

Tribological effects of engine oil type on diesel engine efficiency and pollutant formation

ARTICLE INFO

The goal of this research is to determine how different types of engine oil affect how well a four-stroke, single-cylinder, air-cooled, direct-injection diesel engine performs and how much pollution it produces. At 1000, 2000, and 2500 rpm, the engine was linked to a hydraulic dynamometer and driven with a continuous load of 4.0 N·m. Local Baghdad Oil (B1), Gulf Oil (G1), and PRO-TEC Oil (P1) – three lubricating oils – were assessed. Using an AIRREX HG-540 gas analyser, engine performance and emissions were assessed based on brake-specific fuel consumption (BSFC), exhaust gas temperature, and nitrogen oxides (NO_x), carbon monoxide (CO), and carbon dioxide (CO₂) emissions. For all oils, results show that BSFC dropped as engine speed rose. PRO-TEC Oil (P1) had the lowest BSFC of 0.290 kg/kWh at 2500 rpm; Baghdad Oil (B1) had the highest value of 0.351 kg/kWh at 1000 rpm. Exhaust gas temperature increased with speed, reaching a maximum of 243°C for B1 at 2500 rpm; P1 consistently had the lowest exhaust gas temperature, with a minimum of 188°C. As engine speed rose, CO emissions rose; P1 had the highest value at 1000 rpm (0.018%), while B1 had the lowest (0.013%). Rising speed also increased CO₂ and NO_x emissions; B1 had the highest NO_x (300.1 ppm) and CO₂ (2.451%), whereas P1 consistently showed the lowest emissions. The outcomes highlight the advantages of oils with improved viscosity and thermal stability for enhanced performance and decreased environmental impact by showing that engine oil qualities greatly influence diesel engine efficiency and emissions.

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1. Introduction

Internal combustion engines are complex systems in which a significant fraction of the energy produced is consumed within, primarily due to friction and the heat generated between moving parts [9, 30]. Over time, this friction causes wear and deterioration of engine components and raises energy losses [15]. Overcoming friction – which always opposes motion – takes more energy, which eventually turns into heat. This makes wear worse and makes the engine less efficient overall. Lubrication is therefore very important in all engines, as it creates a thin oil film between moving metal surfaces, thereby decreasing direct contact and lowering frictional losses. Given the numerous moving components and frictional surfaces inside an engine, lubrication oil is essential to ensure long life and trouble-free operation. In diesel engines, efficiency depends on how well they are lubricated. Increased friction affects the compression ratio, which can affect engine efficiency. Furthermore, at higher engine speeds, friction forces increase; hence, the importance of proper lubrication to preserve mechanical efficiency and avoid excessive wear. Improved lubrication also helps to improve gas mileage since it lowers frictional losses [4, 5].

Generally speaking, oil viscosity is among the most crucial characteristics that greatly affect its lubricity; usually, high viscosity reduces frictional losses [7, 10]. Oil viscosity, however, is quite susceptible to temperature changes; it drops as temperature rises. The lubricating film may be broken down by high temperatures, which accelerates wear and increases metal-to-metal contact. Though minor increases in oil temperature lower viscosity and friction [18].

The demands on lubricants likewise vary depending on engine load. Increasing load increases cylinder pressures

and friction losses; this is partially offset by the related drop in oil viscosity due to high temperatures [14, 16]. Engine lubrication primarily reduces friction, removes heat, removes contaminants such as wear particles and carbon, and keeps critical parts like piston rings and seats clean. Lubricating oil also reduces engine noise, cushions shocks, and keeps moving parts from touching each other, which helps the engine last longer [3, 4].

Given the high operating temperatures of engines, lubricating oils have to be somewhat thick, stable, and thermally resistant [20]. Heat and mechanical stress degrade oil quality over time; therefore, regular oil changes are essential to keep the engine running in perfect condition [24, 25]. Another key metric is the viscosity index, which shows how temperature affects oil viscosity. A vital attribute that stops engine parts from rusting at high temperatures is oxidation resistance [26].

Although mineral oils perform reasonably well under normal conditions, contemporary engines and challenging operating environments often require improved oil compositions. Detergents, anti-wear agents, anti-rust chemicals, and anti-foam agents are among the additives added to oil to improve its performance, protect engine parts, and keep the oil clean [21, 23]. Notably, studies show a close relationship between engine speed, load, and exhaust emissions, including nitrogen oxides (NO_x), where higher levels are observed at higher operating loads [18, 22]. For these reasons, this study looks at how three different engine oils, Baghdad Oil (B1), PRO-TEC Oil (P1), and Gulf Oil (G1), affect how well a single-cylinder, four-stroke diesel engine runs and how much pollution it puts out. While P1 and G1 are well-known companies that offer a range of additives, including anti-wear agents, oxidation and corrosion inhibi-

tors, detergents, and shear-stability improvers, B1 oil is locally produced with no additives. This study aims to clarify the relationships among oil type, engine performance, and environmental impact by closely examining factors such as brake-specific fuel consumption (BSFC), friction power, exhaust gas temperature, and key emissions (NO_x , CO, and CO_2), thereby guiding the selection of optimal lubricants for diesel engines.

2. Test procedure

This investigation looked at three different types of engine oils: B1, P1, and G1 for their impact on the performance and emissions of a single-cylinder, four-stroke, air-cooled, direct-injection diesel engine. The experimental procedure looked at three speed levels: 1000, 2000, and 2500 rpm. Throughout all the tests, a constant load of 4.0 N·m was maintained.

Before every test, the first step was to drain all remaining oil so the oil samples wouldn't get mixed. Ten minutes of engine running after filling with the preferred oil type, Baghdad Oil (B1), first helps achieve thermal and operational stability. The engine speed was adjusted to 1000 rpm under the fixed load once steady state was reached, and the system was allowed to run for another 10 minutes to ensure steady-state conditions. Each test recorded the following measurements.

Exhaust gas temperature was measured using the test panel display, which has a gas temperature sensor.

Fuel consumption was measured using a graduated fuel tube, with the consumption time tracked via the panel.

Engine power output was calculated from electronic platform readings.

Exhaust emissions by an AIRREX HG-540 exhaust gas analyser with the sampling probe put into the exhaust stream (CO , HC , CO_2 and NO_x) were determined.

The engine speed was raised to 2000 rpm after the 1000 rpm measurements were taken. Following a 10-minute stabilization period, the same set of readings was gathered. The approach was repeated at 2500 rpm.

After the tests with Baghdad Oil were finished, the engine oil was drained and replaced with PRO-TEC Oil (P1). Once more, run for 10 minutes to guarantee stability. The engine was tested at every speed using the full measurement protocol. This method was later applied to the third oil sample, Gulf Oil (G1), to ensure that every oil kind was tested under the same conditions. For subsequent study, all relevant data, including fuel consumption, exhaust gas temperature, engine speed, load, and emission concentrations, were carefully preserved. This rigorous experimental technique ensures reliable, replicable results. It allows a reliable test of the effects of several engine oils on diesel engine performance and emissions under regulated laboratory conditions.

3. Materials and methods

3.1. Test engine

The experiments were conducted using a British-manufactured, single-cylinder, four-stroke, air-injected diesel engine (see Fig. 1). The technical specifications of the engine are detailed in Table 1.



Fig. 1. Testing engine

Table 1. Technical specifications of the engine

Engine manufacturer	TQ company for testing and training
Type of engine	TD 111
Piston displacement	230 cm ³
Stroke	60 mm
Bore	70 mm
Nominal output	3.5 kW at 3600 rev/min
Maximum torque	10.5 Nm at 2200 rev/min

3.2. Test panel and instrumentation

Instruments for monitoring torque, exhaust gas temperature, engine speed, and fuel usage abound on the engine test panel. Over a given period, a graduated tube helped us calculate fuel usage. Using an AIRREX HG-540 exhaust gas analyzer (Korea), real-time CO , CO_2 , and NO_x emissions were measured in ppm. Table 2 lists the specifications of the analyzer; Fig. 2 shows it.

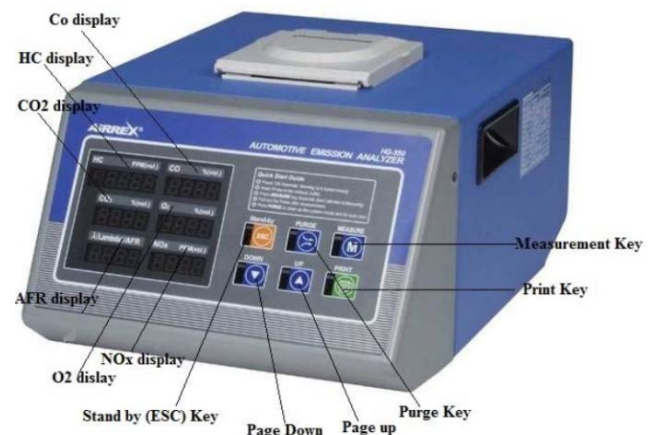


Fig. 2. Exhaust analysis device

Table 2. Technical specifications of the exhaust analyzer

HG-540	Specification			
Measuring range	CO ₂	0–200,000 ppm	CO	0.000–9.999%
Resolution		1 ppm		0.001%
Measuring range	NO _x	0–5000 ppm	AFR	0.5–3.0
Resolution		1 ppm		0.001%
Flow rate	L/min	Power supply	AC90-260 V 50/60 Hz	

3.3. Engine oils

Petroleum labs examined the three oils tested – Baghdad Oil, PRO-TEC Oil, and Gulf Oil – to verify their qualities before and after use; the findings are shown in Table 3.

Table 3. Types of engine oil and its analysis

Lab. Ins. Data	Babil Oil before use	Babil Oil after use	Gulf Oil before use	Gulf Oil after used	PRO-TEC Oil before use	PRO-TEC Oil after use
Vis.c.st @40°C	84.89	70.99	93.1	84.98	94.12	85.99
Vis.c.st @100°C	17.22	16.8	14.82	12.83	14.1	13.78
Vis. index	98	101	161.99	146	156.98	145
T.B.N mg KOH/gm Oil	5.61	4.9	7.45	6.82	6.66	6.42
Ash wt. %	0.64	0.60	0.91	0.82	0.78	0.75

3.4. Performance indicators

The evaluation of engine performance was based on measurements of the following parameters.

- Brake power: It represents the net power output from the engine, and it was calculated using Eq. 1 [12]

$$PW = \frac{2\pi NT}{60000} \quad (1)$$

- BSFC in kg/kW·h: It was determined using Eq. (2) [7]:

$$BSFC = \frac{mf}{B.P} \quad (2)$$

- Friction power: It was calculated according to Eq. (3) [6]:

$$F.B = I.P - B.P \quad (3)$$

4. Results and discussion

Three different engine oils – B1, P1, and G1 – were tested to determine how they affected the performance and emissions of a single-cylinder, four-stroke diesel engine at 1000, 2000, and 2500 rpm under a constant load of 4.0 Nm. Power output, BSFC, exhaust gas temperature, and CO, CO₂, and NO_x emission levels were among the key performance indicators. As shown in Fig. 3, the applied load remained constant across the tested oils, yet there were minor differences in brake performance. Reduced frictional losses cause the lighter, more thermally stable oil (P1) to deliver slightly more brake power across all engine speeds. On the other hand, the higher-viscosity oil (B1) showed somewhat lower power output because it offered greater resistance. G1 showed intermediate behavior.

For all tested oil types (B1, P1, and G1), Fig. 4 shows a decrease in BSFC with increasing engine speed. Usually explained by improved combustion efficiency and lower relative frictional losses at higher speeds, this inverse relationship is a well-documented phenomenon. To be more precise, the engine performs less effectively at the lowest

speed (1000 rpm) due to increased relative friction and insufficient combustion. The highest BSFC values, particularly with B1 (0.351 kg/kWh), point to this. The combustion process is more thorough, and the mechanical losses of the engine represent a smaller proportion of total power output at the highest tested speed (2500 rpm). With a BSFC of 0.290 kg/kWh, P1 here has the lowest BSFC, i.e., the best fuel efficiency.

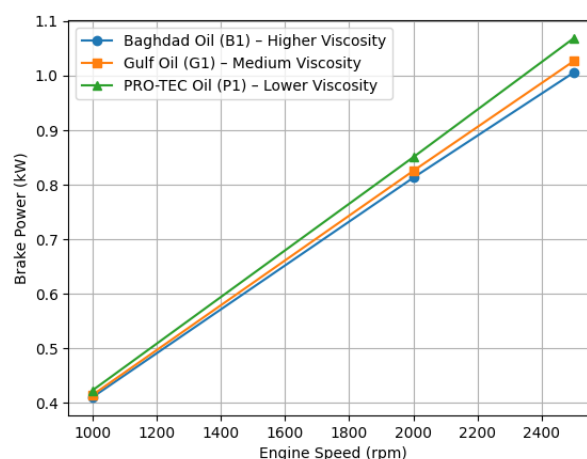


Fig. 3. Effect of oil type on brake power for different engine speeds

Their thermal stability and viscosity indices [2, 6] account for most of the differences in oil performance. The most stable viscosity across the speed and temperature range is found in PRO-TEC Oil (P1). It maintains a protective oil film and reduces friction. Lower BSFC readings result from less energy lost battling internal engine friction. Most likely due to either inadequate viscosity or poor additive package, Baghdad Oil (B1) has better BSFC at all speeds. More friction from this could increase engine wear over time. Gulf Oil's performance ranges from P1 to B1, indicating good viscosity stability and lubricity.

P1's lower BSFC across all speeds shows it is more efficient at lowering frictional losses than B1 and G1. At higher speeds, when oil-film breakdown is a possibility and frictional forces rise, this is particularly important. On the other hand, B1's higher BSFC points to greater internal resistance, perhaps due to low viscosity or insufficient anti-wear chemicals, which not only raise fuel consumption but may also accelerate wear of engine parts. Good lubrication (like that of P1) keeps piston motion more regular and improves sealing, hence enhancing combustion quality and lowering fuel waste [27–30]. On the other hand, insufficient lubrication causes the engine to burn more fuel, incomplete combustion, and increased blow-by [26], as B1 does.

Lower BSFC directly translates into less fuel use per unit of power, thereby benefiting the economy (reduced operating expenses) and the environment (less CO₂ emissions). As a result, the type of oil you use is a crucial operational choice, particularly in high-utilization or large-scale diesel applications, where even minor changes in BSFC can yield high cost and emissions reductions over time. Oils like P1, which retain their thickness well, not only help your car use less gas now but also protect the inside of your

engine. This could help your engine run longer and lower how often you have to change the oil. Modern diesel engines should use premium, thermally stable oils in line with industry advancements toward tougher emission standards and cleaner, more efficient operation. The results reinforce this need. Later plots show that the BSFC trend in Figure 4 backs up the documented decreases in exhaust temperature and emissions (NO_x , CO_2) with P1 oil. This full evolution makes clear how closely related environmental performance, combustion efficiency, and lubrication are.

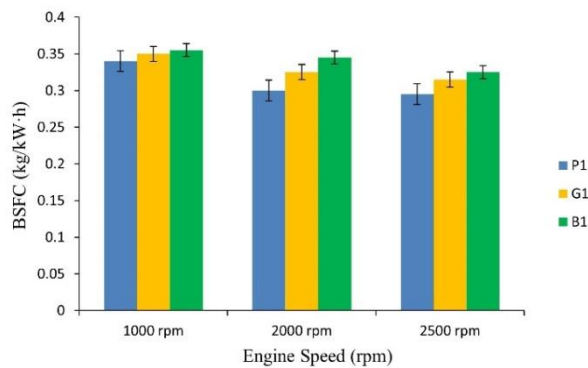


Fig. 4. Effect of oil type on BSFC for different engine speeds

Figure 5 shows a clear, consistent trend across all oil types: exhaust gas temperature (EGT) increases with engine speed. This is natural, since more fuel is required per unit time at higher engine speeds, which generates more heat and results in higher exhaust temperatures. Given the great impact of oil type on EGT, more research is nevertheless justified. Remarkably, Baghdad Oil (B1) has the highest exhaust temperatures across all engine speeds, 243°C at 2500 rpm. On the other hand, PRO-TEC Oil (P1), with a minimum of 188°C , has the lowest exhaust temperatures across all speeds. Usually, between B1 and P1, Gulf Oil (G1) has values in the middle. The various EGT values of the oil kinds may be explained by their viscosity indexes, additives, and thermal stability. P1's superior performance likely results from its high viscosity index and complex additives, which help maintain a stable lubricating film even at high speeds and temperatures. Great viscosity also reduces friction between moving engine parts, and mechanical losses generate less heat. On the contrary, B1's higher EGT points to a lower viscosity index or a less effective additive composition, which increases friction and the heat transferred to the exhaust gases. P1's lower EGT suggests improved engine thermal control [17]. P1 oil's improved frictional heating reduction lowers the thermal burden on engine components and helps prevent oil breakdown and thermal degradation.

Lower exhaust temperatures may signal more efficient energy conversion, since more of the fuel's energy is used for mechanical work rather than being wasted as heat [5]. Although the extraordinarily high EGTs might also encourage the development of nitrogen oxides (NO_x), as these emissions are very temperature-dependent [19]. The lower EGT observed with P1 confirms the link between oil choice, combustion temperature, and pollutant generation,

thereby supporting the study's findings on decreased NO_x emissions.

Therefore, PRO-TEC Oil (P1) not only enhances fuel economy (as seen in Fig. 3) but also helps to better manage temperature, which is very important for engines running under varying or high-load conditions. Although using Baghdad Oil (B1) may lead to higher operating temperatures, increased emissions, and faster engine wear, it is less appropriate for demanding or long-term use.

Lower EGTs have benefits for the environment and the economy by reducing thermal pollution and lowering the risk of heat-related engine failure. Therefore, not only about present engine performance but also about engine durability, emission law compliance, maintenance costs, and other domino effects of oil choice. As will be seen in subsequent pages, the lower EGTs detected with P1 match its overall improved thermal stability, lower NO_x and CO_2 emissions, and lower BSFC profile. This extensive advantage profile makes it obvious the need to pick premium, thermally stable lubricants for modern diesel engines.

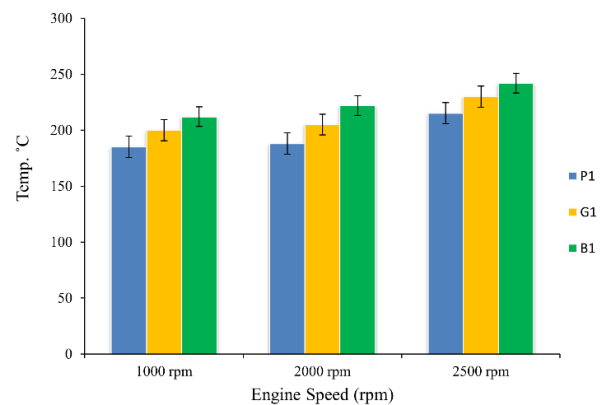


Fig. 5. Effect of oil type on the exhaust gas temperature through different engine speeds

Figure 6 shows that CO emissions for all kinds of oil increase with engine speed. Diesel engines' combustion dynamics match this trend: speed increases; fuel injection and combustion get faster and less complete; hence, carbon monoxide emission rises, a sign of incomplete combustion. Particularly at faster speeds, P1 generated the most CO emission (0.018%); At 1000 rpm, B1 had the least CO emission (0.013%); G1 always showed values between B1 and P1.

Among the oils, variations in CO emissions may be explained by their viscosity and their impact on combustion quality. P1's higher viscosity and thermal stability will help reduce friction and lower engine temperatures, enabling a more sophisticated design. However, at higher speeds, this same feature can create a somewhat thicker oil film that could slow flame propagation or interfere with ideal air-fuel mixing, leading to pockets of incomplete combustion and higher CO emissions. On the other hand, B1's decreased viscosity could enhance atomization and mixing at low speeds, therefore lowering CO emissions; this comes at the cost of higher friction, wear, and other emissions (as shown in Fig. 3, 4, 6, and 7).

P1 oil gives the usual trade-off. As shown by slightly increased CO emissions, its recipe could marginally increase the likelihood of incomplete combustion at high speeds, even though it is very good at reducing friction, heat stress, NO_x, and CO₂. B1 oil is better even if its total emission profile is greater, since its smaller CO production at lower speeds, possibly due to faster combustion and less oil film interference, makes it preferable. Still, this benefit vanishes with more velocity. CO clearly shows combustion efficiency. The somewhat higher CO emissions with P1 at high speeds indicate that although the oil's lubricity is good for engine wear and fuel economy, it can affect the combustion chamber environment in ways that promote partial combustion under certain conditions.

CO emissions are regulated contaminants due to their toxicity and their role in lowering urban air quality. For fleets or high-use engines in particular, even small increases might be quite apparent overall [8]. The data imply that oil selection should align with operational priorities; if lowering CO is important (e.g., in indoor or urban settings), oil choice and engine calibration may need to be adjusted jointly. A slight rise in CO with P1 can be reduced by adjusting injection timing, air-fuel ratio, or using an oxidation catalyst. Future oil mixes could aim to maximize combustion completeness through sophisticated additive packages while still preserving P1's friction-reducing properties.

The CO emission trend in Fig. 6 supports the conclusions from Fig. 3 and 4. P1's better performance in lowering CO₂, NO_x, exhaust temperature, and BSFC comes at a little price in CO emissions at faster speeds. This underlines the complex interaction among lubrication, combustion, and emissions: supporting improvements in one field may occasionally cause problems in another. Lean diesel running shows mostly full combustion, as indicated by low CO emissions (0.013–0.018%). These values are common in part-load situations and support the conclusion that local fuel-rich regions, not global mixture enrichment, determine carbon monoxide production.

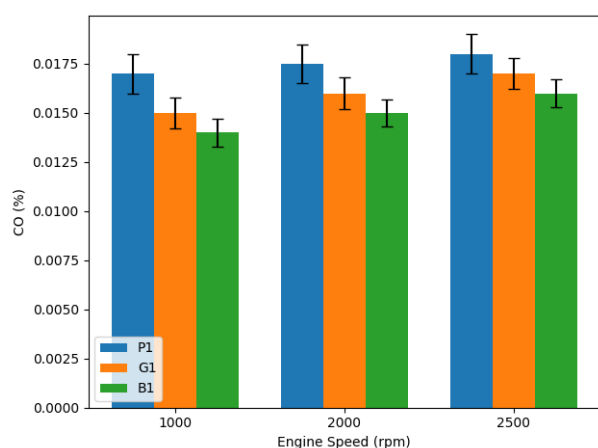


Fig. 6. Effect of oil type on CO emissions for different engine speeds

For every oil tested, Fig. 7 shows that HC emissions increase with increasing engine speed; a trend often observed in diesel engines under load. Unburned fuel components and hydrocarbons in exhaust gases directly indicate that

combustion is incomplete. The variations among oils underscore how lubricant characteristics affect this process. To be more exact, P1 oil produces the least HC emissions at lower speeds (e.g., 18 ppm at 1000 rpm), but shows a steeper rise at higher speeds, reaching 42 ppm at 2500 rpm. At low speeds (25 ppm), B1 type shows higher baseline HC emissions; at higher speeds, though, it shows a steadier increase to a maximum of 38 ppm. Consistent with its performance in past research, the G1 type shows a middle path.

Better combustion chamber sealing is shown by the lower HC emissions of P1 oil at low speeds, hence reducing fuel blow-by into the crankcase. It's a great additive package and constant viscosity, which maintains ideal piston ring lubrication, probably causes this. As engine temperatures increase with P1 oil, less combustion efficiency could account for the higher HC emission at high speeds. Reducing friction at high velocities with P1 oil can also slightly impede flame propagation or air-fuel blending, hence leaving unburned hydrocarbons. In contrast, B1 oil's higher HC emissions suggest poorer low-speed combustion efficiency, most likely due to inadequate lubrication. Still, its lower viscosity at higher speeds may improve mixing and thereby moderate the HC increase.

P1's performance indicates a sensitive equilibrium where its capacity to reduce friction raises fuel efficiency, as seen in Fig. 4, and lowers exhaust temperatures, as shown in Fig. 5. However, at extremely fast speeds, it could somewhat reduce combustion completeness and so produce more HC emissions. Conversely, the opposing trend of B1 stresses its disadvantages in low-speed sealing but some flexibility to fast conditions, albeit with trade-offs in wear, CO₂, and NO_x emissions (Fig. 8, 9). P1's anti-wear additives could reduce oil consumption, thereby controlling HC emissions from burned lubricant. On the other hand, B1's simpler form may raise oil volatility, therefore adding to HC emissions. G1's intermediate results indicate a balance between viscosity stability and additive effectiveness; hence, it performs in the middle of the spectrum across all measures.

Reducing HC emissions is therefore a top compliance priority with emissions standards (e.g., EPA Tier 4, Euro 6) since they help to cause respiratory problems and contribute to pollution. Given that engines often run at lower RPMs, P1's low-speed HC advantage is consistent with urban driving cycles. It should be noted that in applications such as heavy-duty transportation or generators, High-speed HC surges (as seen with P1) may cause issues, underscoring the need to select oil appropriate for the application. The data imply that improving the combustion system (e.g., injector design, swirl ratio) may help to lower P1's high-speed HC increase. Likewise, matching P1 with sophisticated after-treatment systems (such as diesel oxidation catalysts) would further enhance its environmental benefits.

It should also be noted that incomplete combustion yields both HC and CO [13]. P1's higher HC at high speeds should correspond to its higher CO emissions under identical conditions, thereby confirming the link between combustion dynamics and lubrication quality. The better performance of P1 in reducing CO₂, as indicated in Fig. 8, also

comes with a small trade-off in HC/CO at high speeds, underscoring the challenge of reducing emissions.

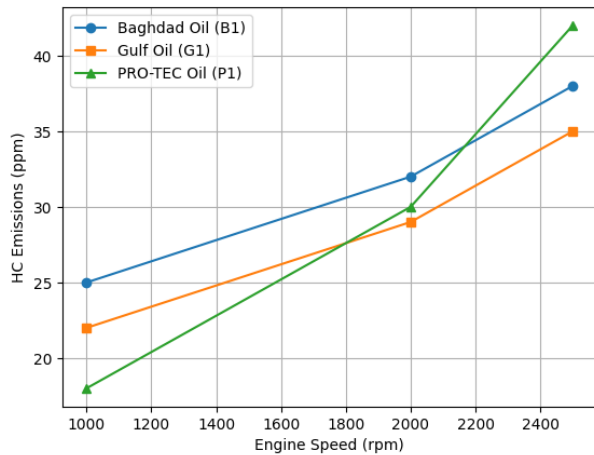


Fig. 7. Effect of oil types on the HC emissions for different engine speed

For every oil type examined, Fig. 8 shows that CO₂ emissions rise with engine speed, thereby highlighting the fundamental link between CO₂ generation and gasoline consumption. As an engine's load and speed increase, more fuel is consumed. More CO₂ results from the oxidation of the fuel's carbon content, hence driving up production. P1 oil has the least CO₂ emissions across all torque and speed ranges; B1 oil emits the most CO₂. G1 form lies between B1 and P1. P1's lower CO₂ emissions suggest better fuel efficiency, consistent with its lower BSFC and exhaust gas temperature, as shown in Fig. 4 and Fig. 5.

P1's increased lubrication lowers engine friction, thereby enabling more of the fuel's chemical energy to be transformed into mechanical work rather than being wasted overcoming friction losses. Lower fuel use from this translates into lower CO₂ emissions. B1's higher CO₂ production points to greater mechanical losses and less effective combustion, likely due to poor oil film stability and increased friction. P1's oil thermal stability and additive systems may also help to keep the combustion chamber in good working order, which stops incomplete combustion and reduces fuel waste.

The main greenhouse gas causing human-induced climate change is CO₂. It makes up most of the greenhouse gas emissions from burning fossil fuels worldwide. The modest CO₂ values (≈ 2.2 – 2.5%) point to high excess air availability throughout combustion, which is typical of diesel engines running at constant low load. Lean operation ($\lambda \geq 1$) and the rise in fuel consumption with engine speed both align with these levels. P1 oil's lowering of CO₂ emissions directly equates to a lesser carbon footprint for diesel engines, hence promoting sustainability objectives and regulatory compliance in ever more demanding emissions norms globally. Lowering CO₂ emissions improves fuel economy, which lowers the cost to operate industrial motors and vehicle fleets. Particularly in applications where they are utilized frequently, great lubricants like P1 can save a lot of fuel over time. Therefore, as shown here, the first stages of reducing emissions are crucial developments at the lubricant and engine levels. The results show the

necessity of well-coordinated plans that employ modern lubrication technology in conjunction with engine design and operating methods to achieve significant reductions in CO₂ emissions.

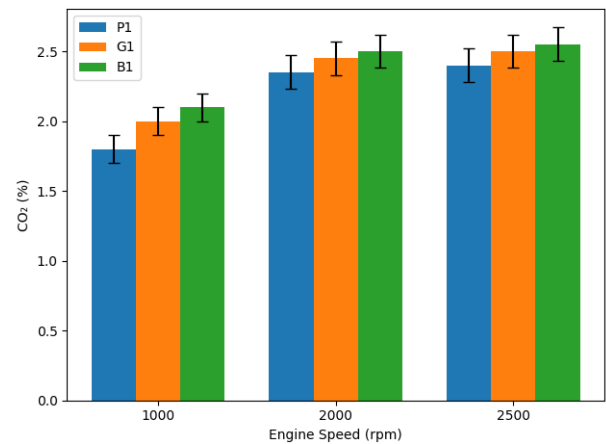


Fig. 8. Effect of oil type on CO₂ emissions for different engine speeds

Given P1's favorable influence on NO_x and hydrocarbon emissions, the CO₂ emission reductions reflect its equal improvement across a range of pollutant categories. Apart from its mechanical performance, the lubricant composition helps with environmental stewardship, as shown in this general emission reduction graph. For all examined engine oils, as shown in Fig. 9, higher combustion temperatures at higher speeds lead to increased NO_x emissions. P1 produces the lowest NO_x emissions among the oils, followed by G1; B1 has the highest values at all speeds. Higher engine speeds bring out the differences more clearly, showing that oils like P1, with better viscosity stability and thermal properties, reduce NO_x generation and frictional heating.

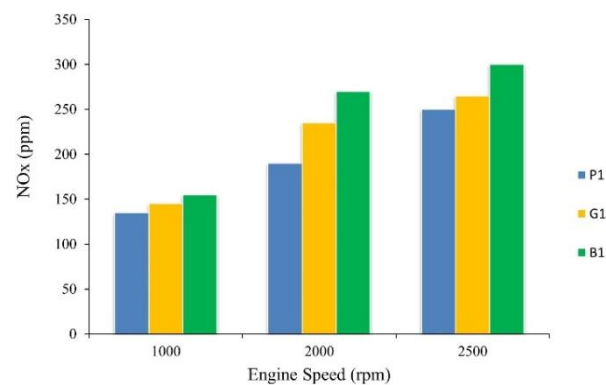


Fig. 9. Effect of oil type on the NO_x through different engine speeds

As shown in Fig. 10a, the friction coefficient for all oils increases with engine speed due to thermal effects and higher sliding velocity. Showing better lubrication and lower mechanical losses, P1 has the least friction; G1 has moderate behavior; B1 has the most friction. For all oils, the wear depth, as seen in Fig. 10b, also increases with engine speed. While P1 shows the lowest wear depth, indicating improved surface protection and increased anti-wear capability, B1 shows the highest wear, and G1 shows intermediate wear.

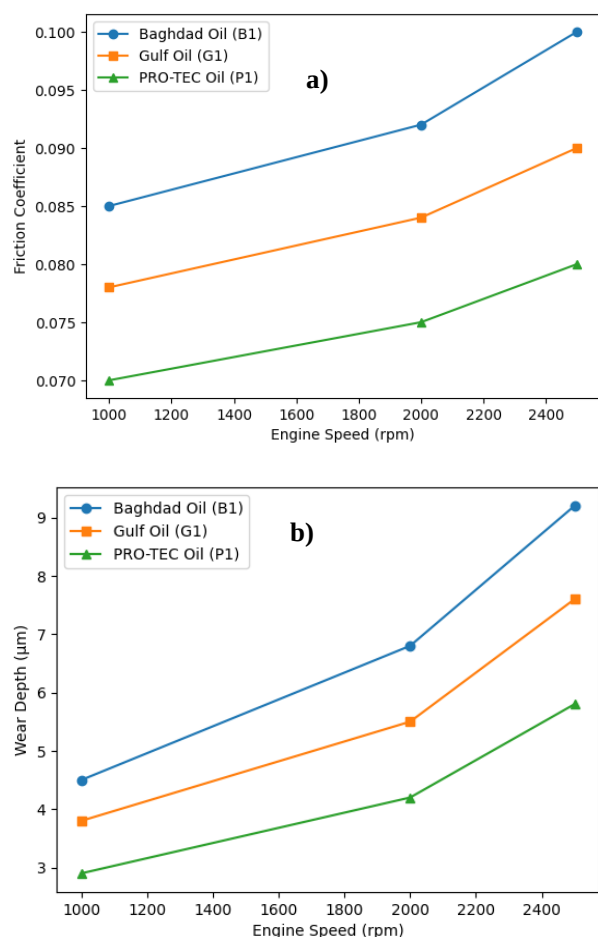


Fig. 10. a) Effect of oil type on the friction coefficient through different engine speeds; b) wear depth

5. Conclusions and future work

In controlled laboratory environments, three different engine oils, B1, P1, and G1, were meticulously evaluated for their impacts on the performance and emission profile of a single-cylinder, four-stroke diesel engine. The results show that oil type significantly affects engine efficiency, exhaust gas temperature, and emissions across a range of engine speeds.

Among the oils investigated, P1 oil showed the lowest BSFC and exhaust gas temperatures, indicating its excellent lubricating properties that help minimize heat stress and friction losses at higher speeds. Higher combustion efficiency and decreased production of harmful substances are also indicated by the lowest NO_x and CO₂ emissions seen with P1 oil use. But with the P1 type at higher engine speeds, a tiny rise in CO emissions was seen. B1, on the other hand, possibly due to its lower viscosity and reduced thermal stability under load, exhibits higher BSFC, higher exhaust gas temperatures, and higher NO_x emissions.

The results of this research emphasize the need for the kind of engine oil applied to lower the environmental footprint and boost engine efficiency. Emphasizing especially the necessity of aligning oil grades with specific engine operating conditions, P1 oil at the lowest examined engine speed (1000 rpm) provided the ideal balance of lower friction, reduced exhaust temperatures, and the least emissions. Future research might look into these avenues to build on these findings:

- To evaluate oil deterioration, wear rates, and maintenance intervals for each oil type under actual operating conditions, long-term engine tests were conducted; therefore, durability testing was expanded.
- Broader oil compositions are researched by observing their behavior to determine how synthetic and semi-synthetic oils, as well as oils with advanced additive packages, influence modern diesel engine technologies.
- Engine performance and emissions under varying loads and transient speed conditions should be evaluated using variable loads and transient conditions to better reflect real-world driving situations.
- Analyzing oil prices, engine maintenance expenses, and possible fuel savings in light of which to direct useful recommendations for fleet managers and single consumers.

By further defining the link between lubricating oil properties, engine lifespan, and environmental performance, these phases help improve the selection of oil for various diesel engine applications.

Bibliography

- Adril E, Abdullah S, Ariffin AK, Muchtar A, Omar K. Comparative study of characteristic of lubricant oils in gasoline and compressed natural gas engines. *Eur J Sci Res*. 2009;30:282-293.
- Agocs A, Nagy AL, Tabakov Z, Perger J, Rohde-Brandenburg J, Schandl M et al. Comprehensive assessment of oil degradation patterns in petrol and diesel engines observed in a field test with passenger cars conventional oil analysis and fuel dilution. *Tribol Int*. 2021;161:107079. <https://doi.org/10.1016/j.triboint.2021.107079>
- Beşergil B, Özer MS, Eskici M, Atik E. Study on lubricant quality and its effect on engine component performance. *Ind Lubr Tribol*. 2008;60:172-177. <https://doi.org/10.1108/00368790810881506>
- Charalampous A, Karkanis A, Sparis P. Behavior of a small four-stroke engine using as fuel methanol-gasoline mixtures. *SAE Technical Paper 2003-32-0024*. 2003. <https://doi.org/10.4271/2003-32-0024>
- Di Battista D, Cipollone R. Waste energy recovery and valorization in internal combustion engines for transportation. *Energies*. 2023;16:3503. <https://doi.org/10.3390/en16083503>
- Durango-Giraldo G, Zapata-Hernandez C, Santa JF, Buitrago-Sierra R. Palm oil as a biolubricant: Literature review of processing parameters and tribological performance. *J Ind Eng Chem*. 2022;107:31-44. <https://doi.org/10.1016/j.jiec.2021.12.018>
- Elango T, Senthilkumar T. Performance and emission characteristics of CI engine fuelled with non-edible vegetable oil and diesel blends. *J Eng Sci Technol*. 2011;6:240-250.
- Fleiter T, Frago J, Lux B, Alibaş Ş, Al-Dabbas K, Manz P et al. Hydrogen infrastructure in the future CO₂-neutral European energy system: How does the demand for hydrogen affect the need for infrastructure? *Energy Technol*. 2025;13: 2300981. <https://doi.org/10.1002/ente.202300981>

- [9] Gligorijevic R, Jevtic J, Borak DJ. Engine oil contribution to diesel exhaust emissions. *J Synth Lubr.* 2006;23:27-38. <https://doi.org/10.1002/jsl.10>
- [10] Hassan QH, Alalwan H, Mohammed M, Mohammed MF. Identifying the impact of methanol–diesel fuel on the environment using a four-stroke CI engine. *J Appl Eng Sci.* 2023;1-6. <https://doi.org/10.5937/jaes0-39809>
- [11] Hassan QH, Ali NSM, Alalwan HA, Alminshid AH, Mohammed MM. The impact of adding nanoparticles to bio-diesel fuel prepared from waste sunflower oil on the performance and emission of diesel engines. *Circ Econ.* 2025;4: 100138. <https://doi.org/10.1016/j.ccc.2025.100138>
- [12] Hassan QH, Araibi AS, Shather AH, Mohammed MM, Alalwan HA. The impact of utilizing waste sunflower oil as a biodiesel blend on four-stroke engine performance and emissions. *Designs.* 2024;8:38. <https://doi.org/10.3390/designs8030038>
- [13] Horák J, Kuboňová L, Hopan F, Kremer J, Dej M, Tomšej T et al. Influence of co-combustion of unsuitable fuels with standardized fuels in households on CO, OGC, PM, and PAH emissions. *Environ Sci Pollut Res.* 2022;29:44297-44307. <https://doi.org/10.1007/s11356-022-18948-y>
- [14] Lee PM, Priest M, Stark MS, Wilkinson JJ, Smith LJR, Taylor RI et al. Extraction and tribological investigation of top piston ring zone oil from a gasoline engine. *Proc Inst Mech Eng Part J J Eng Tribol.* 2006;220:171-180. <https://doi.org/10.1243/13506501JET148>
- [15] Mihaljuš Sklepić V, Podobnik M, Bambić J. Engine oil viscosity index improver behaviour at extended shear stability test. *Goriiva i Maziva.* 2008;47:107-117.
- [16] Mohammed AS, Atnaw SM, Ramaya AV, Alemayehu G. A comprehensive review on the effect of ethers, antioxidants, and cetane improver additives on biodiesel–diesel blend in CI engine performance and emission characteristics. *J Energy Inst.* 2023;101227. <https://doi.org/10.1016/j.joei.2023.101227>
- [17] Nie X, Bi Y, Liu S, Shen L, Wan M. Impacts of different exhaust thermal management methods on diesel engine and SCR performance at different altitude levels. *Fuel.* 2022; 324:124747. <https://doi.org/10.1016/j.fuel.2022.124747>
- [18] Onyeji LI, Aboje AA. The effect of additives on the viscosity index of lubricating oil (engine oil). *International Journal of Engineering Science and Technology.* 2011;1864-1869.
- [19] Pribadi AP, Rauf AU, Rahman YMR, Haq ZF. Air quality and urban sustainable development – current issues and future directions. *Inustainable Urban Environment and Waste Management: Theory and Practice.* Springer 2025:23-51. https://doi.org/10.1007/978-981-96-1140-9_2
- [20] Raghuvanshi NS, Johari A, Saxena M, Gupta AK, Choudhary A, Kumar A et al. Thermally stable lubricants. In: *Performance Characterization of Lubricants.* CRC Press. 2024:262-288.
- [21] Ren C, Zhang X, Jia M, Ma C, Li J, Shi M et al. Antifoaming agent for lubricating oil: Preparation, mechanism and application. *Molecules.* 2023;28:3152. <https://doi.org/10.3390/molecules28073152>
- [22] Saaidia R, Hamdi F, Krotli M, Bouabidi A, Cuce E, Koten H et al. Performance and emission characteristics of hydrogen enriched CNG in a dual fuel diesel engine: An experimental and numerical research. *Renew Energy.* 2025;241:122387. <https://doi.org/10.1016/j.renene.2025.122387>
- [23] Şimşek M, Nteziyaremye ÖS, Kaleli H, Tunay RF, Durak E. Experimental analysis of effect to friction of commercial oil additive used in automobiles. *Politeknik Dergisi.* 2024; 27(3):921-929. <https://doi.org/10.2339/politeknik.1204731>
- [24] Su R, Cao W, Jin Z, Wang Y, Ding L, Maqsood M et al. Deterioration mechanism and status prediction of hydrocarbon lubricants under high temperatures and humid environments. *Lubricants.* 2024;12:116. <https://doi.org/10.3390/lubricants12040116>
- [25] Szpica D, Gęca MS, Hunicz J, Jakubowski M, Krzemiński A, Mieczkowski G. Cycle-by-cycle performance evaluation of a diesel engine fueled with a mixture of hydrotreated vegetable oil mixed with waste plastic pyrolysis oils. *Combustion Engines.* 2025;202(3):109-117. <https://doi.org/10.19206/CE-207383>
- [26] Taylor RI. Fuel–lubricant interactions: Critical review of recent work. *Lubricants.* 2021;9:92. <https://doi.org/10.3390/lubricants9090092>
- [27] Uniyal P, Gaur P, Yadav J, Khan T, Ahmed OS. A review on the effect of metal oxide nanoparticles on tribological properties of biolubricants. *ACS Omega.* 2024;9:12436-12456. <https://doi.org/10.1021/acsomega.3c08279>
- [28] Wang Z, Shuai S, Li Z, Yu W. A review of energy loss reduction technologies for internal combustion engines to improve brake thermal efficiency. *Energies.* 2021;14:6656. <https://doi.org/10.3390/en14206656>
- [29] Zacharewicz M, Bogdanowicz A, Socik P. Capacitance-based assessment of water content in fuels and lubricating oils for marine engines. *Combustion Engines.* 2025;202(3): 81-87. <https://doi.org/10.19206/CE-204692>
- [30] Zangana LMK, Yaseen AH, Hassan QH, Mohammed MM, Mohammed MF, Alalwan HA. Investigated kerosene–diesel fuel performance in internal combustion engine. *Clean Eng Technol.* 2023;12:100591. <https://doi.org/10.1016/j.clet.2022.100591>

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