Study on efficient removal of NO from CI engine exhaust gas by wet scrubbing method using NaOH solution

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Abstract: Pollutants like Nitrogen oxide (NO) and Hydrocarbon (HC) exhausted from automobiles are very harmful. The scrubber method is most widely used in power plants and marine engines for emission control. In this study, the Diesel Plastic oil blend (DPB) and wet scrubber method are employed to reduce the pollutants. The scrubber treatment with NaOH (Sodium hydroxide) solution is used to reduce emissions in the Internal Combustion (IC) engine. The NO is drastically reduced. Hydrocarbon (HC) is also gradually reduced using the NaOH solution. The DPB was tested in a computerized, water-cooled, 4-stroke, single-cylinder, 5.2 kW diesel engine for analyzing its performance and emission characteristics with a scrubber. The experiments are conducted under different loading conditions (0, 1.3, 2.6, 3.9, and 5.2 kW). At 5.2 kW loading condition, the diesel engine running on DPB with scrubber reduced the NO emission up to 25% and HC emission up to 14%.

Keyword: Plastic oil; Wet scrubber; NaOH; Spray Nozzle; NO absorption.

1. Introduction

Ecological pollution, mostly produced from transportable sources like automotive and industries, creates severe pollution problems in the rural and metropolitan areas in both developed and developing countries. Air pollution has become a major concern in terms of international regulation standards because it is not limited to the country of origin. In fact, air pollution, with its solitary capacity to diffuse into all areas and countries, is now threatening the worldwide environment. Automobiles are found to be a huge source of air pollution in the form of fuel combustion [1]. Another problem is the increase in petroleum expenditure due to global demand. The essential objective of the National energy council is the selection of the optimal blend of petroleum. Another objective is to minimize the energy demand by conserving the natural energy and the identification of other energy contributors to create alternative sources [2]. Plastic oil is one of the alternative fuels to reduce emissions. It contains a hydrogen chain link with carbon, which has the potential for waste plastic administration. Scientists have examined the oil prepared from the useless
tires and abandoned plastics for usage in automobile engines. An endeavor to increase the performance level of a diesel engine using plastic oil blend with fuel additives is considered. Also, waste plastic oil is employed for extended performance. The diesel blend with plastic oil is investigated by various researchers [3]. The conclusion is the reduction in BTE under the diesel blend with plastic oil usage under a wide range of loads and maximum cylinder pressure and engine emission [4]. The NOx emission levels decrease when scrubber technology is applied. The scrubber process is a cost-effective choice that will be effectively implemented in future works [5]. This process consists of a full tank, where the gas and liquid phases are concurrent for reduction. These scrubbers are designed to the utmost levels in the interfacial surface areas of the gas and liquid states [6]. Chemical solutions are identified carefully because of their non-reaction tendency and their functioning as a negative agent [7]. Wet scrubber for prediction of exhaust gas emission removal is effective when the nozzle is fitted within the internal part. This is where the collaboration between exhaust gas and the chemical solution takes place. Further developed designs of wet scrubber for nitrogen removal include chemical absorption solution. Mathematical models are studied to implement the mass and heat transfer in the exhaust gas in a wet scrubber system. The mathematical models are beneficial for liquid film formation in wet scrubbers to reduce emission. The terminal velocity of the liquid droplets is identified as rough assumptions. The wet scrubber facilitates excellent absorption emission. Also, the liquid-gas ratio levels increase proportionately with the droplet diameter in a step by step manner. The temperature, as well as the flow rate of the gases, are reduced in these methods [8]. Hence, the wet scrubber technique is viable, economically feasible, and mutually exclusive to the chemicals absorbing solution. Recently, scrubbers are proposed mainly in thermal power plants and also marine diesel engines for emission reduction. Hence, a chemical solution with mostly high alkaline content is selected in this work for its seamless absorption quantity. Most of the research focus on chemicals with high salinity, which easily reduces emissions. NO emission easily affects the human respiratory system. Major pollutants are produced by thermal power plants and automobiles. Pollutants like NO, HC, CO, Chlorofluorocarbon (CFC), Particulate matter (PM), and other trace gas species are produced [9-10]. This paper deals with wet gas scrubbing, which cleans the impurities in the exhaust gas, making it suitable for IC engines. The exhaust from the IC engines is contaminated and also has high temperatures (500-800°C). As a result, it leaves the atmospheric fluid in a gasified state. Due to the increased use of automobiles and engine-based applications, engine efficiency has become an important focus of research. Various methods are implemented to increase engine efficiency, which contributes to the company's requirements in an effective manner. One such method is the pre-heating of air before entering into the engine [11-12]. The mentioned emissions are found only in a few pieces of literature, which are focused on particulate matter and HC gas. The removal of air, toxic gases, and PM using maximum high-efficiency electrostatic precipitators (ESP) is also analyzed. At the same time, the ESP is not completely effective for pollutants removal when compared to other methods. The wet scrubber material design and optimization are vital for the understanding of the operating characteristics like droplet flow, pressure drop, and mass transfer between the gas and liquid across a wet scrubber. This research shows the increasing gas and liquid droplet flow rates, which easily reduce emissions. Further ranges of liquid and gas molecules ratio are higher and effective. This induces a pressure drop proportional to the liquid flow rate. Liquid flow rate is found to reduce emissions. Other factors, including the velocity above the emission levels, are found to be reduced. When the liquid droplet level increases, the emission level decreases. The investigated liquid and gas ratio was colloidal with each other.
resulting in emission drop [13-14]. This investigation is unique due to scrubber technology usage done to control emissions in the exhaust of CI engines. Fuel burns in the combustion chamber, which produces hazardous particulate emissions through the exhaust manifold. The objective of this research is the control of emissions in an optimal manner using the scrubber system with water in different proportions.

The basic principle behind the scrubber methodology is the absorption or particle wetting. This involves the contact of the solid particles with the liquid. As a result, the solid particles get absorbed in colloidal form. They either dissolve in water or settle down as colloidal form bubbles. The experiment was done in accordance with the Indian emission standards. A cartridge smoke unit type included in the “Pollution under Control” Testvan (PUC) system was used in the diesel vehicles [15-16]. A large assortment of scrubber systems is available for the control of air pollution. In Europe, the following pathways (PW) are identified to recover NH$_3$ via (stripping) scrubbing on a full-scale PW1. The air-cleaning pathway only makes use of a scrubbing unit to treat the rich NH$_3$ indoor air found in animal stables, drying units, and mechanically ventilated composting installations. Long term monitoring of acid scrubbers at five farm locations was carried out in another research. The research reported an average NH$_3$ removal efficiency of 90–99% with a minimum and maximum peak of 40% and 100%, respectively, in the wet scrubber method involving urea and sodium, sulfide functions as an easily reducing agent. The NO emission is very hazardous due to its ability to affect the environment. Excellent solubility, stability, and oxygen variant selection are preferred for emission reduction. Another perspective is the usage of a low-cost solution for emission reduction [17]. The solutions which are selected easily reduces emission at p.H values of 14. This is because they use vital alkaline base substances, which are quickly recirculated as chemical particles [18]. The research shows outstanding potential for converting chemical scrubbers into spray filters at several publicly owned treatment works.

2. Methodology

The experimental research work is done using a 5.2 kW diesel engine. The specifications include natural aspiration, 1500 rpm, and a water-cooled power train, which is contiguous to an eddy current dynamometer. The AVL di gas 444 is placed in the exhaust pipe. The smoke meter is also placed nearby for measuring the exhaust emission. The physical and chemical properties of the chemical solution are revealed in table 1. The structure is shown in table 2.

| Appearance     | Colorless to slightly hazy liquid |
|---------------|-----------------------------------|
| Formula       | NaOH                              |
| Odor          | No                                |
| Boiling Point | 145°C                             |

**Table 1:** Properties of NaOH
| Vapour Pressure | 1.5 mm Hg |
|-----------------|-----------|
| Solubility      | Completely soluble in water, Ethanol, Methanol |
| Specific gravity| 1.52      |
| Freezing Point  | 14°C      |
| pH              | 14.0      |
| Molar mass      | 39.987 g/mol |
| Density         | 2.14 g/cm³ |

**Table 2: Structure of NaOH**

| S.no | Main elements     | Formula | Structure |
|------|-------------------|---------|-----------|
| 1.   | Sodium            | Na⁺     | ![Na⁺ Structure](image) |
| 2.   | Hydroxide         | OH⁻     | ![OH⁻ Structure](image) |
| 3.   | Sodium Hydroxide  | NaOH⁻   | ![NaOH⁻ Structure](image) |

3. **Fabrication of Scrubber and Nozzle spray**

The hollow sheet metal is used to fabricate the scrubber. The main section (length 32cm and width 15cm) is used to make a scrubber material. A solution tank of (length 12cm and width 4cm) is used as the scrubber tank. Also, four nozzles are fitted inside the scrubber tank. The nozzles spray the chemical solution as illustrated in Fig 3.
Figure 1: Layout of engine

Figure 2: View of engine

Figure 3: View of Assembly Process

Figure 2 shows the experimental setup. The dynamometer is used to calculate the power over the engine operating ranges and also the torque. Generally, different methods are used to absorb the output energy of the CI engine. The AVL gas analyzer and smoke analyzer are used for measuring the emissions of the exhaust gas.

The experimental scrubber setup shown in figure 3 features four types of nozzle fitted inside the scrubber. The liquid and gas molecules are colloidal with each other. They also interface together as gas state molecules, which reduce emissions. Also, velocity is reduced since the pressure droplets...
are colloidal with the gaseous state. This also reduces emissions. The temperature is also minimized.

For all the above-mentioned purposes, the nozzles are used.

4. Result and Discussion
The fabricated scrubber setup was fitted in the exhaust pipe of diesel engine. Then, the fuel consumed and the gas temperature monitoring at the outlet are done in the gas treatment system at 0, 1.32, 2.6, 3.9, and 5.2 kW. For all load conditions, the engine speed was maintained at 1500 rpm.

![Figure 4: Variation of NO emission](image)

Figure 4 represents the variations in NO emission for diesel, DPB without scrubber, and DPB with the scrubber. The NO emission is lower in DPB when compared to diesel. But, DPB with scrubber method is found to mainly reduce. The hazardous emission in an IC engine is NO during the combustion period. It was found that the extension of emission in a high load level also increased. This is the reason for the proportionate increase in speed with the cylinder temperature level. NO emission for diesel, DPB without scrubber, and DPB with scrubber are 950ppm, 987ppm, and 612ppm, respectively. The NO emission was reduced by 24% under DPB with scrubber when compared to DPB without scrubber. The NO absorption reaction mechanism with the NaOH solution is represented as an alkali solution in the following reaction. The alkali solution quickly absorbed NO emission [12]. In this experiment, the NaOH solution gets reduced to NO₂. It is known as the exact removal solutions. It also has a pH value from 7 to 10. Hence, it quickly absorbed NO emission. Due to these reasons, the scrubber method as typical water injection reduces exhaust emission.

\[
\text{NO}_x + \text{NaOH} \rightarrow \text{NaNO}_2 + \text{H}_2\text{O}
\]

Figure 5 shows the difference between HC emission against Brake power. HC emission increases because of the increasing load. Due to an increase in engine load, the fuel level increased for the primary purpose of combustion. Hence, the time required also increased. The availability of oxygen levels decreased proportionally to the HC emission increase. Another reason is due to the cylinder wall deposits emission, cervical volume, absorption of thin oil film, etc. [1]. The emissions for diesel, DPB without scrubber, DPB with scrubber are 30 ppm, 32 ppm, 29 ppm, respectively. The HC emission increased by 6% for DPB with a scrubber. The HC emission was reduced by 9% for DPB with scrubber when compared to diesel.
Figure 5: Variation of HC emission

Figure 6: Variation of CO emission

Figure 6 shows the variation in CO emission at full load conditions. Due to the factors of high equivalence ratio, low residence time, insufficient oxygen quantity, the CO emission under maximum load is increase. For DPB with scrubber, the CO emission levels decreased significantly. The CO emission measured for diesel, DPB without scrubber, DPB with scrubber are 0.36%, 0.38%, 0.32% by volume, respectively. The CO emission decreases by 6% for DPB with scrubber when compared to DPB without scrubber. Figure 7 shows the variation of smoke emission with brake power. Smoke is the solid soot particles present within the exhaust gas. Smoke emission is less in DPB when compared to diesel. Due to the availability of homogeneous charge inside the engine well and premixture at combustion initiation, the smoke levels were subdued. Other reasons for the reduction of smoke under DPB with scrubber include the maximum duration of combustion, high
combustion temperature, and extensive flame propagation. Another important reason for the reduction of smoke is the oxygen content present in DPB with a scrubber.

Figure 7: Variation of Smoke emission.

Figure 8 shows the occurrence in brake thermal efficiency with DPB without scrubber and DPB with a scrubber. The brake thermal efficiency is an existent representation of the power output. It is aggravated by cetane number, calorific value, and other fuel properties of diesel when compared to DPB. With an increase in load, the brake thermal efficiency level gradually increased. The brake thermal efficiency for base fuel diesel was 28.7%. For DPB without scrubber, the brake thermal efficiency was found to be 27.3%. For DPB with a scrubber, the brake thermal efficiency was found to be 26.4%. The brake thermal efficiency increased for DPB with scrubber due to the presence of a highly active surface when compared to diesel.

Figure 8: Variation of BTE
5. Conclusions
In this investigation, an exhaust treatment setup is fabricated and tested for DPB fuel. The following conclusions are listed, as shown below.

- The NO decreased by 25% at maximum load condition to the chemical reaction of NaOH solution.
- The HC emission was reduced by 14% at maximum load condition. The reasons were due to the chemical solution are strong alkaline content.
- The CO and smoke emissions were also marginally reduced.

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