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# DESIGN AND EXPERIMENTAL EVALUATION OF AN AQUA SILENCER FOR REDUCTION OF DIESEL ENGINE EMISSIONS

**Engineering**

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## ABSTRACT

With the rapid development of industry and agriculture, the environmental pollution has been becoming more and more serious, which poses a serious threat to the sustainable development of human being. Meanwhile, emissions of diesel engines have become the focus of more and more people. In order to alleviate these problems, the exhaust emissions from diesel engines are being studied. In this paper, a kind of novel exhaust emission reduction equipment called aqua silencer is developed and applied to control the exhaust emission from stationary diesel engine. By the experiments results, the emissions of exhaust gas were significantly decreased after passing through the aqua silencer. The changes of emission concentrations of exhaust gas measured by gas analyzer showed that the emissions of CO and $CH_4$ decreased about 34.69% and 29.41% respectively. The emission of NO decreased about 15.97%. The $NO_2$ decreased about 6.03%. The results indicate that aqua silencer is an effective emission reduction. So, it can be very suitable to applied in the exhaust emission of the stationary diesel generator set, and farm machine, etc.

## KEYWORDS

Aqua Silencer, Diesel Engine, Emission, Catalytic Converters, Activated Charcoal.

## INTRODUCTION

The rapid expansion of the world's industrialization and agriculture mechanization requires large quantity of energy, so CI diesel engines are increasingly applied for their high thermal efficiency, low fuel consumption and long maintenance interval etc. However, in running processes, these engines always emit a large quantity of pollutions including carbon monoxide (CO), nitrogen oxides (NO ), unburnt hydrocarbons (HC), and particulate matter (PM), which can cause serious environment pollutions and health influence, such as respiratory diseases, formation of photochemical smog, and even global warming etc. Therefore, researchers at home and abroad focus their attentions on the development of technique for decrease of the engine emissions [1–4].

There has been a significant shift in emission legislations globally with newer standards requiring multiple parameters to be controlled. Road vehicles in Europe and India are now rated as Euro VI and Bharat Stage VI (BS-VI) respectively, and these standards require advanced exhaust after-treatment technologies (AET) such as diesel oxidation catalysts (DOC), diesel particulate filters (DPF), and selective catalytic reduction (SCR) systems. The aforementioned technologies have been found to achieve or even exceed conversion efficiencies of 90%, yet they suffer from several drawbacks like high initial investment, contain precious metals (Pt, Pd, Rh), are sensitive to fuel quality, and demand complex refurbishment schedules. These limitations restrict the application of such technologies to only large fleet operators in the transportation sector, and therefore, remain unaffordable for small-scale industries, agricultural machineries, and decentralised power and energy generation systems that also need to comply with emission legislations [5–8].

To address these problems, an integrated system is required which can effectively reduce exhaust pollutants. Such a system should be also economically efficient. One such system is an aqua silencer which unites wet pollution scrubber, gas absorption, and adsorption in one unit. The exhaust gases are sent through a perforated pipe placed into a wet medium, commonly limewater $Ca(OH)_2$. After gas passing through the liquid, an additional filtration on activated charcoal is performed. Due to such construction, increased interactions between exhaust gases and liquid or solid media occur, which allows for effective removal of emitted pollutants by physical and chemical way [9–11].

The emission reduction principle of Bio-Green is based on gas absorption and chemical reactions similar to those in gas purification. These reactions include [12]:

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + H_2O$$

$$SO_2 + H_2O \rightarrow H_2SO_3$$

$$2H_2SO_3 + O_2 \rightarrow 2H_2SO_4$$

$$2NO + O_2 \rightarrow 2NO_2$$

$$4NO_2 + 2Ca(OH)_2 \rightarrow Ca(NO_2)_2 + Ca(NO_3)_2 + 2H_2O$$

In addition to its absorbent function, activated charcoal also provides a high specific surface area of 500–1500 $m^2/g$ (typically) to adsorb hydrocarbons and particulate matter via van der Waals interaction.

All existing designs of aqua silencers have their advantages; however, they also have some inherent disadvantages such as the rapid saturation of limewater, clogging by the precipitate, increase of backpressure, etc. Moreover, it is very difficult to repair or replace the activated charcoal layer [10,11,14].

To address the problems faced by the researchers in the paper, the proposed aqua silencer includes improvements in two major areas: (1) a modified silencer design that incorporates a detachable modular flange–gasket assembly for easy replacement of the activated charcoal bed without having to dismantle the facility; (2) an enhanced perforated tube design, with 90 holes for better dispersion of gas and for increasing gas–liquid interfacial area for improved absorption.

The primary objectives of this study are to design and construct a modified version of an aqua silencer for stationary diesel engines to exhaust emissions (CO, NO , HC) and to analyze its effectiveness in reducing emissions from small and medium-sized diesel-powered engines in developing countries.

Experimental study of engine performance has been conducted on single-cylinder four-stroke small diesel engine comparing it with a baseline experiment performed without an aqua silencer attached. The experimental data show that very efficient emission can be achieved with an economical silencer of simple construction applicable to decentralized engine installations.

To further understand the underlying mechanisms and existing challenges associated with such systems, relevant theoretical and experimental insights are discussed below. Alternative emission control approaches based on physico-chemical treatment of exhaust gases have gained attention due to their applicability in low-cost and decentralized systems. Among these, wet scrubbing combined with adsorption provides a simplified yet effective pathway for pollutant removal, particularly for applications where compactness and ease of operation are essential. The performance of such systems is primarily governed by the interaction between exhaust gases and the scrubbing medium, where both solubility and chemical reactivity play crucial roles. In this context, alkaline solutions such as limewater exhibit favorable characteristics due to their ability to neutralize acidic exhaust constituents while maintaining operational simplicity [12].

The underlying removal mechanism involves gas–liquid mass transfer coupled with chemical reactions, where the rate of pollutant absorption is dependent on the concentration gradient and the effective interfacial area between phases. Enhanced dispersion of exhaust gases in the liquid medium significantly improves mass transfer rates, thereby increasing overall removal efficiency. This highlights the importance of flow distribution and geometric design in determining system effectiveness. In particular, the configuration of the gas delivery system directly influences bubble formation, residence time, and contact area, which are critical parameters in maximizing absorption performance [15].

In addition to liquid-phase treatment, secondary purification through adsorption plays a vital role in capturing residual hydrocarbons and fine particulate matter. Porous materials such as activated charcoal provide high surface area for adsorption through physical interactions, enabling further reduction of pollutants that are not fully absorbed in the liquid phase [13].

Despite these advantages, practical implementation of such systems is often hindered by operational challenges. The progressive saturation of the scrubbing medium reduces its effectiveness over time, while accumulation of reaction by-products and particulates can lead to clogging and increased flow resistance. Furthermore, conventional designs often lack modularity, making maintenance and replacement of internal components labor-intensive and time-consuming. These limitations reduce long-term reliability and restrict wider adoption in real-world applications [14].

To overcome these challenges, there is a need for design improvements that enhance both performance and maintainability. Optimizing gas distribution to increase interfacial contact, along with incorporating modular features for easy servicing, can significantly improve system practicality.

The present study focuses on addressing these aspects through a modified configuration that enhances gas–liquid interaction and facilitates straightforward maintenance, thereby improving the overall effectiveness of emission control in stationary diesel engine applications.

## METHODOLOGY AND EXPERIMENTAL SETUP

The new system for road vehicle exhaust treatment is based on a multi-stage method for reducing poisonous emissions consisting of a gas–liquid system using absorption and a solid-phase adsorption system. The construction of the system features the promotion of intense gas–liquid contact, sufficient treatment time and ease of maintenance. The high-temperature exhaust gas from the vehicle is introduced into the scrubber through a perforated tube dipping into the alkaline liquid scrubbing medium (Fig. 1). The scrubbed gas then permeates through activated charcoal contained in the secondary filter.

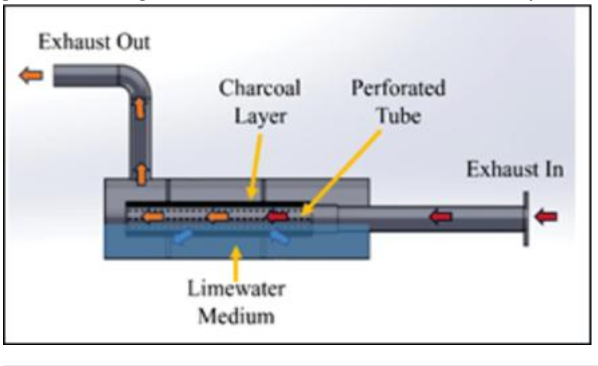



**Figure 1: Schematic representation of the internal configuration of the modified aqua silencer showing perforated tube, limewater medium, and activated charcoal layer.**

The perforated tube in Fig. 2 (a) and (b) serves as a crucial element in increasing mass transfer by dispersion of exhaust gas into fine bubbles and thereby greatly increasing the surface area of contact between the gas and liquid phases. The diameter of the tube is set at 60 mm and length at 440 mm with 90 identical holes of 16 mm diameter drilled uniformly into the surface. These design parameters facilitate adequate gas dispersion throughout the liquid while concurrently providing sufficient structural strength to the tube and maintaining minimal resistance to fluid flow.

**(a)**

**(b)**

**Figure 2: (a) Perforated tube with charcoal layer and (b) Perforated tube with charcoal layer.**

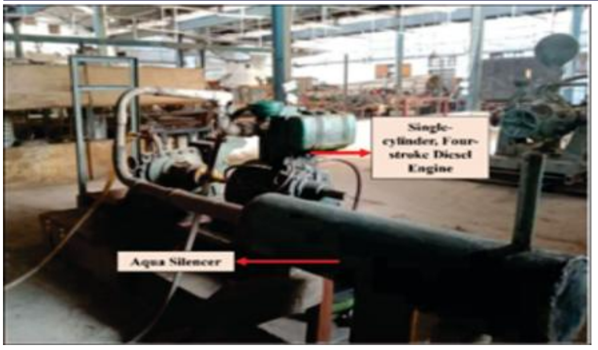
In general, the outer part of the system in Figure 3 has a diameter of 186 mm and height of 625 mm; it is some 60% filled with limewater, $Ca(OH)_2$, which acts as the primary scrubbing liquid and performs chemical neutralisation on acidic exhaust species. Surrounding the gas flow path is a secondary filter layer comprising 2 kg of activated charcoal that seizes any unreacted hydrocarbons and smaller particulate matter not neutralised in the limewater solution.

**Figure 3: Outer shell of the system.**

To make the respirator more maintainable, a conventional flange and gasket interface has been incorporated into the respirator in a modular fashion, which allows good access to internal parts and allows replacement of the activated charcoal canister without having to take the entire respirator apart. This provides a very practical means of recharging the respirator.

Fig. 4 Experimental setup for performance evaluation of fabricated aqua silencer setup connected to single cylinder four stroke diesel engine rated at 5.9 kW at 1600 rpm having engine displacement of 780 cc. Infrared gas analyzer is used to measure the concentration of pollutants such as CO, NO, $NO_2$ and HC.

**Figure 4: Experimental setup showing the aqua silencer connected to a single-cylinder diesel engine and exhaust gas analyzer.**




Performance assessment is carried out under identical operating conditions by measuring the emissions before and after installing the aqua silencer. The emission reduction efficiency is then calculated from these values

$$\eta = \frac{C_{\text{without}} - C_{\text{with}}}{C_{\text{without}}} \times 100$$

where $C_{\text{without}}$ and $C_{\text{with}}$ represent pollutant concentrations before and after treatment, respectively.

Overall system performance is affected by several key parameters including gas residence time, interfacial surface area, and concentration gradients. While increasing interaction enhances performance, it places greater flow resistance generating backpressure that must be controlled in order to maintain acceptable performance on the engine over which it is attached. Periodic replacement of the liquid and sorbent are also required to maintain performance as they saturate with repeat exposure to odorous gases.

## RESULTS AND DISCUSSION

Experimental results are also presented to show emission reduction capability of developed aqua silencer. Tested results are tabulated and depicted graphically, also compared with same test conditions.

The exhaust emissions were tested using a gas analysis with the diesel engine running under constant state running conditions. Table 1 listed the average exhaust emission of the diesel engine without the attachment of aqua silencer. The average exhaust emission of carbon monoxide (CO) was 0.098%. The exhaust emissions of nitrogen oxides (NO & $NO_2$) were 105.33 and 30.33 ppm respectively. The exhaust emissions of hydrocarbon ($CH_4$ equivalent) are at 0.17% level. The average temperature of tested fuel was 39.66 °C.

**Table 1: Baseline exhaust emission characteristics of the diesel engine without aqua silencer.**

| Parameters | Readings | | | Avg. |
|---|---|---|---|---|
| | 1st Trial | 2nd Trial | 3rd Trial | |
| Fuel Temperature | 38°C | 40°C | 41°C | 39.66°C |
| CO | 0.102% | 0.091% | 0.103% | 0.098% |
| $NO_2$ (in PPM) | 30 | 27 | 34 | 30.33 |
| NO (in PPM) | 127 | 100 | 89 | 105.33 |
| CH4 | 0.17% | 0.17% | 0.17% | 0.17% |

The overall characteristics of emission after installing the device called the "aqua silencer" are presented in Table 2. There is a noticeable decrease in the all four pollutants observed, which decreased to 0.064% on an average. This indicates complete oxidation of CO during its passage through the aqua silencer due to the scrubbing action. NO and $NO_2$ got reduced to 88.5 ppm and 28.5 ppm respectively, showing partial reduction. Hydrocarbon got decreased to 0.12% as the activated charcoal in the silencer gets the hydrocarbons adsorbed. This proves the mechanism of the silencer in treating the exhausted gases of the engine. The fairly constant temperature of the fuel (37.25°C) justifies the effectiveness of the silencer rather than variation in the parameters of the engine under test.

**Table 2: Exhaust emission characteristics of the diesel engine with modified aqua silencer.**

| Parameters | Readings | | | Avg. |
|---|---|---|---|---|
| | 1st Trial | 2nd Trial | 3rd Trial | |
| Fuel Temperature | 37°C | 38°C | 38°C | 37.25°C |
| CO | 0.062% | 0.053% | 0.072% | 0.064% |
| $NO_2$ (in PPM) | 29 | 28 | 32 | 28.5 |
| NO (in PPM) | 83 | 73 | 72 | 88.5 |
| $Ch^4$ | 0.12% | 0.12% | 0.11% | 0.12% |

From Table 3, it is observed that, carbon monoxide possesses highest percentage reduction (34.69%) of emissions, due to enhanced gas—liquid interaction, along with partial oxidation. Hydrocarbon possess the percentage reduction of emissions as 29.41%, because of adsorption on surface of activated charcoal. Since, hydrocarbons are nonpolar gases possessing very low solubility in water; therefore, their complete removal cannot be achieved through the system. NO possesses moderate percentage reduction of emissions as 15.97%, and $NO_2$ is found to possess very low percentage reduction of emissions as 6.03%. Nitrogen oxides having very low solubility in water, require prior conversion of NO to $NO_2$. Therefore, developed aqua silencer provides better performance through combined effects of gas dispersion, chemical absorption, and adsorption, and emission reduction performances vary based on properties of different pollutants.

**Table 3: Comparative emission reduction achieved using the modified aqua silencer.**

| Parameters | Without Aqua Silencer | With Aqua Silencer | Reduction |
|---|---|---|---|
| Fuel Temperature | 39.66°C | 37.25°C | 6.07% |
| CO | 0.098% | 0.064% | 34.69% |
| $NO_2$ (in PPM) | 30.33 | 28.5 | 6.03% |
| NO (in PPM) | 105.33 | 88.5 | 15.97% |
| CH4 | 0.17% | 0.12% | 29.41% |

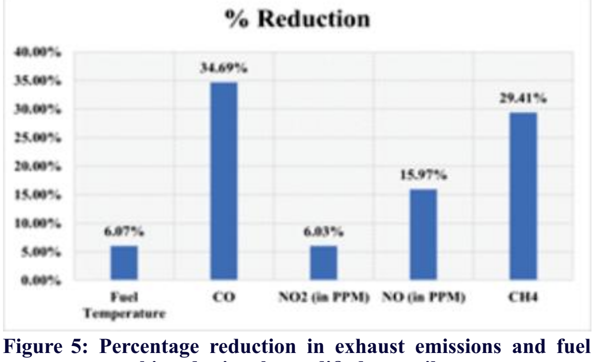



**Figure 5: Percentage reduction in exhaust emissions and fuel temperature achieved using the modified aqua silencer.**

A consistent reduction in all measured pollutants is observed in Fig.5. The results indicate that the developed aqua silencer effectively reduces multiple exhaust pollutants simultaneously, demonstrating its capability as an integrated emission control system.

## CONCLUSIONS

A modified simple structure called aqua silencer was designed, fabricated and tested to simultaneously reduce both exhaust emissions produced by a single-cylinder diesel engine. In the developed system, gas dispersion, chemical absorption, and adsorption were combined and achieved in a simple and low-cost configuration.

The results from practical trials show a marked decrease in primary pollutants. The data for carbon monoxide showed a 34.69% decrease, for hydrocarbons—29.41%, and for nitrogen oxides—15.97% and 6.03% respectively. These results are largely due to increased contact between exhaust gases and liquid, alkaline neutralisation by limewater, and adsorption by activated charcoal.

Significant performance improvements have been realised in the novel reactor through the optimisation of the perforated tube design, specifically through increasing the number of perforations to 90° slots. Both the expanded gas dispersion and the increased surface area between the liquid and gas phases have increased mass transfer efficiency.

The work significantly enhances the maintainability of the emission control technology by incorporating a modular flange and gasket assembly configuration that enables easy removal and replacement of the activated charcoal, thereby simplifying servicing of the technology. In comparison to conventional emission control technologies, the presented aqua silencer offers a simple and practical solution that is economically advantageous for decentralized emission control applications.

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