqui, M.N., Redhwi, H.H., 2009, Catalytic coprocessing of waste plastics and petroleum residue into liquid fuel oils, *Journal of Analytical and Applied Pyrolysis,* 86(1), 141-147.

Walendziewski, J., 2002, Engine fuel derived from waste plastics by thermal treatment, *Fuel,* 81(4), 473-481.

Wang, H., Chen, D., Yuan, G., Ma, X., Dai, X., 2013, Morphological characteristics of waste polyethylene/polypropylene plastics during pyrolysis and representative morphological signal characterizing pyrolysis stages, *Waste Management,* 33(2), 327-339.

Wang, L.-F., Rhim, J.-W., 2016, Grapefruit seed extract incorporated antimicrobial LDPE and PLA films: Effect of type of polymer matrix, *LWT - Food Science and Technology*, 74, 338-345.

İbrahim BİLİCİ graduated from Gazi University department of Chemical Engineering. He recived M. Sc. degree aout chemcial enginnering at same university in 2006. Ph.D degree is about waste evaluation from Ankara University Chemical Engineering Department in 2012. He worked as a Res&Teach at several university Gazi University, Hitit University and Ankara University respectively. He has been as a post doctorate and visiting researcher in Waterloo University , ON, Canada, Abu Dhabi Petroleum Institute, Abu Dhabi UAE several times. He is currently Assistant Proffessor in the Department of Chemcial Engineering in Hitit University. His main research interest lie in the area of recycling, composite materials and waste plastics.

Metin GÜRÜ was born in Nazilli at 1957, he has received his bachelor and master degree in Chemical Engineering from Ankara University, Ankara, Turkey. He recived Ph.D. degree from Gazi University Chemical Engineering Department. He started to career as lecturer at Gazi University and became Assitant Proffefsor, Associated Proffessor and Professor at Gazi University since 2006. He has supervised more than 45 master degree and 20 PhD degree. His research interest are boron technologies, chemical processes, material science, bitumen, cement and concrete, hydrogen, catalyst, biodisel production and renewable and clean energy. He has almost 140 WoS papers, eleven books and six patents. He is a chief editor of Journal of Boron.

Ali KESKİN was born in Adana at 1975. He graduated from Gazi University department of Mechanical Education. He has received his master degree from Mechanical Engineering from Çukurova University. He recived Ph.D. degree from Gazi University Mechanical Education Department. He started to career as Assitant Proffesor at Mersin University and became Professor at Çukurova University in 2015. His research topics are internal combustion engines, diesel engine emission control systems, alternative renewable fuels and clean energy. He is a reviewer for many international journals.

.