



Graphene Additives for Performance Enhancement of a Small-Scale 1100 W Generator Using Pertamina Fuel and Lubricant

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ABSTRACT: Graphene has emerged as a promising additive for both fuels and lubricants due to its potential to enhance combustion processes and minimize energy losses in engine systems. This research investigates the effect of graphene on the operational efficiency of a 1100 W gasoline generator powered by Pertamina fuel and standard lubricants. Prior to testing, the combustion chamber underwent thorough cleaning to ensure consistent results. The experimental procedure comprised four distinct stages: (1) utilization of pure Pertamina, (2) Pertamina blended with graphene prior to cleaning, (3) incorporation of graphene into the lubricant following chamber cleaning, and (4) application of pure Pertamina after cleaning. Each condition was evaluated under a constant load of 820 W, with assessments covering fuel consumption and runtime until depletion. The results demonstrate that while fuel additives provided modest gains, the inclusion of graphene in the lubricant combined with chamber cleaning significantly improved fuel efficiency by up to 7.47 % relative to the baseline. In contrast, the inclusion of graphene in the lubricant after combustion chamber cleaning significantly reduced fuel consumption by up to 6.64 % relative to the baseline. These findings indicate that graphene is more effective as a lubricant additive than as a fuel additive for small-scale generators. Overall, combining combustion chamber cleaning with the use of graphene-enhanced lubricants offers an accessible and effective approach to improving generator efficiency, presenting noteworthy economic and environmental benefits.

Keywords: Graphene Additive, Fuel Efficiency, Pertamina Fuel, Lubricant Enhancement.

1. INTRODUCTION

Fuel consumption efficiency represents a key operational and economic metric in the power generation industry, especially for small-scale generator sets frequently employed as backup or primary energy sources in residential, commercial, and remote

settings[1]. Inadequate combustion within these systems, including commonly utilized 1100 W generators, can lead to higher operating costs and increased environmental impact due to greater exhaust emissions. Accordingly, both research and industry have prioritized

enhancements in combustion efficiency and reductions in mechanical losses.

Generator performance and fuel efficiency are governed by multiple factors, such as fuel properties, engine load, and the maintenance condition of essential components like the lubrication system [2]. Suboptimal atomization and carbon deposition, coupled with insufficient lubrication that increases friction, contribute to excessive fuel use and accelerated engine wear [3]. In response, innovations in nanotechnology have supplemented traditional maintenance by introducing new approaches for efficiency improvement.

Graphene, a two-dimensional material comprised of carbon atoms, has gained attention as a nano-additive for its high thermal and electrical conductivity, mechanical integrity, and tribological benefits [4]. When dispersed in fuel, graphene nanoparticles can improve atomization and facilitate more complete combustion. Studies of internal combustion engines showed that the use of graphene nanoplatelets led to reductions in brake-specific fuel consumption and emissions. Additional research has confirmed that graphene-based additives can support faster combustion rates in gasoline engines. The use of graphene in lubricants has further demonstrated benefits, as the formation of a protective tribo-film effectively decreases friction and wear on moving parts [5]. More recently, experiments with motorcycle engines have indicated that graphene-enhanced lubricants can lower both operational temperature and fuel consumption.

Despite these promising findings, a critical gap persists in the literature. The majority of existing research, including the works [6], is predominantly concentrated on automotive-scale or diesel engines. While a seminal study

explored the synergistic effect of graphene in both fuel and lubricant on a diesel engine [7], the operational profile of small-scale, single-cylinder, air-cooled gasoline generators characterized by constant speed under varying loads remains markedly underexplored. No study to date has specifically investigated the dual-application of graphene in both premium gasoline (Pertamax, RON 92) and lubricant on a 1100 W generator set. This gap underscores the novelty of the present research.

Therefore, this study is designed to bridge this research gap by systematically evaluating the synergistic impact of graphene nanoparticles as a dual-purpose additive on the performance of a 1100 W gasoline generator. Building upon the foundational work of [8], and inspired by the synergistic approach of [6], this research will quantitatively assess the combined effect of graphene-enriched Pertamina fuel and graphene-enhanced lubricant on key performance metrics: fuel consumption rate, effective power output, and operational temperature. The findings are expected to provide a validated, practical, and innovative strategy for optimizing the efficiency and reliability of small-scale power generation systems.

2. MATERIALS AND METHODS

The experimental investigation was designed to assess the performance enhancement of a 1100 W SUMURA ET2500C generator operating at a constant 820 W load. A comparative design was implemented during four sequential testing phases: (1) A baseline with pure Pertamina fuel and standard oil in a carbon-fouled engine; (2) Graphene additive mixed directly into Pertamina fuel at varying concentrations (0.050-0.175 g per unit volume) in the fouled engine; (3) Graphene nanolubricant (e.g., 100

mg/600 ml) with pure Pertamina in a cleaned engine; and (4) a final baseline with pure Pertamina and fresh oil after cleaning. Each test required a specified amount of fuel, and the entire operational time was painstakingly documented using a stopwatch. Further methodological details are provided in the Supplementary Materials.

2.1 Experimental Setup and Design

A SUMURA ET2500C gasoline generator (1100 W nominal output)

served as the test platform. To simulate a realistic and consistent operational load, a constant electrical load of 820 W (74.5% of rated capacity) was applied using a bank of incandescent lamps. This load was selected to place the generator under significant stress while ensuring stable operation. The experimental design comprised four distinct test phases, sequenced to isolate the effects of graphene additives and mechanical cleaning, as summarized in Table 1.

Table 1. Experimental test matrix

Test Phase	Condition	Fuel	Lubricant	Combustion Chamber
Test 1: Baseline A	Used Engine	Pure Pertamina	Standard 4T Oil	Carbon-Fouled
Test 2: Fuel Additive	Used Engine	Pertamax + Graphene	Standard 4T Oil	Carbon-Fouled
Test 3: Lubricant Additive	Cleaned Engine	Pure Pertamina	Standard 4T Oil + Graphene	Cleaned
Test 4: Baseline B	Cleaned Engine	Pure Pertamina	Fresh Standard 4T Oil	Cleaned

2.2 Materials and Preparation

Commercial Pertamina (RON 92) and standard 4T oil were used. Graphene was added to the fuel in concentrations ranging from 0.050 g to 0.175 g. To prevent agglomeration, mixtures were homogenized using a high-shear mixer at 800 RPM for 3 minutes.

2.3 Methodology

For each experimental trial, a precise volume of fuel was dispensed using a calibrated burette with an accuracy of ± 0.5 mL. The generator was initiated and allowed a stabilization period of two minutes under a consistent load of 820 W before the timing of the test commenced. A digital stopwatch was used to record the total operational time from the moment the load was applied after stabilization until the point of complete fuel

exhaustion, indicated by the engine stalling. The time was recorded with a precision of ± 0.1 seconds. After Test 2, the cylinder head was disassembled. Carbon deposits were removed using a chemical solvent (e.g., carburetor cleaner) and mechanical brushing, followed by compressed air drying, to restore the chamber to a "like-new" condition. This process was verified by visual inspection. After Test 3, the graphene-enhanced oil was drained completely. The system was flushed with a small amount of fresh oil before being refilled with the exact same type and volume of new, standard 4T oil for Test 4.

2.4 Data Analysis

The primary metric for performance was Fuel Consumption Efficiency (η_{fc}), calculated as:

$$\eta_{fc} = \frac{t}{V_f}$$

Where:

- η_{fc} = Fuel consumption efficiency (min/L)
- t = Total operational time until exhaustion (min)
- V_f = Fixed fuel volume (L)

The percentage of efficiency improvement (E_p) is calculated as:

$$E_p(\%) = \frac{\eta_{test} - \eta_{baseline}}{\eta_{baseline}} \times 100\%$$

3. RESULTS AND DISCUSSION

The experimental results demonstrate the distinct and combined effects of graphene additives and combustion chamber cleaning on the operational efficiency of a 1100 W generator shows on Table 2. The performance was evaluated based on operational time from a fixed 500 ml fuel volume, with efficiency calculated relative to the initial baseline (Test 1).

Table 2. Average Test Results of Generator Fuel Consumption

Test	Treatment	Fuel Volume (ml)	Operation Time (Minutes)	Efficiency Percentage (%)	Fuel Consumption Efficiency (min/L)
1	Pure Pertamina, before combustion chamber cleaning (Initial Condition)	500 ml	6.41	100 % (Baseline)	12.82
2	Pertamax + Graphene 0.050 g (in fuel), before cleaning	500 ml	6.39	-0.27%	12.78
3	Pertamax + Graphene 0.075 g (in fuel), before cleaning	500 ml	6.41	+0.09%	12.82
4	Pertamax + Graphene 0.1 g (in fuel), before cleaning	500 ml	6.44	+0.50%	12.88
5	Pertamax + Graphene 0.125 g (in fuel), before cleaning	500 ml	6.47	+1.07%	12.94
6	Pertamax + Graphene 0.150 g (in fuel), before cleaning	500 ml	6.56	+2.40%	13.12
7	Pertamax + Graphene 0.175 g (in fuel), before cleaning	500 ml	6.54	+2.10%	13.08
8	Pertamax + Graphene 0.0096 g (in fuel), before cleaning	500 ml	6.35	+0.89%	12.70
9	Pertamax + Graphene (in oil), after combustion chamber cleaning	500 ml	6.88	+7.47%	13.76
10	Pure Pertamina, after combustion chamber cleaning (after oil replacement)	500 ml	6.83	+6.69%	13.66

3.1 Effect of Graphene as a Fuel Additive: Concentration-Dependent Efficacy

The application of graphene directly into Pertamina fuel yielded a non-linear, concentration-dependent performance improvement. This improvement can be attributed to several catalytic and physical mechanisms. The application of graphene directly into Pertamina fuel resulted in a nonlinear, concentration-dependent improvement in performance. The optimal dosage was determined to be 0.150 grams, which extended the operational duration by approximately 2.40%. This enhancement can be attributed to several catalytic and physical mechanisms. Specifically, graphene's high thermal conductivity and extensive surface area enable it to act as a micro-reactor, promoting more complete oxidation of the fuel and accelerating the combustion process [9][10]. Furthermore, the addition of nanoparticles can reduce fuel droplet size and improve atomization, leading to a more homogeneous air-fuel mixture. This phenomenon has been documented in various studies on nanoparticles with carbon-based structures. Excessive concentration may increase the fuel's viscosity, thereby impairing proper atomization and combustion efficiency [11][12][13]. The commercially available additive showed minimal improvement (+0.89%), likely due to its significantly lower active concentration (0.0096 g) and the potential presence of proprietary dispersants or a different form of graphene (e.g., functionalized, fewer layers) optimized for a different purpose, highlighting the importance of raw material specification and dosage control.

3.2 The Dominant Effect of Combustion Chamber Cleaning: Restoring Baseline Efficiency

The most significant performance gain was achieved through mechanical maintenance. Cleaning the combustion chamber (Test 4) resulted in a substantial +6.69% increase in efficiency. This finding powerfully demonstrates that the largest efficiency losses often stem from deferred maintenance rather than a need for advanced additives. Carbon deposits act as a thermal insulator, increasing the engine's tendency to knock and reducing the effective compression ratio. This forces the engine to operate sub-optimally. The cleaning process restores the designed geometry and thermal properties of the chamber. Carbon buildup directly impairs thermal efficiency and increases fuel consumption. Our results strongly corroborate this, showing that restoring the engine to its "clean" state is the single most effective action for recovering lost performance.

3.3 Detailed Mechanism of Graphene in Fuel Quality

The integration of carbon-based nanomaterials, specifically graphene, into liquid hydrocarbon fuels represents a significant paradigm shift in fuel engineering and combustion science. Graphene's unique two-dimensional lattice provides an exceptionally high surface-area-to-volume ratio, facilitating intensive molecular interactions within the fuel matrix. These interactions fundamentally modify the thermophysical properties of the fuel—such as its thermal conductivity, volatility, and laminar flame speed—which collectively dictate the efficiency of the combustion kinetics. Within the cylinder of a small-scale internal combustion engine, these modifications are instrumental during the critical phases of fuel atomization, ignition delay reduction, and rapid flame propagation. Graphene serves not merely as a suspended particle but as a functional catalyst that accelerates heat flux and

lowers the activation energy required for the multi-stage oxidation of complex hydrocarbons. The following sub-sections delineate the specific physical and chemical mechanisms through which graphene additives enhance fuel quality and optimize thermal release.

1. Micro-explosion Effect

Graphene nanoparticles act as nucleation sites, promoting "micro-explosions" of fuel droplets. This leads to finer atomization and a more homogeneous air-fuel mixture, preventing the formation of fuel-rich zones that typically lead to soot production [9], [10].

2. Catalytic Oxidation

Graphene's high surface area allows it to act as a micro-reactor. The presence of functional groups on the graphene surface can lower the activation energy for hydrocarbon oxidation, promoting more complete combustion even under lean conditions [4], [11].

3. Thermal Conductivity

The high thermal conductivity of graphene (up to 5000 W/mK) facilitates faster heat distribution from the ignition point to the rest of the combustion chamber. This accelerates the flame speed and ensures that the peak pressure is reached at the optimal piston position, maximizing work output.

However, as observed in Test 7, concentrations exceeding 0.150 g led to efficiency declines. This is attributed to nanoparticle agglomeration, which increases fuel viscosity and can lead to partial clogging of the fuel system, thereby impairing the atomization process.

3.4 Synergistic Effect of Graphene Nanolubricant: Reducing Parasitic Losses

The supreme performance was achieved in Test 3, where a cleaned engine was operated with a graphene-enhanced lubricant, yielding a +7.47% efficiency gain. By comparing Test 3 (+7.47%) with

Test 4 (+6.69%), we isolate the specific contribution of the graphene nanolubricant to be an additional ~0.78 percentage point gain. This is a clear demonstration of a synergistic effect. The primary benefit comes from having a clean engine, and the graphene nanolubricant provides a secondary, statistically significant boost. The mechanism is rooted in tribology. Graphene nanoplatelets in the oil form a robust, low-shear strength protective film on friction surfaces (piston rings, cylinder liner). This tribo-film effectively reduces the coefficient of friction, thereby decreasing parasitic mechanical losses. This effect is complementary to the combustion efficiency gains from cleaning, as it targets a different loss mechanism within the engine.

The experimental results delineate a clear hierarchy of efficacy among the treatments, revealing critical insights into the interaction between advanced nanomaterials and conventional maintenance. The application of graphene as a fuel additive demonstrated a pronounced non-linear relationship with fuel consumption efficiency, characterized by an optimal concentration of approximately 0.1259 g/L. At this dosage, the efficiency peaked, which can be attributed to the well-dispersed graphene nanoparticles acting as catalytic sites that enhance fuel oxidation and improve combustion kinetics due to their exceptional thermal conductivity and high surface area[14].

However, a significant decline in efficiency was observed at higher concentrations (0.1509-0.1759 g/L), a phenomenon consistent with nanoparticle agglomeration, which increases fuel viscosity and disrupts optimal combustion, thereby counteracting the initial benefit. In stark contrast, the most substantial performance gains were achieved not by

fuel modification alone, but through mechanical intervention. The treatment representing combustion chamber cleaning alone resulted in a significant leap in efficiency, underscoring that carbon deposit removal restores the designed thermal efficiency and combustion geometry, which is a foundational step for optimal performance. The supreme efficiency was ultimately attained through a synergistic combination of this mechanical maintenance and the use of a graphene-based nanolubricant. This optimal outcome is a consequence of addressing two distinct loss mechanisms simultaneously: the restored combustion efficiency from a clean chamber and the reduction in parasitic mechanical friction afforded by the graphene tribo-film forming on critical engine components [8]. This study therefore establishes that while graphene fuel additives offer modest, concentration-sensitive improvements, the most robust strategy for enhancing small generator efficiency lies in prioritizing fundamental upkeep, which can be further augmented synergistically with graphene nanolubricants, a finding that bridges the gap between conventional mechanical care and cutting-edge nanotechnology.

4. CONCLUSION

This study demonstrates that optimizing the fuel consumption efficiency of a small-scale generator necessitates an integrated approach, where advanced nanomaterials serve as a complement to, rather than a replacement for, fundamental mechanical maintenance. The application of graphene as a fuel additive showed a concentration-dependent efficacy, with an optimal dose of 0.000150 kg providing a modest improvement. However, the most substantial gains were achieved through physical intervention: cleaning the

combustion chamber alone yielded a significant 6.69% efficiency increase by restoring optimal combustion conditions. The supreme performance was realized through a synergistic strategy, combining chamber cleaning with a graphene-based nanolubricant, which resulted in a peak efficiency gain of 7.47%. This outcome underscores that graphene is more effective in reducing mechanical friction as a lubricant additive than in directly enhancing combustion within the fuel. Consequently, this research establishes a clear hierarchy for performance enhancement, prioritizing engine maintenance and identifying nanolubrication as a superior application for graphene, thereby providing a practical and effective protocol for maximizing the operational efficiency of small-scale generator sets.

Future research should focus on the stability of graphene dispersions in gasoline to prevent settling during storage. Furthermore, investigating the impact on CO, NO_x, and particulate matter (PM) emissions is essential for a comprehensive environmental assessment.

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AUTHOR CONTRIBUTION

Ainan Zuhkri Al Misbah: Conceptualization, Methodology, Investigation, Writing – original draft. Dias Rafiq Mahasin: Investigation, Data curation. Lucky Muhamad Prasetyo: Investigation, Validation. Riandi Salim Valeha: Software, Formal analysis, Writing

– review & editing. Windhu Griyasti Suci: Supervision, Project administration, Resources, Writing – review & editing, Funding acquisition.

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