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Original Paper

Research on the Hazards and Emission Control Strategies of Small Agricultural Gasoline Engine Exhaust

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Abstract
With the widespread use of small gasoline engines in lawnmowers, generators, and chainsaws, their exhaust emissions have become a significant environmental pollution issue. Small gasoline engine exhaust primarily contains carbon monoxide (CO), nitrogen oxides (NOx), and hydrocarbons (HC), which negatively impact air quality and pose threats to human health. To mitigate these emissions, research on emission control strategies for small agricultural gasoline engines is increasingly important. This study aims to explore and evaluate different exhaust treatment technologies for small gasoline engines, including traditional catalytic converters, emerging particulate filters, electric catalysts, and selective catalytic reduction (SCR) technology. The study highlights the importance of these exhaust treatment technologies in reducing environmental pollution and promoting sustainable development, contributing significantly to environmental protection and the sustainable development of the ecological environment.

Keywords
Small gasoline engines, Exhaust treatment, Catalysts, Emission control, Environmental protection

1. Introduction

1.1 Background

In the agricultural sector, small gasoline engines are widely used in modern life for lawn mowers, generators, chainsaws, brush cutters, and small agricultural transport tools. These devices are favored for their portability and fuel efficiency, especially in areas such as home gardening, agriculture, and construction. However, the exhaust emissions from small gasoline engines, particularly the high levels of particulate matter (PM) and toxic gases, pose a serious threat to both the environment and public health. Among the harmful emissions, carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), as well as lead compounds and particulate matter, are particularly hazardous (Anderson, DiCicco, Ginder, Kramer, Leone, Raney-Pablo, & Wallington, 2012). Gasoline engine emissions differ from those of diesel engines. For example, with PM2.5, the proportion of total carbon (TC) and organic carbon (OC) in the exhaust emissions of gasoline engines is significantly higher than that of diesel vehicles (Benson, Burns, Hochhauser, Koehl, Painter, Rippon, & Schleyer, 1991). Additionally, the particulate matter emitted by gasoline engines contains large amounts of polycyclic aromatic hydrocarbons (PAHs), which are highly carcinogenic, teratogenic, and mutagenic, posing great harm to human health (Caton, 2000). Therefore, as environmental awareness grows, controlling exhaust emissions from small gasoline engines has become an urgent issue that needs to be addressed.

1.2 Research Objectives

Small gasoline engines are widely used in various sectors, including agriculture, and their exhaust emissions pose serious threats to both the environment and public health. By studying the hazards of emissions from small gasoline engines and proposing corresponding emission reduction measures, we aim to promote the protection of public health and the ecological environment. Additionally, with increasingly stringent global environmental regulations, developing new exhaust treatment technologies for small gasoline engines is key to meeting regulatory requirements and enhancing technological competitiveness. Therefore, the objective of this paper is to explore and optimize existing exhaust treatment technologies and propose practical improvements to achieve the dual goals of reducing the harmful emissions from small gasoline engines and improving engine operational efficiency.

2. Composition and Harmful Effects of Small Gasoline Engine Exhaust

2.1 Components of Small Gasoline Engine Exhaust

Compared to large vehicles and industrial equipment, small gasoline engines have lower combustion efficiency and often lack external exhaust control systems, leading to relatively higher emission levels of pollutants (Czerwinski, Comte, & Kasper, 2002). The main pollutants in gasoline engine exhaust emissions include carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx), a small amount of sulfur dioxide (SO2), various harmful gases emitted during combustion, and particulate matter generated from incomplete combustion.

2.1.1 Harmful Gases in Small Gasoline Engine Exhaust

Carbon monoxide (CO) is a colorless and odorless gas that binds with hemoglobin in the blood much more readily than oxygen. Once inhaled, it reduces the oxygen-carrying capacity of the blood, leading to poisoning and potentially death. CO is produced under conditions of incomplete combustion, particularly when temperatures are low or oxygen levels are insufficient, which lowers the efficiency of gasoline combustion and increases CO emissions. Long-term exposure to CO can result in chronic diseases, such as heart disease and respiratory illnesses. Additionally, CO indirectly contributes to the formation of ozone (O3) in the atmosphere, exacerbating urban air pollution (Davies, Morris, & Boulter, 2007).

Nitrogen oxides (NOx) are produced when nitrogen and oxygen react under the high temperatures and pressures present in gasoline engine combustion. NOx is a key precursor to photochemical smog and also contributes to acid rain, disrupting the ecological balance of soil and water bodies, harming vegetation, buildings, and human health. Respiratory illnesses, such as asthma and bronchitis, are more likely to occur in environments with high NOx concentrations. NOx also reacts with volatile organic compounds (VOCs) in the air, creating secondary pollutants and worsening air quality (Eyre, 2005).

Hydrocarbons (HC) are residual unburned fuel present in vehicle exhaust. As volatile organic compounds, HC reacts with NOx in the presence of sunlight to form ozone, which causes photochemical smog, reducing urban visibility and air quality. Ozone has a strong irritant effect on the respiratory system, leading to symptoms like difficulty breathing and decreased lung function, particularly among children, the elderly, and people with pre-existing respiratory conditions. Some components of HC, such as benzene, are carcinogenic, increasing the risk of cancer in humans. Therefore, controlling the emissions of CO, NOx, and HC from gasoline engines is critical for protecting the environment and human health (Fino, Russo, Saracco, & Specchia, 2001).

2.1.2 Particulate Matter (PM) in Small Gasoline Engine Exhaust

In this context, the high-temperature and high-pressure environment within the gasoline engine cylinder causes intense dehydrogenation and cracking reactions in the air-fuel mixture. As these reactions take place, a large number of soot particles are produced, which, during cooling, combine with incompletely burned hydrocarbons (HC) and various condensable substances generated during engine operation, forming particulate matter (PM) in the exhaust emissions. Additionally, during the fuel injection process, part of the fuel spray may diffuse onto the piston surface, forming an oil film due to the high temperature and pressure. These oil films exhibit higher thermal resistance, slowing the evaporation of residual fuel on the piston surface, which, under poor fuel-air mixing conditions, leads to increased soot formation and the subsequent production of large amounts of particulate matter. Moreover, during cold starts when fuel evaporation is reduced, or under low-speed and high-load conditions with large fuel injections, fuel films on the piston surface or cylinder walls also contribute to the generation of exhaust particulate matter (Heck, Farrauto, & Gulati, 2009).

3. Exhaust Emission Control Strategies for Small Gasoline Engines

Currently, the most commonly used exhaust after-treatment technology for general-purpose small gasoline engines is the three-way catalytic converter. This technology not only has a high purification efficiency but also offers advantages such as low cost and ease of operation, making it widely applied in the exhaust treatment of general-purpose small gasoline engines.

3.1 Application of Catalytic Converters

Catalytic converters accelerate chemical reactions at high temperatures using a catalyst, converting harmful substances in the exhaust into harmless ones. The core technology of catalytic converters is the use of catalysts, typically composed of precious metals such as platinum, palladium, and rhodium. The most common type is the three-way catalytic converter, which can simultaneously reduce carbon monoxide (CO), nitrogen oxides (NOx), and unburned hydrocarbons (HC). In the three-way catalytic converter, CO is oxidized into carbon dioxide (CO_2), HC is also oxidized into carbon dioxide and water (H_2O), and NOx is reduced to nitrogen (N_2) and oxygen (O_2) (Heywood, 1988; Johansson & Eriksson, 2006). Despite the good performance of three-way catalytic converters in reducing these major pollutants, their efficiency depends on the engine's exhaust temperature, generally needing to reach above 300℃ for normal operation. Consequently, their emission control under low-temperature conditions is poor, and they have high fuel quality requirements. Furthermore, their effectiveness is highly dependent on the oxygen content in the exhaust and the temperature of the catalyst. Under low-temperature conditions, the oxidation reaction rate of the catalyst slows down, leading to poor treatment results.

3.2 Selective Catalytic Reduction (SCR)

Selective catalytic reduction (SCR) technology offers significant advantages in treating nitrogen oxides (NOx). SCR technology reduces NOx to nitrogen (N_2) and water (H_2O) by injecting a reducing agent (such as urea solution) into the exhaust system, utilizing a catalyst (Maddineni, 2016). SCR's strength lies in its efficient NOx reduction capability, significantly lowering NOx emissions. However, the SCR system requires precise control over the dosage of the reducing agent, with high maintenance and operational requirements. Accurate monitoring of the exhaust composition and system operation is essential.

4. Future Research Directions

4.1 Optimization of Catalyst Materials

4.1.1 Development of Non-Precious Metal Catalysts

The development of non-precious metal catalysts has become a key research direction due to the high cost of precious metal catalysts such as platinum, palladium, and rhodium, which limits their widespread application. To reduce costs and improve economic viability, researchers are focusing on transition metal catalysts, such as iron, copper, and cobalt and their compounds (e.g., oxides and sulfides), for their potential in exhaust treatment (Maddineni, 2016). Transition metal catalysts, being relatively inexpensive and offering good catalytic performance, are a strong alternative to precious metal catalysts. For example, cobalt-based catalysts have shown outstanding performance in the reduction of NOx. Cobalt has high catalytic activity and selectivity, effectively reducing NOx emissions (Yang, Chien, Chao et al., 2005). Moreover, cobalt-based catalysts are far more cost-effective than precious metal catalysts, making them a more economical option for practical applications. Research into non-precious metal catalysts also includes exploring their performance under various reaction conditions, their stability, and synergistic effects with other catalysts. By optimizing their composition and structure, researchers can develop more cost-effective and efficient catalysts, advancing exhaust treatment technology.

4.1.2 Research on Catalyst Regeneration Technologies

Catalyst regeneration technologies play a crucial role in the long-term use of catalysts. In practical applications, catalysts often lose catalytic activity due to carbon buildup, pollutant deposition, or other chemical reactions. Thus, developing efficient catalyst regeneration technologies has become a vital area of future research. Common regeneration techniques include high-temperature oxidation, reduction treatment, and chemical regeneration. High-temperature oxidation involves heating the catalyst to burn off carbon deposits, restoring its catalytic activity. Reduction treatment removes surface oxides from the catalyst, restoring its original activity. In addition, chemical regeneration methods use chemical agents to remove impurities from the catalyst, restoring its functionality. These regeneration techniques not only extend the catalyst's lifespan but also reduce resource waste and lower maintenance costs. Researchers are exploring more efficient regeneration methods to enhance activity recovery efficiency and cost-effectiveness, improving the sustainability of catalytic processes.

4.1.4 Optimization of Catalyst Microstructure

The microstructure of catalysts significantly affects their catalytic performance. Therefore, optimizing the microstructure is an important future research direction. Increasing the specific surface area, optimizing pore structure, or using nanotechnology to uniformly distribute active metals can enhance the catalyst's reactivity and selectivity. For example, increasing the specific surface area provides more active sites, enhancing catalytic ability. Optimizing pore structure improves the diffusion rate of reactants and reduces resistance during reactions (Nagel, Zart, Barbosa, et al., 2017). Utilizing nanotechnology ensures even distribution of active metals on the catalyst surface, increasing effective catalytic sites and improving efficiency. Researchers are also exploring how adjusting the surface structure of catalysts can enhance pollutant conversion efficiency, improving overall exhaust treatment effectiveness. Microstructure optimization measures will help boost catalyst performance and economic viability, advancing catalytic technologies.

4.2 Exploring More Innovative Treatment Methods

4.2.1 Electrocatalysts and New Catalytic Technologies

Electrocatalysts represent an emerging catalytic technology that significantly improves reaction efficiency by activating catalysts with electric current. This technology's key lies in applying current to the catalyst surface to activate catalytic reactions and accelerate reaction rates. Compared with traditional catalysts, electrocatalysts can perform effective reactions at lower temperatures, improving energy efficiency and reducing emissions. Future research could focus on applying electrocatalysts to small gasoline engine exhaust treatment, adjusting the current intensity and frequency to achieve more efficient purification. Further exploration should include developing novel catalyst systems combining electrocatalytic technology, reducing costs and simplifying system design. For instance, new integrated power and catalyst devices can be designed to make the system more compact and efficient. Additionally, material selection and surface modification of electrocatalysts are critical research areas. Optimizing the conductivity and catalytic activity of materials can improve performance and stability.

Through these innovations, electrocatalysts are expected to play an important role in future exhaust treatment technologies, improving the effectiveness and efficiency of environmental protection.

4.2.3 Application of Particulate Traps

Particulate traps play a key role in treating particulate matter, but future improvements should focus on enhancing filtration efficiency, reducing back pressure, and optimizing structural design (Qi, Yang, Ma, et al., 2016). First, exploring new filter materials, such as high-performance nanomaterials or composites, could significantly improve trapping capabilities while minimizing particle buildup. These materials should offer better high-temperature resistance and chemical stability to suit various working conditions. Second, optimizing the structure of particulate traps, especially in terms of reducing their impact on engine performance, can be achieved by improving airflow channel design or incorporating advanced fluid dynamics simulation technologies. This ensures that while efficiently capturing particles, the trap doesn't significantly increase exhaust resistance. Additionally, reducing the cleaning and replacement frequency of traps is another key goal for future improvements. Research into self-cleaning technologies or materials that extend lifespan could reduce maintenance costs and improve overall system efficiency. These advancements will significantly enhance the practical application of particulate traps, contributing more to environmental protection.

4.2.4 Development of Integrated Treatment Technologies

Integrated treatment technologies combine multiple exhaust treatment methods to achieve comprehensive pollution control. Currently, catalytic converters, SCR systems, and particulate traps are widely used, but effectively combining these technologies to form an optimized integrated treatment solution is an important direction for future research. For example, combining catalytic converters with SCR systems can efficiently handle multiple gaseous pollutants, including CO, NOx, and HC. On this basis, small gasoline engine particulate traps can further treat particulate matter, forming a multi-layer pollution control system. The realization of this technology will help achieve higher levels of pollution control, providing stronger technical support for environmental protection.

5. Conclusion

Small gasoline engines, due to their emission characteristics, cause significant harm to the environment and human health. As environmental regulations become increasingly stringent, the development and application of exhaust treatment technologies for small gasoline engines are essential. This research reveals that while traditional catalytic converter technologies have matured, challenges remain in controlling low-temperature emissions and capturing exhaust particulates. Solutions such as particulate traps and electrocatalysts offer new potential, particularly in reducing NOx and particulate emissions. However, these technologies still face challenges in terms of cost and system complexity. Therefore, future research should focus on optimizing gasoline engine particulate traps, enhancing catalyst efficiency, and improving fuel efficiency to achieve more efficient and economical exhaust emission control. Through continuous innovation and development of technologies, the challenges posed by small gasoline engine emissions can be better addressed, promoting environmental protection and sustainable ecological development.

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