ASSESSMENT OF EMISSIONS AND ENVIRONMENTAL IMPACT OF USING FIG WASTE BIOALCOHOL/NANOPARTICLE FUEL IN A TRACTOR WITH A COMMON RAIL SYSTEM DIRECT INJECTION

by

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This study investigates the potential benefits of using bioalcohol and nanoparticle-enhanced fuel derived from fig waste in a direct injection common rail tractor. The aim of this study is to understand how these alternative fuels derived from agricultural waste affect emissions and the environment. Engine performance and emission levels were tested when running on fig waste bioalcohol mixed with nanoparticles. The results showed a significant reduction in harmful emissions such as NO_x *and CO compared to conventional diesel. Furthermore, the sustainability of using fig waste as biofuel was examined, highlighting its potential to reduce dependence on fossil fuels and its positive impact on the environment. This research supports the development of renewable energy sources and promotes sustainable agricultural practices.*

Key words: *fig waste bioalcohol, nanoparticle fuel, sustainable, tractor*

Introduction

In recent years, some of the hottest days on record have been experienced, and the intense heat has been felt by many people in their daily lives. The impact of global warming has become more noticeable, emphasizing the urgent need for effective solutions. A growing recognition of the serious threat posed by global warming has emerged.

One important solution to combat global warming is the reduction of exhaust emissions. Emissions from internal combustion engines are prevalent and are recognized as a significant environmental threat. Consequently, significant effort is being put into finding ways to reduce these emissions [1].

In recent years, significant research has been conducted in several key areas:

– The use of fuels derived from biological sources to replace fossil fuels is frequently highlighted for reducing exhaust emissions. Biofuels such as biodiesel or bioalcohol, sourced from local and national resources, are favored because they can be used in Diesel engines without requiring extensive modifications. Studies indicate that emissions can be reduced through the use of these biofuels [2, 3].

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- Another significant research area focuses on enhancing engine assemblies to reduce exhaust emissions. Research often involves applying thermally conductive metals to engine sections that generate heat loss. It has been reported that such treatments effectively lower exhaust emissions [4-6].
- Recent research has focused on adding hydrogen gas to enhance power, reduce fuel consumption, and lower exhaust emissions in high-power Diesel engines. Studies indicate that introducing hydrogen gas alongside diesel fuel, either directly from a tank or through hydrogen generators, can effectively reduce exhaust emissions [7-11].
- Nanoparticles have become a significant focus area for researchers, who report that adding nanoparticles to diesel fuel reduces exhaust emissions. Researchers commonly agree that nanoparticles enhance combustion by inducing micro-explosions, thereby lowering exhaust emissions [12-15].

In recent years, agricultural production, which is at the forefront of the food sector, has been recognized as one of the most important areas of research. Particularly, emphasis has been placed on innovations in agricultural mechanization and machinery. Despite the acceleration of efforts to increase the efficiency of agricultural machinery, reducing exhaust emissions remains crucial for agricultural production [16]. Diesel engines are commonly used in tractors in the agricultural sector. Diesel engines are preferred particularly in places where high power and torque are required, making them significant agricultural vehicles.

In recent years, alongside fuel consumption, commercial firms have increasingly focused on exhaust emissions as a critical area of concern. Restrictions imposed on internal combustion engines have become highly significant and progressively stringent. Recently, both the EU and the USA. Environmental Protection Agency have introduced regulations governing exhaust emissions released during fuel combustion in various vehicles, including agricultural tractors, automobiles, trucks, ships, and off-road vehicles. These regulations specifically limit emissions of NO_x, CO, PM, and HC, which are becoming subject to increasingly stringent requirements (97/68/EC, 2010/22/EU, 2010/26/EU). As a result, tractor manufacturers have had to equip existing tractors with technological solutions such as catalytic converters and exhaust gas recirculation systems to comply with these exhaust emission standards [17].

Researchers are focusing on using fuels derived from agricultural waste as an energy source in studies conducted on tractors. Bioalcohols stand out among these fuels. Bioalcohols, which can be produced through the fermentation of biological waste, especially biological ethanol and methanol, are preferred as fuel additives in internal combustion engines. In recent years, the use of such bioalcohols has held a significant place in the quest for sustainable energy sources. These methods offer potential to both reduce environmental impacts and enhance energy independence. Research efforts are concentrated on developing technically and economically feasible solutions to expand the widespread use of these bioalcohols in the agricultural sector [18-22]. However, every product produced may face challenges in transforming into commercial products. Nevertheless, studies focusing on the use of nanoparticles are not encountered very frequently.

This study has examined the effects of adding bioalcohol derived from waste figs and alcohol/CuO_2/TiO_2 mixtures to diesel fuel used in tractor engines on exhaust emissions.

Materials and methods

Biyoalcohol production

Biological fig materials used in the production of bioalcohol were purchased from fig processing facilities in Germencik district of Aydin province, Turkey. All figs used were waste figs that were no longer suitable for consumption. The figs were processed into fuel through fermentation. To expedite fermentation, including those completely rotten, the collected figs were chopped into smaller pieces. The resulting figs were placed in fermentation tanks at a ratio of 5 kg of figs to 5 L of water. To accelerate fermentation, 1 kg of sugar and 500 g of yeast nutrient were added to the fermentation tank. The CO_2 emission was monitored during fermentation, and the tank was opened after seven days when CO_2 emission ceased.

The mixture obtained was filtered multiple times and subjected to distillation. The liquid mixture was distilled under vacuum and controlled temperature conditions. During distillation, alcohol mixtures ranging from 65 °C to 78 °C were separated to create a bioalcohol mixture. This process was repeated three times. Approximately 1.1 L of bioalcohol mixture was obtained from 5 L of water.

Figure 1 depicts the alcohol distillation set-up. Following distillation, the mixture was subjected to a 24-hours process with silica gel desiccant in a 1:1 ratio to remove water from the obtained mixture.

The obtained bioalcohols were analyzed for certain chemical and physical properties, and the resulting data are presented in tab. 1.

Figure 1. Alcohol distillation set-up

Nanoparticles

The TiO_2 and Cu_2O used in the experiments were purchased from a commercial supplier. Some technical specifications of the purchased nanoparticles are provided in tab. 2.

Table 1. Physical and Chemical Properties of the Obtained Bioalcohols [23, 24]

	Bioalcohol mixture
Density [kgm^{-3}] at 15 °C	792
Viscosity [mm^{2}s^{-1}] at 20 °C	1.87
Lower heat [MJkg^{-1}]	28.65

Table 2. Physical Properties of the nanoparticles

	Cu_2O	TiO_2
Purity [%]	99.95	99.99
Color	Brown	White
Particle size [nm]	16	17

Preparation of experimental fuels

During the experiments, diesel fuel used was purchased from a local commercial supplier. Experimental fuels were prepared volumetrically. Initially, the obtained bioalcohol was supplemented with Cu_2O and TiO_2 nanoparticles at concentrations of 25 ppm, 50 ppm, and 100 ppm. The resulting nanoparticle-infused bioalcohol mixtures were subjected to 40 kHz ultrasonic waves for one hour using an ultrasonic mixer. These new mixtures were then blended with diesel fuel at a ratio of 20% by volume to create experimental fuels. The chemical and physical properties of the resulting fuel mixtures were analyzed. The test results of these chemical mixtures are presented in tab. 3. The fuel mixtures used in the experiments are abbreviated in graphs as follows: D100 (100% diesel), D80B20 (80% diesel + 20% bioalcohol), D80B2025Cu_2O (80% diesel + 20% bioalcohol + 25Cu_2O), D80B2050Cu_2O (80% diesel + 20% bioalcohol + 50Cu_2O), D80B20100Cu_2O (80% diesel + 20% bioalcohol + 100Cu_2O), D80B2025TiO_2 (80% diesel + 20% bioalcohol + 25TiO2), D80B2050TiO_2 (80% diesel + 20% bioalcohol + 50TiO_2), D80B20100TiO_2 (80% diesel + 20% bioalcohol + 100TiO_2).

Table 3. Physical and chemical properties of experimental fuels

Experimental fuels	Density [kgm^{-3}] at 15 °C)	Viscosity	Calorific value	Flash point
D100	840	3,38	42,5	55
D100B20	802	2.65	41.3	49
D80B2025Cu_2O	811	2.71	41.2	49
D80B2050Cu_2O	815	2.79	41.2	51
D80B20100Cu_2O	821	2.85	41.1	55
D80B2025TiO_2	807	2.73	41.3	50
D80B2050TiO_2	812	2.81	41.3	57
D80B20100TiO_2	829	2.93	41.2	61

Experimental set-up

The engine loading process was carried out using the PTO test unit. All engine tests adhered to the OECD Standard Code for the Official Testing of Agricultural and Forestry Tractor Performance. Throughout the experiments, the PTO speed of the tractor was set to 540 rpm. Subsequently, the engine was brought to full throttle, and its operational speeds varied at 1000 rpm, 1200 rpm, 1400 rpm, 1600 rpm, 1800 rpm, 2000 rpm, 2200 rpm, and 2400 rpm using the PTO shaft loading unit. During each loading cycle, measurements and recordings were taken for engine exhaust gas temperature, fuel consumption, and exhaust emission values. All procedures were repeated three times, and the average data was computed. The schematic diagram of the experimental set-up is shown in fig. 2, and the schematic diagram of the experimental apparatus is depicted in fig. 3.

Figure 2. Experimental set-up diagram

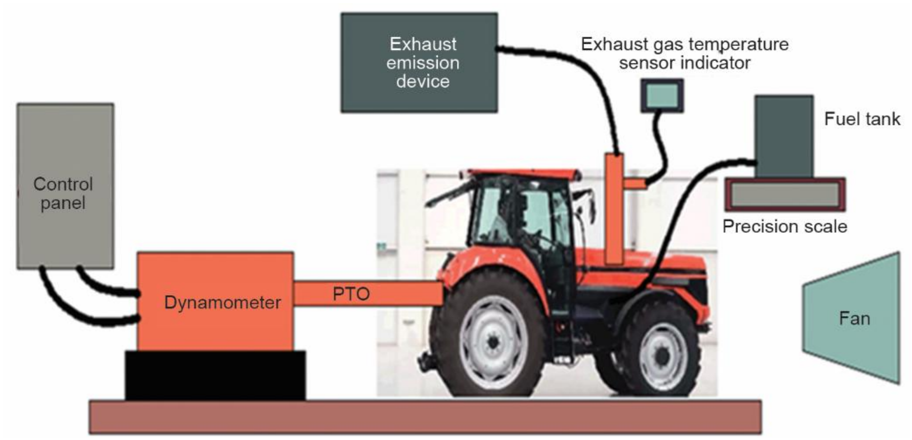

Figure 3. Schematic diagram of the experimental set-up

Exhaust emission measurements were made with a Capelec CAP3201 brand emission device. Technical specifications of the Exhaust Emission device are given in tab. 5.

The tractor used during the experiments is already used by many farmers in Turkey. Information on the internal combustion engine of the tractor is given in tab. 6.

Table 5. Technical specifications of exhaust emission device

Brand and model	Capelec CAP 3201-4
Preheat time	Min. 1 minute
Pump capacity	6 Lpm
Operating temperature	–10 °C-55 °C
Moisture	30%-90%
Storage temperature	–32 °C- +55 °C
HC (sensitivity 1 ppm)	0-20000 ppm
CO (accuracy 0.001%)	0-5 vol.%
CO_2 (sensitivity (0.1%)	0-20 vol.%
O_2 (accuracy 0.01%)	0-21.7 vol.%
NO_x (sensitivity 1 ppm)	30-10000 ppm
Oil temperature	5 °C-150 °C
Lambda (air/fuel ratio coefficient)	0.8-1.2
PM (accuracy 0.01%)	0-9.99 m^{-1}

Table 6. Technical specifications of tractor engine

Characteristic	Specification
Maximum engine power	75 HP
Number of cylinders	4
Air intake system	Turbo/intercooler
Engine capacity	3.9 L
Compression ratio	17:1
Maximum torque	298/1400 min
Transmission	8 forward + 2 reverses
Dry spindle cycle	540 rpm at 1967 rpm
Fuel type	Diesel
Fuel system	Direct injection

The CO_2 emissions are directly associated with global warming and climate change. Therefore, reducing CO_2 emissions is critically important for a sustainable future. The mass of CO_2 emissions released into the atmosphere is determined using the following equation [25]:

$$C_{x\mathrm{CO_2}} = N_{\mathrm{CO_2}} \dot{E}x_{\mathrm{in}} t_{\mathrm{year}} \qquad (1)$$

In the study, the economic value of CO_2 emissions attributable to the fuel blends used is determined using eq. (2). In economic assessment, P_{CO_2} = 0.0145 $ per kg CO_2 is assumed [26]:

$$E_{xCO_2} = C_{xCO_2} P_{xCO_2} \tag{2}$$

Results and discussion

Figure 4 shows the effects of fuel blends on CO emissions as a function of engine speed. The CO emissions represent unburned exhaust emissions. Diesel engines operate with a turbocharger and always work with excess air than what they can burn, resulting in very low levels of CO emissions. Studies indicate that an increase in the amount of oxygen inside the cylinder leads to a decrease in CO emissions [27]. In this study, it was also found that the addition of oxygen-containing alcohol/nanoparticles to diesel fuel resulted in a decrease in CO emissions at all engine speeds. Additionally, the inclusion of oxygen-rich nanoparticles accelerated the reduction in CO emissions. Studies involving nanoparticles have indicated that adding nanoparticles to diesel fuels increases the combustion surface area, thereby leading to a reduction in emissions [27, 28].

The highest CO value of 850 ppm was obtained at an engine speed of 1000 rpm with the D100 fuel blend, while the lowest CO emission value of 61 ppm was achieved at an engine speed of 2400 rpm with the D80B20+100TiO_2 fuel blend. In this case, the greatest reduction, approximately 19%, was observed at an engine speed of 2400 rpm using the D80B20+100TiO_2 fuel blend. The CO emissions tend to be higher at lower engine speeds and show a decreasing trend as the engine speed increases. This can be explained by the operating principle of Diesel engines. In Diesel engines, the engine load is adjusted by increasing the amount of fuel. At low engine loads, lean fuel mixtures create partially unburned regions inside the cylinder, increasing CO emissions. As the engine speed increases, the amount of fuel in the cylinder also increases, resulting in higher combustion end temperatures and cylinder ambient heat, which accelerates the reduction of CO emissions. The results of this study are similar to those found by Kumar and Bedal [29]. In this regard, the addition of bio-alcohol/nanoparticles has been effective in reducing CO emissions in Diesel engines.

Figure 5 illustrates the effects of fuel mixtures on CO_2 emissions depending on engine speed. The CO_2 emissions represent those resulting from complete combustion in Diesel engines. While CO_2 emissions are undesired, they provide insight into combustion efficiency

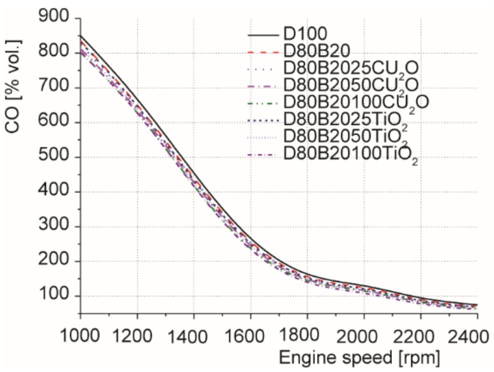

Figure 4. Variation in CO emissions

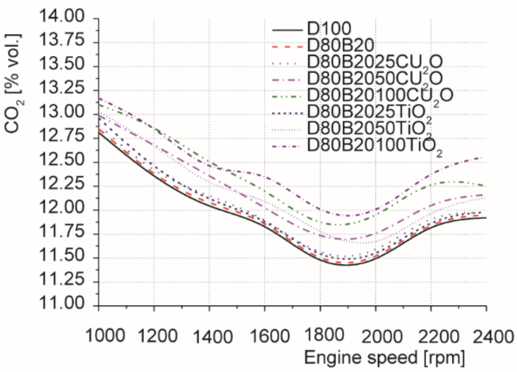

Figure 5. Variation in CO_2 emissions

in Diesel engines. The addition of nanoparticles to diesel fuel mixtures has increased CO_2 emissions across all loads and engine speeds, correlating with an increase in CO emissions. It is expected that an increase in combustion efficiency results in higher CO_2 emissions. Studies involving nanoparticles attribute this phenomenon to changes in fuel properties [30, 31], micro-explosions, oxidation of oxygen within nanoparticles, and thus an increase in combustion efficiency. Additionally, it is known that the OH atoms in bioalcohols contribute to increased oxidation effects within the cylinder of fuels.

In the study conducted [29], it is stated that oxygen-enriched fuels have an enhancing effect on combustion performance. The highest increase rate, approximately 5%, was achieved at 2400 rpm engine speed with the D80B20100TiO_2 fuel mixture. At this engine speed, a value of 11.92% was obtained with the D100 fuel and 12.56% with the D80B20100TiO_2 fuel mixture. The results of the study have shown similar outcomes to those found in the literature [32].

Figure 6 illustrates the effects of fuel mixtures on HC emissions depending on engine speed. Studies indicate that HC emissions in Diesel engines occur due to suboptimal mixing of air/fuel mixtures within the cylinder, fuel particles hitting cylinder walls and extinguishing, or worsening combustion [33]. Researchers indicate that blending oxygen-enriched alcohols and biodiesel into diesel fuel tends to partially improve combustion, thereby reducing HC emissions [34]. Blending bioalcohol/nanoparticle fuel mixtures into diesel fuel has shown a tendency to decrease HC emissions across all engine speeds and fuel mixtures. In experiments, the highest HC emission value was 220 ppm at 1000 rpm engine speed, whereas at the same speed, the D80B20100TiO_2 fuel mixture resulted in 189 ppm HC emissions. The highest reduction percentage, approximately 24%, was observed with the D80B20100TiO_2 fuel mixture at 2200 rpm engine speed. The primary factor contributing to the reduction in HC emissions is attributed to the fuel mixtures containing bioalcohol/nanoparticles, which increase the combustion surface area, partially improving combustion efficiency. This results in decreased HC emissions and can be explained by the decrease in the total number of carbon atoms within the fuel mixtures.

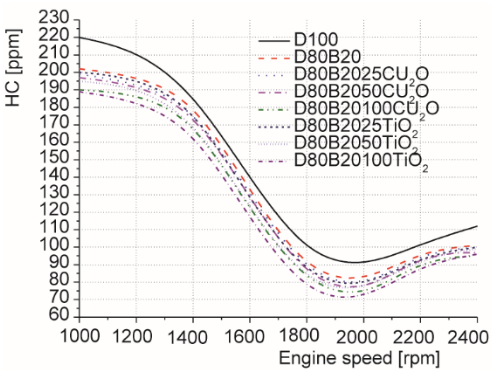

Figure 6. Variation in HC emissions

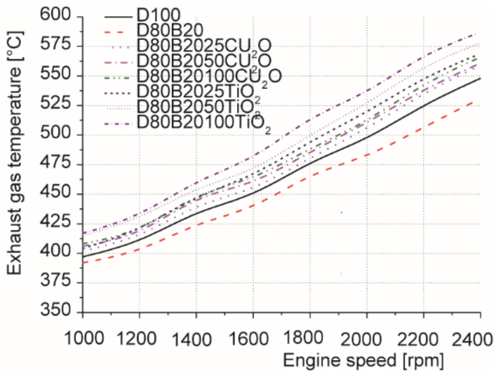

Figure 7. Changes in exhaust gas temperature

Figure 7 illustrates the effects of fuel mixtures on exhaust gas temperature depending on engine speed. Researchers indicate that exhaust gas temperature in Diesel engines partly describes combustion within the cylinder [35]. When bioethanol was added to diesel fuel, we noticed that the exhaust gas temperature tended to decrease. This could be explained by looking at the thermal properties of the fuel blends. As the thermal value decreased, the exhaust gas temperature also showed a partial decrease. However, when we introduced a mixture of bioethanol and nanoparticles into the fuel, we saw an increase in exhaust gas temperature across all fuel blends. The highest exhaust gas temperature reached 587 °C at an engine speed of 2400 rpm, whereas the lowest temperature, 397 °C, was recorded with pure D100 fuel at 1000 rpm. The most significant decrease, 3.61%, occurred at 2200 rpm, while the highest increase, 8.1%, was seen at the same speed as the D80B20100TiO_2 fuel blend. These findings closely mirror those reported in similar studies in the literature [36].

Figure 8 illustrates the effects of fuel blends on NO_x emissions as a function of engine speed. The NO_x emissions are significant pollutants in Diesel engines, arising spontaneously due to high temperatures within the cylinder reaching the nitrogen gases present in the air. Studies also indicate that NO_x emissions rapidly increase with the use of oxygen-rich fuels inside the cylinder and during processes such as fuel particle micro-explosions [37, 38]. Adding bioethanol and nanoparticles to diesel fuel has resulted in increased NO_x emissions across all engine speeds and fuel mixtures. The most significant increase, approximately 8.6%, was observed at 2200 rpm when using the D80B20100TiO_2 fuel blend. This rise is primarily linked to the oxygen content within the fuel mixes. The presence of oxygen enhances combustion efficiency within the cylinder, leading to higher combustion temperatures and subsequently higher NO_x emissions. These study results align closely with findings [39, 40], where researchers have similarly identified oxygen-rich fuel blends and the micro-explosion of nanoparticles in fuels as key factors contributing to increased NO_x emissions [41].

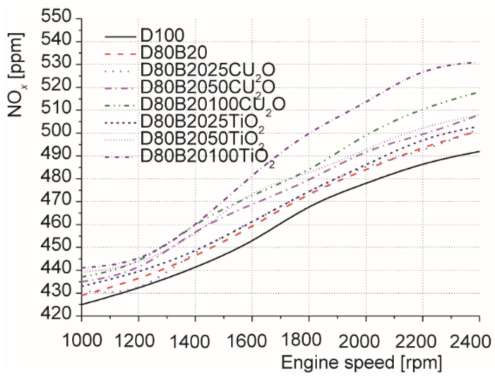

Figure 8. Variation in NO_x emissions

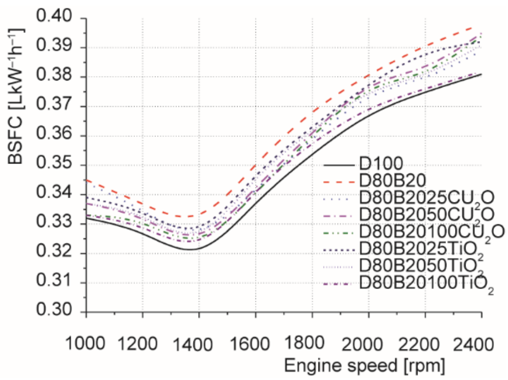

Figure 9. Variation in BSFC

Figure 9 shows how different fuel blends affect brake specific fuel consumption (BSFC) depending on engine speed. The BSFC refers to the amount of fuel needed to produce 1 kW of power in internal combustion engines, rather than just the amount of fuel consumed. When bioalcohol/nanoparticles are added to diesel fuel, there is a tendency for BSFC to increase across all engine speeds and fuel mixtures. The highest BSFC value, 0.395 L/kWh, is seen with the D80B2050CU_2O fuel mixture at 2400 rpm, while the lowest BSFC value, 0.316 L/kWh, is achieved with pure D100 fuel at 1400 rpm. The addition of bioethanol/nanoparticles to diesel fuel results in varied increases in BSFC. The highest increase, about 4.4%, occurs with the D80B20 fuel blend, whereas the lowest increase, 0.26%, is observed at 2400 rpm with the D80B20100TiO_2 fuel mixture. Furthermore, when using the bioalcohol/nanoparticle blend D80B20100TiO_2, there is approximately a 3% decrease in thermal value and a slight 0.26% increase in BSFC. This relationship is attributed to the oxygen content within bioalcohol and nanoparticles. Studies [42, 43] suggest that oxygen-rich fuels enhance oxidation within the cylinder, partially improving combustion efficiency and thus positively affecting BSFC.

This study aims to comply with sustainability goals within the framework of environmental analysis and to develop strategies for more efficient resource utilisation. Based on energy and exergy analysis data, monthly CO_2 emissions calculated based on the use of different fuel types were analysed. Figure 10 shows these emissions. The highest CO_2 emission was recorded as 588,705 kg CO_2 per month for the D40W50P1 fuel blend at 5 kW power. On the other hand, the D100 fuel consistently exhibited the lowest CO_2 emissions at all engine powers. The addition of additives to fuel blends increased CO_2 emissions. Uysal *et al.* [26] pointed out higher environmental impact rates due to the increase in fuel consumption with increasing engine load; however, they emphasised that the environmental impact rate per exergy unit is low.

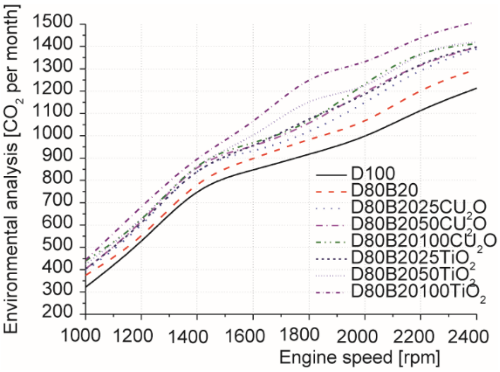

Figure 10. Monthly CO_2 amount of fuel blends according to environmental analysis

References

[1] Nguyen, T., *et al.*, Spray, Combustion, Performance and Emission Characteristics of a Common Rail Diesel Engine Fueled by Fish-Oil Biodiesel Blends, *Fuel, 269* (2020), 117108

[2] Cho, S. G., A Study on Characteristics of Combustion and Exhaust Emissions on Bio-Diesel Fuel in Marine Diesel Generator Engine (Low Load Centering), *Journal of the Korean Society of Marine Engineering*, 39 (2015), 7, pp. 716-721

[3] Gulum, M., Effects of Compression Ratio, Blending Ratio and Engine Speed on Fuel Cost, Performance and Exhaust Emissions of a Diesel Engine Fueled With Bio-Derived Alternative Fuels, *Sustainable Energy Technologies and Assessments, 53* (2022), 102464

[4] Ertugrul, I., *et al*., Analysis of Thermal Barrier Coated Pistons in the COMSOL and the Effects of Their Use with Water + Ethanol Doped Biodiesel, *Thermal Science, 26* (2022), 4A, pp. 2981-2989

[5] Udayakumar, M., *et al.*, Performance and Emissions of Lemon Peel Oil Biodiesel Powered Single Cylinder Direct Injection Diesel Engine Loaded with Ceria Nanoparticles Additives and Stabilized Zirconia Coating, *Materials Today: Proceedings, 66* (2022), Part 4, pp. 1994-2000

[6] Raja E., Premjeyakumar, M., An Influence on Prospis Juliflora (PF) Oil Biodiesel of Thermal Barrier Coated in Compression Ignition Engine, *Materials Today: Proceedings*, *62* (2022), Part 4, pp. 1729-1737

[7] Zhao, B., *et al.*, Effects of Hydrocarbon Liquid and HHO as the Alternate Fuel for Unmodified Compression Ignition Engines, *Fuel*, *324* (2022), 124726

[8] Subramanian, B., *et al.*, Detailed Analysis on Engine Operating in Dual Fuel Mode with Different Energy Fractions of Sustainable HHO Gas, *Env. Prog. and Sustain. Energy*, *41* (2022), 5, e13850

[9] Najafi, B., *et al.*, Effects of Low-Level Hydroxy as A Gaseous Additive on Performance and Emission Characteristics of a Dual Fuel Diesel Engine Fueled by Diesel/Biodiesel Blends, *Engineering Applications of Computational Fluid Mechanics, 15* (2021), 1, pp. 236-250

[10] Thangaraj, S., Govindan, N., Consequences of Suplementing The HHO Gas and CNG with Egr on Diesel Engine Characteristics, *Thermal Science, 26* (2022), 5A, pp. 4003-4016

[11] Paparao, J., *et al.*, Experimental Studies on the Effect of Tbc Piston in a Dual-Fueled Diesel Engine, *Fuel, 306* (2021), 121700

[12] Banković-Ilić, I. B., *et al.*, Application of Nano CaO-Based Catalysts in Biodiesel Synthesis, *Renewable and Sustainable Energy Reviews, 72* (2017), May., pp. 746-760

[13] Dubey, S., *et al.*, Application of Common Nano-Materials For Removal of Selected Metallic Species From Water and Wastewaters: A Critical Review, *Journal of Molecular Liquids*, *240* (2017), Aug., pp. 656-677
[14] Avhad, M. R., Marchetti, J. M., A Review on Recent Advancement in Catalytic Materials for Biodiesel Production, *Renewable and Sustainable Energy Reviews*, *50* (2015), Oct., pp. 696-718
[15] Atadashi, I. M., *et al.*, The Effects of Catalysts in Biodiesel Production: A Review," *Journal of Industrial and Engineering Chemistry*, *19* (2013), 1, pp. 14-26
[16] Lovarelli, D., Bacenetti, J., Exhaust Gases Emissions from Agricultural Tractors: State of The Art and Future Perspectives for Machinery Operators, *Biosystems Engineering*, *186* (2019), Oct., pp. 204-213
[17] Cavallo, E., *et al.*, Consumption of Diesel Exhaust Fluid (DEF) Of Agricultural Tractor Engines Using Selective Catalytic Reduction (SCR) System, *Proceedings,* 69th International Conference on Agricultural Engineering: Solutions for Intelligent and SUSTAINABLE FARMING in 2124, Hannover, Germany, 2011, pp. 259-265
[18] Feng, B., *et al.*, Toward the Mechanism Study of $Pd/\gamma\text{-}Al_2O_3$-Assisted Bioalcohol Combustion in a Flow Reactor, *Energy Fuels*, *35* (2021), 18, pp. 14954-14962
[19] Yamamoto, S., *et al.*, Comparison of Combustion Characteristics of Ethanol and Butanol Blended with Gas Oil in Direct Injection Diesel Engine, *Trans. JSME, B*, *79* (2013), 799, pp. 380-389
[20] Hergueta, C., *et al.*, Impact of Bio-Alcohol Fuels Combustion on Particulate Matter Morphology from Efficient Gasoline Direct Injection Engines, *Applied Energy*, *230* (2018), Nov., pp. 794-802
[21] Tanwar, M. D., *et al.*, Promising Bioalcohols for Low-Emission Vehicles, *Energies*, *16* (2023), 2, 597
[22] Noh, H. K., No, S.-Y., Effect of Bioethanol on Combustion and Emissions in Advanced CI Engines: HCCI, PPC and GCI mode – A Review, *Applied Energy*, *208* (2017), Dec., pp. 782-802
[23] ***, Titanyum Dioksit (TiO_2), https://shop.nanografi.com.tr/titanyum-dioksit-tio2-nano-tozu-safl-k-99-995-boyut-17-nm-anataz/
[24] ***, Bakir Oksit (Cu_2O), https://shop.nanografi.com.tr/bak-r-oksit-cu2o-nano-tozu-safl-k-99-95-boyut-16-nm/
[25] Yildiz, I., *et al.*, Energy, Exergy and Environmental Assessments of Biodiesel and Diesel Fuels for an Internal Combustion Engine Using Silicon Carbide Particulate Filter, *J. Therm. Anal. Calorim.*, *145* (2021), 3, pp. 739-750
[26] Uysal, C., *et al.*, Exergetic, Exergoeconomic, and Sustainability Analyses of Diesel–Biodiesel Fuel Blends Including Synthesized Graphene Oxide Nanoparticles, *Fuel*, *327* (2022), Nov., 125167
[27] Arslan, E., *et al.*, Examination of the Effect on the Engine of Diesel-Nanoparticle Mixture with Natural Gas Addition, *Fuel*, *357* (2024), 129911
[28] Dogan, B., *et al*., Energy, Exergy and Sustainability Analyses of Nanoparticles Added to Fuels to Reduce Carbon Footprint, *Case Studies in Thermal Engineering*, *56* (2024), 104252
[29] Kumar, S. K, G. N., Bedar, P., A Novel Approach to Enhance the Combustion Quality of C5 Alcohol with 2-Ethylhexyl Nitrate as a cetane Enhancer in Common Rail Direct Ignition Diesel Engine, *Journal of Cleaner Production*, *446* (2024), 141314
[30] Manimaran, S., *et al.*, Enhancing Diesel Engine Performance and Emissions Control: The role of RuO_2 Nanoparticles and Ammonia Additives with Microalgae Blends, *Fuel*, *368* (2024), 131662
[31] Milano, J., *et al.*, Strategies in the Application of Nanoadditives to Achieve High-Performance Diesel, Biodiesels, and Their Blends, *Fuel Communications*, *19* (2024), 100111
[32] AbdulRahman A. H., *et al.*, Utilizing Alpha Alumina as a Fuel Additive to Enhance the Performance and Reduce Emissions of a Diesel Engine, *Fuel*, *371* (2024), 132011
[33] Venkatesan, S. P., Study the Effects of Dimethyl Carbonate as a Fuel Cetane Improver on Diesel Engine Emissions, *Environmental Quality Mgmt.*, *33* (2023), 2, pp. 123-126
[34] Ayazi, M., *et al.*, Experimental Investigation of Fuel Consumption and Emissions of Diesel Engine Fueled with Ternary Fuel Blends of Diesel, Biodiesel and Bioethanol, *Energy Reports*, *9* (2023), 470475
[35] Almanzalawy, M. S., *et al.*, Enhancement of Energy, Exergy and Soot Characteristics with the Utilization of MEK in Diesel Engine, *J. Therm. Anal. Calorim.*, *149* (2024), 1, pp. 463-478
[36] Yang, Y., *et al.*, Performance of Large-Bore Methanol/Diesel Dual Direct Injection Engine Applying Asymmetrical Diesel Nozzle Strategies, *Applied Thermal Engineering*, *244* (2024), 122674
[37] Agarwal, A. K., *et al.*, Di-Ethyl Ether-Diesel Blends Fuelled off-Road Tractor Engine: Part-II: Unregulated and Particulate Emission Characteristics, *Fuel*, *308* (2022), 121973
[38] Al-Lwayzy, S., Yusaf, T., Chlorella Protothecoides Microalgae as an Alternative Fuel for Tractor Diesel Engines, *Energies*, *6* (2013), 2, pp. 766-783

[39] Janulevičius, A., *et al.*, Nitrogen-Oxide emissions From Diesel-Engine Farm Tractors During Real-Life Cycles and Their Correlation with the Not-to-Exceed Operating Zones, *Biosystems Engineering*, *161* (2017), Sept., pp. 93-105
[40] Emberger, P., *et al.*, Emission Behaviour of Vegetable Oil Fuel Compatible Tractors Fuelled with Different Pure Vegetable Oils, *Fuel*, *167* (2016), Mar., pp. 257-270
[41] Agarwal, A. K., *et al.*, Ultra-Low Soot/ Particulate Emissions from a Dimethyl Ether-Fueled Agricultural Tractor Engine, *Fuel*, *356* (2024), 129637
[42] Rajesh, K., *et al.*, Investigating the Impact of Alumina Nanoparticles in Coconut Oil Distillate Biodiesel to Lessen Emissions in Direct Injection Diesel Engine, *Sci. Rep.*, *14* (2024), 1, 13228
[43] Almanzalawy, M. S., *et al.*, Combined Effects of Ferric Oxide Nanoparticles and C2–C4 Alcohols with Diesel/Biodiesel Blend on Diesel Engine Operating Characteristics, *Alexandria Engineering Journal*, *103* (2024), Sept., pp. 38-50

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