IMPACT OF NANOPARTICLES AS A HOMOGENEOUS CATALYST IN IGNITION CHARACTERISTICS OF WASTE PLASTIC OIL

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ABSTRACT

A novel approach was employed to develop alternative fuels by blending pyro-oil from used plastic with graphene, which acted as a combustion additive. The biofuels were produced through pyrolysis of high-density polyethylene (HDPE). When evaluating the fuel blends, the fuel properties were analyzed and compared to commercially available diesel fuel, while Fourier transform infrared (FTIR) spectrometry was employed to know the fuel character. The findings demonstrate that including graphene as a combustion additive significantly enhances the Fuel's performance. The phenomena suggest that graphene effectively weakens the dispersion forces among the triglyceride molecules. Consequently, the droplet is easier to burn. By incorporating graphene, the alternative fuels droplet exhibits improved ignition properties, offering potential benefits in terms of efficiency and performance. The additive plays a crucial part in modifying the molecular structure of the Fuel, resulting in enhanced reactivity and ignition characteristics. Furthermore, the analysis of physical properties and spectroscopic data provides valuable insights into alternative fuels' molecular composition and behavior.

Keywords: Oil droplet, waste plastic oil, graphene, catalyst, ignition characteristics.

INTRODUCTION

The contemporary issue of the energy crisis and coincidental degradation caused by the growth of industrial life and the global populace has become a pressing concern [1]–[3]. Consequently, the demand for environmentally friendly alternative fuels has gained paramount importance.

Apart from conventional alternative energy like biofuels, used plastic oil (UPO) will effectively change into usable fuels such as fossil fuel through pyrolysis ways, which offers an environmentally benign solution [4]–[7], including many types of waste plastics already successfully changed into UPO and utilized in diesel engines [8]–[10].

Nevertheless, to enhance the performance of UPO, researchers have incorporated graphene oxide (GrO) in diesel fuel blends [10], [11]. These studies' outcomes have demonstrated that adding GrO as nanoparticles to diesel engines effectively enhances fuel performance while reducing CO2 and NOx emissions.

In summary, the utilization of UPO in combination with the catalyst GrO shows promise as an environmentally friendly alternative fuel source. However, the existing research has primarily focused on vehicle ability, power, and speed. It has not opened the underlying mechanisms of GrO in the burning stages of UPO-based combustion vehicles to fill this void, and the current research utilizes a technique where a single droplet is ignited by combining UPO with GrO as nanoparticles. The molecular makeup of GrO can create atomic interactions and alter the arrangement of atoms, thereby reducing the strength of the dispersion forces between the triglyceride of UPO [12], consequently enhancing the reactivity and ignitability of the Fuel. Recognizing the significance of obtaining scientific information regarding the impact of GrO on UPO abilities, thus a comprehensive and detailed research investigation is warranted. Furthermore, the limitation of the study is the impact of using GrO on the physicochemical properties (see Table 1, Table 2, and Figure 3) and the performance of the Fuel, especially about droplet evolutions and fuel ignition rate (see Figure 4 to 6).

MATERIAL AND METHOD

The present research employed GrO nanoparticles (depicted in Fig. 1) with thicknesses ranging from 0.8 to 1.2 nm and a Ø50 and 200 nm. The UPO was mixed with the GrO with a dosage ratio of 1 ppm catalyst to 100 ml of oil volume. The fuel mixture was prepared by manually shaking in a closed glass.

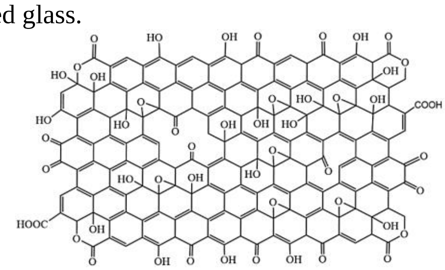

Figure 1. The atomic structure of GrO

However, the experimental setup, as illustrated in Figure 2. The droplet diameter ranged from approximately 0.6 mm to 1.1 mm. An electric coil heater with a diameter of 0.7 mm, made of Ni-Cr wire and measuring 30 mm in length, was used to supply power to the fuel droplets. The coil had a 1.02 Ω and operated at a 12 V with 5 A.

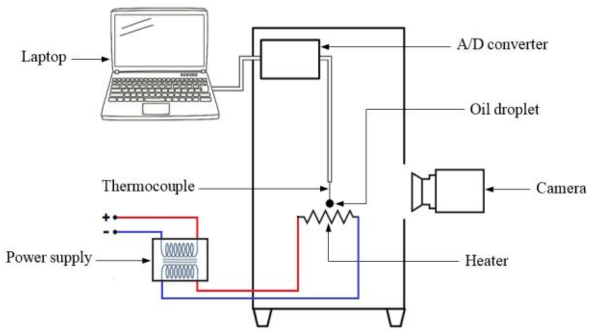

Figure 2. The experimental apparatus.

To determine the ignition time, the deformation of the droplets was recorded using a micro camera with 100x magnification. Simultaneously, the temperature at the center of the fuel droplet was monitored using a thermocouple sensor [13].

RESULTS AND DISCUSSION

Table 1 presents the test results of the primary nature of UPO with various blends and compared with those of diesel oil. Additionally, GCMS testing was used to identify the primary compounds within the carbon chain of the UPO. The results of this testing are presented in Table 2.

Table 1. The main properties of UPO compared to diesel oil

Components	**Diesel oil**	**UPO without GrO**	**UPO with GrO**
Flashpoint (ºC)	57.3	42	47
Caloric value (cal/gr)	10643	9769	9811
Density at 15 ºC (gr/ml)	0.855	0.8103	0.8401
Viscosity at 40 ºC (cSt)	3.936	2.322	2.408

Table 2. The elements of the UPO

Components	**Field (%)**	**Possibility (%)**
Eicosanoid	3.43	98.5
Hen-eicosanoid	3.69	94.2
Hepta-decane	3.63	95.7
Hexa-decane	3.49	95.8
Nona-decane	3.68	92.3
Octa-decane	3.06	96.5
Pendecane	3.11	96.4
Pentosanoid	3.05	94.7
Tetracosanoic	4.76	97.9

Furthermore, the FTIR test result in Fig. 3, it is demonstrating the atomic dynamics of UPO. Based on previous studies, it is known that when molecules receive heat, they vibrate and become reactive. The test results indicate an initial fluctuation in the 4000-3500 wave region, suggesting that the reactivity of UPO with GrO is higher compared to UPO molecules GrO. Similarly, in the 3000-500 wave region, the UPO fuel molecules without the GrO catalyst exhibit lower transmittance (around 108% T) in response to IR heat, whereas the UPO fuel with the catalyst shows higher transmittance (around 118% T).

These findings suggest that the addition of the GrO catalyst facilitates easier vibration and increased reactivity of fuel molecules. As a result, UPO fuel absorbs heat more readily, leading to a potentially shorter ignition time. Furthermore, other studies have explained that the presence of various carbon chain compounds in UPO fuel contributes to its flammability, as evident in Table 2.

This analysis is made possible by the increased fuel mass with adding catalyst. Consequently, as the fuel droplets receive heat and expand, the closer proximity of the atomic chains increases the likelihood of collisions.

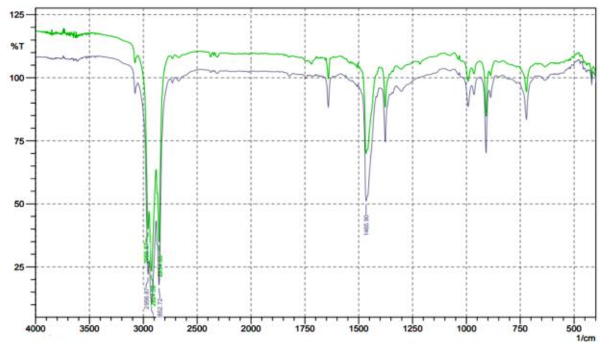

Figure 3. The reaction of UPO to infrared (IR). The green line is GrO in UPO, while the gray line is UPO without GrO.

Furthermore, the excellent superconducting properties of GrO as a catalyst can be attributed to its ability to absorb IR thermal energy, which is indicative of its strong magnetic properties. This can be attributed to the composition of GrO, consisting of carbon atoms with sp2 orbitals that form a hexagonal carbon chain bonded to each other through hydroxyl groups [14]–[16].

The unique structure of GrO enables it to generate strong interactions between electrons within the UPO. The presence of negative ions in hydroxyl and carboxylate groups further enhances these interactions, thereby increasing the mobility and reactivity of the fuel molecules. As a result, fuel droplets with GrO exhibit faster ignition timing compared to those without GrO, as depicted in Figure 4. These findings align with previous studies that have highlighted various beneficial physical properties of GrO in enhancing fuel ability, such as its high electron mobility, electrical conductivity, and thermal conductivity [17], [18].

Figure 4 illustrates the impact of incorporating GrO into UPO, as evidenced by the droplet diameter dynamics, ignition time, and average fuel ignition rate. In general, both UPO droplets have similar ways, with the droplet size decreasing from approximately Ø 2.2 mm to around Ø 1.1 mm during the heating process until ignition.

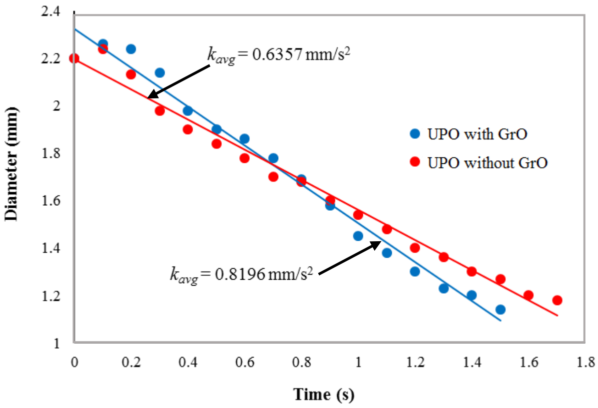

Figure 4. The dynamics of UPO Droplet

These findings show that the GrO accelerates heat absorption by the Fuel, resulting in faster ignition, as indicated by the it is time. Interestingly, although the fuel property tests (refer to Table 1) reveal that the addition of the GrO improves the fuel properties, these factors do not impede the ability of GrO to enhance the UPO's ability. However, the result demonstrates that UPO droplets with the catalyst have smaller diameters than those without the catalyst, indicating that the catalyzed fuels are more volatile and ignite more readily.

This phenomenon is plausible due to the presence of various components in UPO (refer to Table 2). Furthermore, the fuel mass increases, and the proximity by GrO and UPO carbon chains becomes closer when GrO is added. The increased density of fuel molecules facilitates stronger interactions and more effective collisions, leading to the formation of product molecules and flammability.

Consequently, the burning rate of UPO with GrO is better than that of UPO sans GrO. A higher ignition rate signifies greater fuel power, implying the potential for improved engine performance [19], [20]. Moreover, the phenomenon aligns with previous studies [21]. Additionally, previous research has indicated that the length, position, and configuration of double bonds have minimal effects on fuel ignition properties [22].

However, as depicted in Figures 5 and 6, it is evident that during the heating process until ignition, there is no bubbles are observed trapped within the droplet.

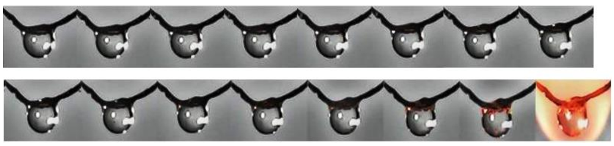

Figure 5. Dynamics droplets of UPO with GrO

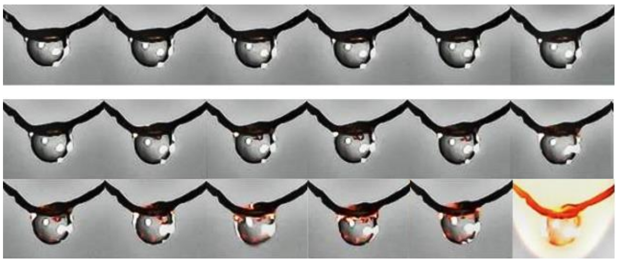

Figure 6. Dynamics droplets of UPO without GrO

Conversely, in the absence of a GrO, internal evaporation occurs twice, as indicated by the presence of trapped bubbles at different intervals of approximately 0.4 s. This phenomenon causes UPO droplets sans GrO to have a larger diameter and consequently take longer to evaporate and ignite compared to UPO droplets with catalysts. This analysis aligns with previous studies [23]–[25].

Moreover, Figure 7 shows that the viscosity of UPO is lower than other fuels but similar to kerosene. This low viscosity is a significant factor indicating that the diameter of UPO droplets does not expand at the burning stages [26].

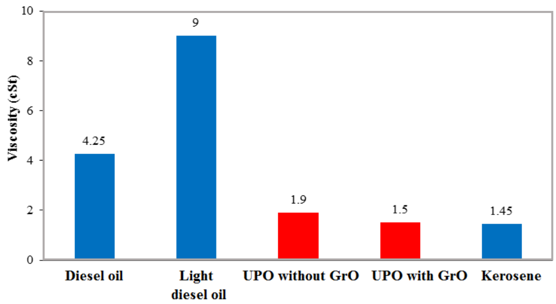

Figure 7. The viscosity of UPO with various fuels

CONCLUSIONS

The investigation was conducted to examine the impact of utilizing GrO as a fuel additive at room temperature and atmospheric pressure. The presence of GrO increased the Fuel's mass, thereby promoting stronger interactions among these molecules, leading to a higher likelihood of effective collisions. This phenomenon had the potential to weaken the dispersion forces [27].

As a result, the Fuel exhibited enhanced heat absorption and quicker ignition when graphene oxide was present. This analysis is supported by the observation that fuel-containing GrO demonstrated a faster burning time and an increasing burning rate compared to UPO sans GrO.

Furthermore, to continue this research in the future, a gap can be developed regarding the mass variation of GrO as a nanocatalyst and its impact on combustion characteristics and zoot formation.

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REFERENCES

[1] Andreev, O., Lomakina, O., and Aleksandrova, A., 2021. Diversification of structural and crisis risks in the energy sector of the ASEAN member countries. *Energy Strategy. Rev.* Vol. 35 (April) pp. 100655.

[2] ktar, M. A., Alam, M. M., and Al-Amin, A. Q. 2021. Global economic crisis, energy use, CO2 emissions, and policy roadmap amid COVID-19. *Sustain. Prod. Consum.* Vol. 26 pp. 770–781.

[3] Nanlohy, H. Y., 2021. Comparative Studies on Combustion Characteristics of Blended Crude Jatropha Oil with Magnetic Liquid Catalyst and DEX under Normal Gravity Condition. *J. Mech. Eng. Sci. Technol.* Vol. 5 (2) pp. 79–88.

[4] Nanlohy, H. Y., Riupassa, H. and Yamaguchi, M., 2022. Performance and Emissions Analysis of BE85-Gasoline Blends on Spark Ignition Engine. *Automot. Exp.* Vol. 5 (1) pp. 40–48.

[5] Sankaranarayanan, A., Lal, S., Namboothiri, I. N., Sasidharakurup, R., Chowdhury, A., and Kumbhakarna, N., 2019. Droplet combustion studies on two novel energetic propellants, an RP-1 surrogate fuel, and their blends. *Fuel*. Vol. 255 (May) pp. 115836.

[6] Auzani, A. S., Clements, A. G., Hughes, K. J., Ingham, D. B., and Pourkashanian, M., 2021. Assessment of ethanol autoxidation as a drop-in kerosene and surrogates blend with a new modelling approach. *Heliyon*. Vol. 7 (6) pp. e07295.

[7] Suyatno, Riupassa, H., Marianingsih, S., & Nanlohy, H. Y., 2023. Characteristics of SI engine fueled with BE50-Isooctane blends with different ignition timings. *Heliyon*, Vol. 9 (1) pp. e12922.

[8] Riupassa, H., Nanulaitta, N. J., Taba, H. T., Katjo, 2022. The effect of graphene oxide nanoparticles as a metal based catalyst on the ignition characteristics of waste plastic oil The Effect of Graphene Oxide Nanoparticles as a Metal Based Catalyst on the Ignition Characteristics of Waste Plastic Oil. *AIP Conf. Proc.* Vol. 030001 (January).

[9] Rodríguez, E. *et al.*, 2019. Co-cracking of high-density polyethylene (HDPE) and vacuum gasoil (VGO) under refinery conditions. *Chem. Eng. J.* (May) pp. 122602.

[10] Khodabakhshi, S., Fulvio, P. F., and Andreoli, E., 2020. Carbon black reborn: Structure and chemistry for renewable energy harnessing. *Carbon N. Y.* Vol. (162) pp. 604–649.

[11] Sachdeva, H., 2020. Recent advances in the catalytic applications of GO/rGO for green organic synthesis. *Green Process. Synth.*, Vol. 9 (1) pp. 515–537.

[12] Singh, R. K., Ruj, B., Sadhukhan, A. K., Gupta, P., and Tigga, V. P., 2020. Waste plastic to pyrolytic oil and its utilization in CI engine : Performance analysis and combustion characteristics. *Fuel.* (May) pp. 116539.

[13] Nanlohy, H. Y., Hamidi, N., and Yuliati, L., 2017. Karakteristik Pembakaran Droplet Minyak Jarak Dengan Menggunakan Katalis Pembakaran Homogen. *Prosiding SENIATI*. Vol. 3 (2) pp. E15-1.

[14] Riupassa, H., Suyatno, S., and Nanlohy, H. Y., 2023. Identifying the Effect of Aromatic Compounds on the Combustion Characteristics of Crude Coconut Oil Droplet. *Eastern-European J. Enterp. Technol.* Vol. 2 (6) pp. 6–14.

[15] Liu, G., Ruan, C., Li, Z., Huang, G., Zhou, Q., Qian, Y., and Lu, X., 2020. Investigation of engine performance for alcohol/kerosene blends as in spark-ignition aviation piston engine. *Appl. Energy*. Vol. 268 (April) pp. 114959.

[16] Behin, J. and Vahed, S., 2007. Effect of alkyl chain in alcohol deinking of recycled fibers by flotation process. *Colloids Surfaces A Physicochem. Eng. Asp.* Vol. 297 (1–3) pp. 131–141.

[17] Notarianni, M., Liu, J., Vernon, K., and Motta, N., 2016. Synthesis and applications of carbon nanomaterials for energy generation and storage. *Beilstein J. Nanotechnol.* Vol. 7 (1) pp. 149–196.

[18] A. Heidari-Maleni, T. M. Gundoshmian, B. Karimi, A. Jahanbakhshi, and B. Ghobadian, "A novel fuel based on biocompatible nanoparticles and ethanol-biodiesel blends to improve diesel engines performance and reduce exhaust emissions," *Fuel*, vol. 276, no. April, p. 118079, 2020, doi: 10.1016/j.fuel.2020.118079.

[19] Nanlohy, H. Y., Wardana, I. N. G., Hamidi, N., Yuliati, L., and Ueda, T., 2018. The effect of Rh^{3+} catalyst on the combustion characteristics of crude vegetable oil droplets. *Fuel*. Vol. 220 pp. 220–232.

[20] Zhang, W., Li, Y., Zhang, X., and Li, C., 2017. Facile synthesis of highly active reduced graphene oxide-CuI catalyst through a simple combustion method for photocatalytic reduction of CO2 to methanol. *J. Solid State Chem.* Vol. 253 (May) pp. 47–51.

[21] Nanlohy, H. Y. and Trismawati, 2022. The role of fatty acid of Morinda citrifolia oil as surface-active chemicals on the deinking process of waste paper. *Materialia*. Vol. 23, pp. 101436.

[22] Plank, M., Wachtmeister, G., Thuneke, K., Remmele, E., and Emberger, P., 2017. Effect of fatty acid composition on ignition behavior of straight vegetable oils measured in a constant volume combustion chamber apparatus. *Fuel*. Vol. 207 pp. 293–301.

[23] Nanlohy, H. Y., Wardana, I. N. G., Hamidi, N., Yuliati, L., 2018. Combustion characteristics of crude jatropha oil droplets using rhodium liquid as a homogeneous combustion catalyst. *IOP Conf. Ser. Mater. Sci. Eng.* Vol. 299 (1) pp. 0–7.

[24] Rotavera, B and Taatjes, C. A., 2021. Influence of functional groups on low-temperature combustion chemistry of biofuels. *Prog. Energy Combust. Sci.* Vol. 86 (xxxx) pp. 100925.

[25] Jiang, W., Chen, Y., Gao, L., Sun, M., Wang, X., Li, Z., ... and Zhou, H., 2020. Hydroformylation for reducing the olefin content in the FCC light gasoline with magnetic rhodium-catalysts. *Fuel.* Vol. 279 (April) pp. 118508.

[26] Dai, Y., Nie, G., Gong, S., Wang, L., Pan, L., Fang, Y., ... and Zou, J. J., 2020. Reduced graphene oxide enhanced emulsification for one-pot synthesis of high-density jet fuel. *Fuel*. Vol. 275 (April) pp. 117962.

[27] Nanlohy, H. Y. and Riupassa, H., 2020. An Experimental Study on the Ignition Behavior of Blended Fuels Droplets with Crude Coconut Oil and Liquid Metal Catalyst. *Automot. Exp.* Vol.3 (2) pp. 39–45.