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PRESSURE DEPENDENT EMISSION CHARACTERISTICS OF ADULTERATED KEROSENE IN DOMESTIC PRESSURE STOVES: A REVIEW

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Abstract

Fuel adulteration, often involving diesel, gasoline fractions, and heavier hydrocarbons at blend ratios between 5% and 40%, significantly alters key fuel properties such as volatility, viscosity, and flash point. Understanding how vessel pressure influences emission characteristics of kerosene pressure stoves widely used in low and middle income countries is critical, particularly under adulterated fuel conditions. This review examines pressure-dependent emission behavior of adulterated kerosene, focusing on vessel pressure variation, combustion chemistry, fuel blending levels, and pollutant formation mechanisms. Laboratory studies indicate that increased vessel pressure improves atomization and combustion efficiency, thereby reducing carbon monoxide emissions. However, higher pressures are also associated with elevated flame temperatures, which promote nitrogen oxide formation. In contrast, field studies consistently report high levels of particulate matter ($PM_{2.5}$) and carbon monoxide in households, often exceeding recommended exposure limits. Despite existing research on combustion and indoor air quality, few

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studies integrate controlled pressure variation with quantified fuel adulteration. This review highlights this gap and emphasizes the need for experimental approaches that reflect real-world fuel conditions. The findings provide insights for improved stove design, fuel regulation, and strategies to reduce household air pollution and related health risks.

Introduction

Kerosene pressure stoves remain among the most widely used domestic cooking technologies in developing countries due to their affordability, portability, and relatively high thermal output. Unlike wick stoves, these systems operate by pressurizing liquid fuel within a sealed vessel, forcing it through a nozzle where it atomizes, vaporizes, mixes with air, and combusts (Adekunle and Okoro, 2021). Despite their advantages, their continued use raises significant environmental and public health concerns, particularly in low- and middle-income countries where access to clean cooking alternatives is still limited (WHO, 2022; Rahman *et al.,* 2023). These concerns are further intensified in regions where kerosene adulteration is common. Adulteration typically involves blending kerosene with diesel, petrol, or other hydrocarbon fractions, leading to changes in volatility, viscosity, density, and overall chemical composition. Such modifications directly influence spray formation, flame temperature, and combustion completeness, often resulting in higher emissions and reduced stove efficiency (Akinola and Ojo, 2022).The interaction between vessel pressure and fuel properties plays a crucial role in determining combustion performance and emission characteristics. Increased vessel pressure generally enhances atomization and air–fuel mixing, leading to more efficient combustion. However, it can also elevate flame temperatures, thereby promoting the formation of nitrogen oxides. Conversely, low pressure conditions tend to produce poor atomization, incomplete combustion, and higher emissions of carbon monoxide and particulate matter (Kumar *et al.,* 2020).The presence of adulterants further complicates combustion behavior by altering physicochemical properties, which can lead to unstable flames and increased emissions of harmful pollutants such as carbon monoxide (CO), unburnt hydrocarbons (UHCs), particulate matter (soot), nitrogen oxides (NO_x), and sulfur oxides (SO_x). These emissions not only degrade indoor air quality but also pose risks to human health and can adversely affect the performance and durability of household combustion systems. Understanding these interactions is essential for improving stove performance, ensuring safer fuel use, and informing regulatory policies. This aligns with global development priorities, including improved public health, access to

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clean energy, and reduction of environmental pollution. However, despite growing research interest, limited studies have simultaneously examined the combined effects of vessel pressure and controlled fuel adulteration under realistic operating conditions. This review addresses this gap by synthesizing existing findings on pressure dependent emission characteristics of adulterated kerosene, with the aim of identifying key trends, underlying mechanisms, and areas requiring further investigation.

Kerosene as a Household Fuel

Kerosene remains widely used across sub-Saharan Africa and South Asia due to its availability and relatively low upfront cost. However, recent studies have shown that kerosene combustion produces significant levels of indoor air pollutants, including $PM_{2.5}$, CO, and volatile organic compounds, often exceeding recommended health limits (Agbo, 2022).

Fuel Adulteration

Fuel adulteration remains a persistent challenge in many developing regions, driven by economic incentives and weak regulatory enforcement. Recent analyses have shown that kerosene is commonly blended with diesel, gasoline, or heavier hydrocarbons at concentrations ranging from 5% to 40% by volume (Obaseki *et al.,* 2022)

Influence of Vessel Pressure on Emissions

Vessel pressure plays a critical role in fuel atomization and combustion efficiency. Reports from after an experimental study conducted by (Li *et al.,* 2022), demonstrated that increasing pressure reduces droplet size, enhances evaporation, and improves air–fuel mixing, leading to lower CO emissions.

Interaction with Adulterated Fuels

Chen *et al.,* 2021, reported that adulterated fuels significantly affects pressure dependent behavior while variations in viscosity and volatility influence spray breakup and evaporation which often leads to unstable combustion and increased emissions even under higher pressures.

Comparison between Field and Laboratory Observations

Zhou *et al.,* 2022, reported that results obtained from laboratory studies under controlled conditions generally improve combustion efficiency with increasing pressure, characterized by reduced CO emissions and increased NO_x formation. In contrast, results obtained from field studies in real households consistently show elevated $PM_{2.5}$ and CO

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concentrations, largely due to poor ventilation, inconsistent fuel quality, and user practices (WHO, 2022; Sakwe and Ebinimi, 2023)

Fundamental Combustion Chemistry of Kerosene

Kerosene is not a single compound but a mixture of hydrocarbons, typically ranging from C_9 to C_{16}. For simplicity, it is often represented by dodecane ($C_{12}H_{26}$) when analysing combustion processes. At its core, combustion is a chemical reaction between fuel and oxygen that releases heat. However, the outcome of this reaction depends on how well the fuel and air are mixed, as well as the temperature and pressure conditions within the system. One useful way to describe this is through the equivalence ratio, which compares the actual fuel–air mixture to the ideal (stoichiometric) ratio. When combustion occurs close to this ideal condition, fuel is burned more completely, resulting in higher efficiency and fewer emissions. But in real stove operation, conditions are rarely perfect. Mixtures may be too rich or too lean, and this imbalance often leads to incomplete combustion and pollutant formation. (Rahman *et al.,* 2023).

Ideal Combustion Reaction

Under ideal conditions, where there is enough oxygen and the fuel is well atomized, kerosene burns cleanly to form carbon dioxide and water vapour. Using dodecane as a representative fuel, the reaction can be written as: In practice, achieving this level of completeness depends strongly on how effectively the fuel is atomized and mixed with air. Proper vessel pressure plays a key role here, as it helps break the fuel into fine droplets that evaporate quickly and burn more uniformly. (Ahmed *et al.,* 2020).

Incomplete Combustion and Pollutant Formation

Real-world combustion in pressure stoves is rarely perfect. When conditions are not ideal particularly when atomization is poor or mixing is insufficient combustion becomes incomplete.

At low vessel pressures, fuel tends to form larger droplets. These droplets take longer to evaporate, creating regions where there is not enough oxygen for complete combustion. As a result, carbon monoxide and soot are formed. On the other hand, very high pressures can push the system in the opposite direction. While atomization improves, the resulting increase in flame temperature can encourage the formation of nitrogen oxides (Anjorin and Adewale, 2024). This highlights an important trade-off: conditions that reduce one type of pollutant may increase another.

Influence of Vessel Pressure on Emission Characteristics

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Vessel pressure essentially controls how the fuel enters the combustion zone. As pressure increases, the fuel is forced through the nozzle more forcefully, producing finer droplets (Scott, 2025). This improves evaporation and promotes better mixing with air, which in turn supports more complete combustion. However, the relationship is not linear. Beyond a certain point, increasing pressure can destabilize the flame or raise temperatures to levels that favors nitrogen oxide formation. This means there is an optimal pressure range where combustion is most efficient and emissions are minimized (Bello *et al.,* 2023). The situation becomes more complicated when adulterated fuels are used. Changes in viscosity and volatility can interfere with atomization, even at higher pressures. In such cases, the expected benefits of increased pressure may not be realized, and emissions of carbon monoxide, soot, and unburnt hydrocarbons can remain high.

Kerosene as a Transitional Household Fuel

In many low and middle income countries, kerosene occupies a middle ground between traditional biomass fuels and cleaner modern energy sources (Oliver *et al.,* 2021). It is relatively accessible and easier to use than firewood or charcoal, but it is not without its drawback. Although kerosene burns more cleanly than biomass, it still produces pollutants such as fine particulate matter and carbon monoxide, often at levels that exceed recommended exposure limits. Despite its widespread use, relatively little attention has been given to how operational factors like pressure and real world issues like fuel adulteration affect its emission profile. (Bonjour *et al.,* 2021)

Chemical Composition and Combustion Reactions

Kerosene consists mainly of paraffinic, naphthenic, and aromatic hydrocarbons. Its combustion follows the general hydrocarbon reaction. When combustion is incomplete, other reactions occur, leading to the formation of carbon monoxide, soot, and unburned hydrocarbons. These by-products are responsible for both efficiency losses and environmental concerns (Mitchell *et al.,* 2020).

Fuel Adulteration and Blend Ratios

Fuel adulteration is a common challenge in many regions, often driven by economic incentives and weak regulatory oversight. Kerosene may be mixed with diesel, petrol, or heavier oils, sometimes in significant proportions. Such blending alters key fuel properties, including flash point, viscosity, and volatility (Agarwal *et al.*, 2022). From a safety and performance standpoint, high levels of adulteration particularly beyond about 10% petrol or 20% diesel can seriously compromise combustion stability. This not only increases emissions but also raises the risk of unsafe stove operation.

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Pressure Stoves and Emission Characteristics

A typical pressure stove includes a fuel tank, a manual pump, a control valve, a vaporizer tube, and a burner assembly. The fuel is pressurized, vaporized, and then mixed with air before ignition.

While pressurization improves combustion efficiency, it can also lead to higher flame temperatures, which may increase nitrogen oxide emissions (Musa *et al.,* 2021).This again points to the importance of balancing operating conditions.

Effects of Adulterated Kerosene on Mechanical Systems

Panwal *et al.,* 2020, opined that the impact of adulterated kerosene extends beyond emissions as it also affects the mechanical integrity of the stove and related systems. Corrosive compounds can damage internal components, while increased soot formation can clog nozzles and reduce heat transfer efficiency (Verma *et al.,* 2021). Unstable combustion may lead to overheating, causing deformation or failure of critical parts. In addition, fuels with lower flash points introduce safety risks, including flare-ups and potential explosions. From an engineering standpoint, these issues translate into higher maintenance demands, reduced lifespan of equipment, and the need for more robust material selection.

Field versus Laboratory Observations

There is often a noticeable gap between laboratory findings and real-world observations. Under controlled conditions, increasing pressure typically reduces carbon monoxide emissions but increases nitrogen oxides. In contrast, field studies especially in low income households frequently report high levels of particulate matter and carbon monoxide. These differences are largely due to factors such as poor stove maintenance, inconsistent operating practices, and the widespread use of adulterated fuels. (Roden *et al.,* 2020)

Health and Environmental Implications

Emissions from kerosene stoves pose serious health risks, particularly in poorly ventilated spaces. Prolonged exposure to pollutants such as $PM_{2.5}$ and carbon monoxide is associated with respiratory and cardiovascular diseases. Environmentally, these emissions contribute to air pollution and, in some cases, climate-related impacts. Reducing these emissions is therefore important not only for individual health but also for broader environmental sustainability. (Smith *et al.,* 2022)

Combined Effects of Pressure and Fuel Adulteration

When vessel pressure and fuel adulteration are considered together, their combined effects become quite complex. Pressure influences how the fuel is delivered and burned,

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while adulteration changes how the fuel behaves chemically (Tryner *et al.,* 2020). Moderate pressure can improve atomization and reduce incomplete combustion, but excessive pressure may increase flame temperature and nitrogen oxide formation. At the same time, adulterated fuels may not respond to pressure changes in predictable ways, due to altered physical and chemical properties. This interaction highlights the need for a more integrated understanding of stove operation one that considers both mechanical and fuel-related factors.

Influence of Vessel Pressure on Emissions

Increasing vessel pressure generally improves combustion by enhancing atomization and mixing. Smaller droplets evaporate more quickly, allowing for faster and more complete reactions (Bhattacharya *et al.,* 2021). At the same time, higher temperatures associated with improved combustion can accelerate reaction rates, as described by Arrhenius kinetics. However, these higher temperatures also favors the formation of nitrogen oxides, reinforcing the idea that optimal operating conditions must strike a balance.

Design Components of Domestic Pressure Stoves

A typical domestic pressure stove includes: fuel tank (pressure vessel), manual pump, control valve, vaporizer/generator tube, burner nozzle, mixing chamber, and pot support frame. Fuel is pressurized manually and vaporized before mixing with air for combustion. (Oluwafemi *et al.,* 2024) reported that designing kerosene stove should be done to make it predictably safe under poor fuel quality, heat feedback, and long term wear and there after recommended the use of right materials such as low carbon steel, stainless steel, and brass to resist corrosion, thermal cycling and to withstand elevated temperatures in order to avoid tank rupture, fuel leakage, sudden flare up and fire accident.

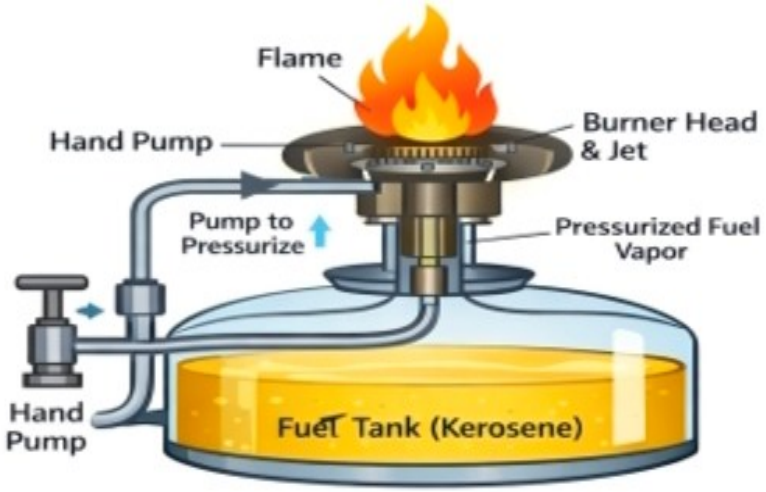


***Figure 1:** Schematic of a Typical Pressurized Kerosene Stove.*

Source: Adopted from Sinha *et al.*, 2019

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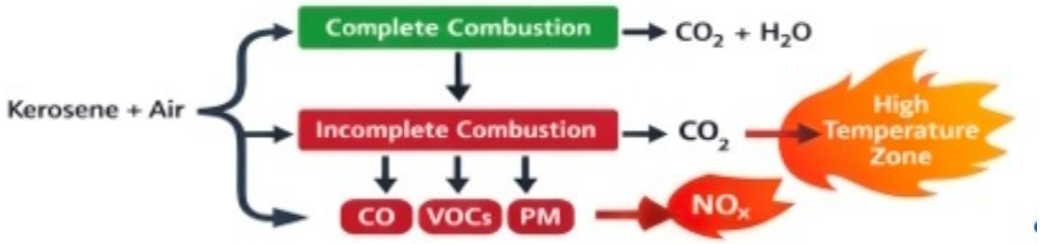


Figure 2: Pollutant Formation Pathways During Kerosene Combustion.

Source: Adopted from Sinha *et al.*, 2019

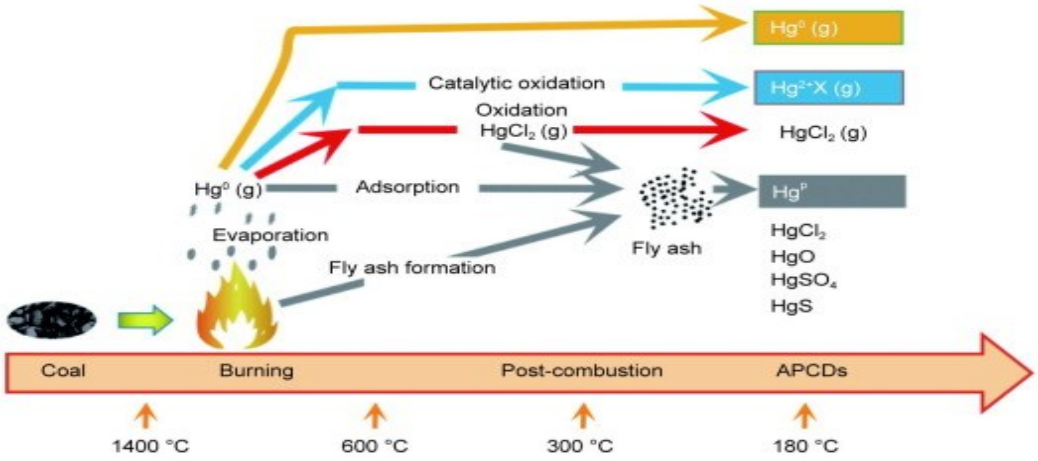
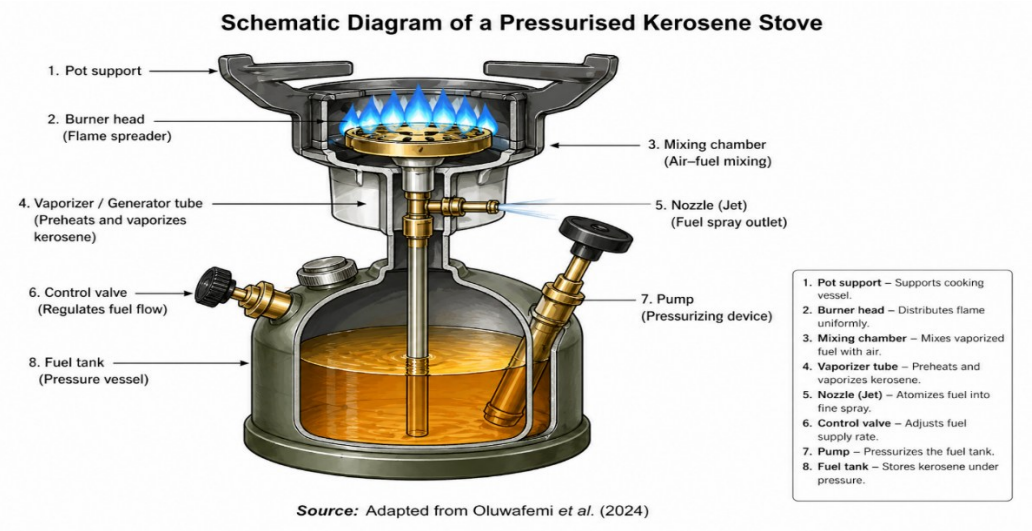


Figure 3. Source, Gaofeng *et al.*, 2024



Source: Adapted from Oluwafemi *et al.* (2024)

Emissions from Domestic Kerosene Pressure Stoves

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Domestic kerosene stoves emit particulate matter (PM2.5), carbon monoxide (CO), nitrogen dioxide (NO_2), and volatile organic compounds (VOCs). Field studies across low- and middle-income countries report indoor pollutant concentrations exceeding recommended health guidelines. Comparative testing indicates that wick stoves generally produce higher CO and soot emissions due to poor atomization, while pressure stoves exhibit improved thermal efficiency but may generate higher NOx under elevated temperature conditions.

Emission Characteristics of Kerosene Blends under Pressure

Laboratory pressurized chamber studies reported increased NOx and reduced CO with rising pressure. Engine-based blend studies show that moderate kerosene blends (5–20%) alter emission indices, while higher blends may reduce efficiency. Few domestic stove studies integrate controlled pressure variation with quantified adulteration ratios.

Table 1 Comparison of ambient and elevated pressure stove operation

Parameter	Units	Ambient pressure	Elevated Pressure
Pressure	Bar	1.0	5.0-10.0
Temperature	^oC	25-100	150-600
Fuel flow	ml/min	Value	Value

Source (Li *et al.*, 2022)

Trends established from the Literature

A synthesis of reviewed studies reveals that most domestic stove emission research is conducted under ambient pressure conditions. High-pressure combustion studies are predominantly engine-based. Few investigations simultaneously vary vessel pressure and adulteration ratio in controlled experiments. There is limited Sub-Saharan African data addressing pressure-dependent emission characteristics of adulterated kerosene in domestic pressure stoves.

Discussion of Review Synthesis

The synthesis highlights that adulterated kerosene significantly affects stove and engine performance. Thermal efficiency, flame stability, and emissions are influenced by fuel blend and stove/engine design. Pressure effects are under researched for domestic stoves. Health impacts from emissions remain relevant but are secondary to the mechanical performance analysis.

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Prospects for Pressure Stoves in a Rapidly Advancing Cities

Although kerosene is increasingly discouraged in global clean energy transitions, it remains widely used in low-income regions due to affordability and accessibility. Technological improvements such as optimized burner geometry, regulated pressure control, and improved atomization systems may enhance efficiency and reduce emissions

Identified Research Gaps

- Lack of controlled vessel pressure variation studies in domestic kerosene pressure stoves.
- Limited experimental coupling of adulteration ratio and pressure variation.
- Insufficient predictive emission modeling for domestic pressure stoves.
- Scarcity of region specific data under real adulteration conditions.
- Limited integration of combustion theory with household emission measurements.

Future research should to better understand pressure-dependent emission behavior of adulterated kerosene fuels so as to address these gaps, which represents critical research factors required for stove design, and policy formulation.

Conclusion

Adulterated kerosene affects stove and engine performance, thermal efficiency, flame stability, and emissions. Pressure further modulates these effects, though evidence in domestic stoves is limited. Future studies should integrate combustion theory, controlled laboratory experimentation, and field-based emission monitoring controlled pressure experiments to optimize stove performance and minimize emissions, thereby indirectly improving health outcomes.

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