STUDY OF EMISSION CONTROL ON STATIONARY DIESEL ENGINE BY SCRUBBING TECHNIQUE WITH SODIUM BICARBONATE SOLUTION

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ABSTRACT:
Increasing automobile emission is becoming a major problem for our environment. Wet scrubber technology is generally used in power plants and marine engines for emission control. In this study, this technique was applied to the internal combustion engine for its suitability and performance to control undesirable emissions. A 5.2 kW diesel engine with an eddy current dynamometer with water cooling and is used for this study. The sodium bicarbonate [NaHCO$_3$] solution was chosen for the study. Experimental readings were taken with the fabricated scrubber at the exhaust with different engine loads (0, 1.3, 2.6, 3.9, and 5.2 kW). Chosen sodium bicarbonate solution was found to be very effective in reducing emissions. The sodium bicarbonate solution effectively absorbed the NO and smoke emissions by 12.35% and 27.21%, respectively.

Introduction:
The environmental pollution resulting from chemical Industries, automobiles, and thermal power plants are mainly due to the undesirable emissions from the IC engines. This contributes to the emission level increase in rural and urban areas in developed as well as the developing countries. The emissions create major problems which have resulted in the formation of international regulations. The emissions create significant problems due to their ability to get diffused into different areas. Sachuthananthan et al. [1]. The emission norms for automobiles are getting stringent at the world level. For effective emission control, emission treatment methodologies need to be researched in detail. Different types of after-treatment techniques are available for the purpose of emission reduction, including Diesel Oxidation Catalyst (DOC), Diesel Particular Matter (DPF), Catalytic Converter (CC), and Selective Catalytic Reduction (SCR). These techniques are used to reduce emissions, which proved to be cost-effective and possessed fuel-efficient technologies. Balaji et al. [2]. The NOx plays a significant influence on the ground-level ozone and smog, which results as acid rain. The usage of after-treatment techniques is very much needed to reduce NOx emission. The mentioned after-treatment techniques are found to reduce NOx emissions. The NOx emission mainly consists of three types, which are listed as the thermal NOx, Prompt NOx, and the fuel mechanism. The combustion process during the high-temperature range breaks the strong triple bond of nitrogen molecules, which is converted into nitrogen as highly unstable molecules. These molecules react with oxygen to form the thermal NOx. Furthermore, the free radicals are formed during the combustion flame before getting converted into hydrocarbons resulting in the assembly of prompt NOx. Hence, the thermal NOx and prompt NOx are mostly formed in the biodiesel. Also, fuel chemistry plays a major role in the reduction of thermal NOx. NOx is also very sensitive to the free radical concentration within the reaction zone of ozone. Balaji et al. [3, 4]. The scrubber techniques are found to reduce the undesirable emissions which are mainly utilized in industries. There are two types of scrubbers, namely, the dry scrubber and the wet scrubber, which effectively reduce emissions.

A wet scrubber is additionally used to remove impurities from the exhaust gas by reducing temperature due to their dispersion into the water. The wet scrubber is also used in the removal of impurities, including the particles.
and soluble components. These emissions are removed as the particulate matter, which is evidenced throughout this experiment. The modeling of the wet scrubber is most advantageous in the reduction of emissions through computational analysis, thermodynamic analysis, and also heat transfer analysis, as reflected in the works of Adeeb Abdul Wahid et al. [5-6], Tien Anh Tran et al. [7-8] established the reduction of NOx emissions using scrubber treatments. The scrubber treatments are also found to reduce the Green House Gas emissions (GHG), which are affecting the human population in a big way. Also, the acid precipitation was avoided using scrubber techniques. The acid precipitation affected the natural minerals present in water. The GHG affects seawater biodiversity, which include fish species and plants. These undesirable effects of GHG are reduced using scrubber techniques.

Marek Balas et al [9] studied the role of wet scrubber in emission control in other aspects. In their research, the combustion process was additionally modified to reduce emissions. High temperatures of gas (500 - 800°C) resulted in pollutant formation resulting in the formation of atmospheric fluid gas. The increase of emission levels along with the engine fuel efficiency was discussed during in their research. The influence of wet scrubber increases the engine efficiency and the control of the pollution level in a step by step manner, were also discussed. The efficiency increased due to the preheating of air before getting converted into the air-fuel ratio mixture. These techniques are mainly used to increase the efficiency level and reduce power consumption.

Some researchers studied particulate emissions, which were resultant of the combustion process. These particulates are also reduced using the scrubber techniques as the water solution was not sufficient for the adsorbing process. The emissions which are reduced in this experiment focused on smoke opacity (65 HSU) and “pollution Under Control” (PUC), which was successfully implemented in diesel vehicles said by Veera Bhadra et al. [10, 11].

Different techniques were implemented using ammonia (NH₃) for the emission regulation. The NH₃ eliminates reluctant agents easily. The thermopile bacterial isolated PW1 reduced undesirable emissions. The emissions got reduced when NH₃ was used as drying units and composting installations, which were mechanically ventilated. The emissions were reduced by 90-99%, as reflected in the works of Melse and Ogink et al. [12, 13].

In some investigations, the pathway water was sprayed at the nozzle-packing. This reduced the unwanted impure air in the form of minimization of the loss of exhaust air. The prevented air was recirculated into the remaining water. The water and the exhaust air are colloidal with each other at the horizontal nozzle, which passes due to the mass transfer between the two phases. Thus, the ammonia absorbs the impurities effectively when compared with the chemical scrubber process, which use bio-trickling methods for the filter of impurities as reflected in the works of Van der Hayden et al. [14, 15].

2. Methodology:

The experimental work was done on a single-cylinder diesel at 1500rpm and the engine specifications are given table 1 and also photographic view of the engine shown in figure 1.

Table 1: Specifications of the test engine

| Specifications                  | Parameters               |
|-------------------------------|--------------------------|
| Make                          | Kirloskar TV1            |
| Number of cylinders           | 1                        |
| Number of strokes             | 4                        |
| Rated power                   | 5.2 kW                   |
| Type of dynamometer           | Eddy current dynamometer |
| Cylinder diameter (mm)        | 87.50                    |
| Stroke length (mm)            | 110                      |
| Compression ratio             | 17.5:1                   |
| Orifice diameter (mm)         | 20                       |
The sodium bicarbonate at 25g and 500ml of water was mixed. This sodium bicarbonate solution settles down at the lowest level of the tank. After this, the sodium bicarbonate solutions were neutralized in the presence of water.

\[
2\text{NaHCO}_3 \rightarrow \text{Na}_2\text{CO}_3 + \text{CO}_2 + \text{H}_2\text{O}
\]

Intermediate

\[
\text{Na}_2\text{CO}_3 + \text{NO}_x \rightarrow 2\text{NaNO}_x + \text{CO}_2
\]

Table 2: Specifications of the NaHCO₃

| Items              | Actual size       |
|--------------------|-------------------|
| Particle Size      | <0.104 ~ 0.075mm  |
| Alkaline content   | 99.7              |
| Sodium Bicarbonate | 1.05              |
| Arsenic            | <0.0015           |
| pH value           | 8.1               |

Sodium bicarbonate reacts at temperature range as 450°C to form sodium carbonate as an intermediate component along with the formation of carbon dioxide and water. The sodium carbonate reacts with nitrogen dioxide at a temperature of 350°C resulting in the formation of sodium nitrate and carbon dioxide. A 5.2 kW diesel engine (an aqua cooled engine) was used to measure the emission characteristics. The eddy current dynamometer was used along with the loading devices. The emissions were measured using the AVL Di gas analyzer 444. The preparation of the solution is shown in Figure 2. Sodium bicarbonate solution was used in this investigation, which was found to reduce the undesirable emission levels in the exhaust emission.
3. Result and Discussion:

The influence of scrubber with diesel in NO emission reduction is compared with that of the diesel without scrubber in the CI engine in this current research work. The different emission parameters mainly measured include NO, other pollutants like HC, CO, CO$_2$, and smoke opacity.
**NO emission:**

Figure 4 depicts the variation in NO emission with Diesel without scrubber and Diesel with scrubber techniques. NO is one of the foremost harmful pollutants at the ignition stage. When the engine load level is increased, the NO emission also increases. Since the flame speed level increased in the stimulated time period for lean speed blends, the NO emission increased. Moreover, the chemicals emphasized that the NO level enlarged at flame temperature level, which is the main reason for the NO emission [2]. The final results showed that the NO emission level at full load condition for diesel without scrubber was 970 ppm and 1050 ppm for diesel with the scrubber. The NO emission level with scrubber were found to be reduced by 12.35%.

**HC emission:**

The variations of HC emission for diesel without scrubber and diesel with scrubber techniques are shown in Figure 5. From the graphs, the HC emission at full throttle condition for diesel without scrubber was 28 ppm. For diesel with scrubber, the HC emission was 26 ppm, which was found to be slightly variable when compared with the initial case. The main reason for the HC emission increase proportionate to the engine load level is due to the enlargement of the fuel-rich sideburn of the reaction zone across the diffusion flame. The fuel mixture with air was considerably leaner when compared to the lean mixture limit.
Figure 5: Variation of HC emission

Figure 6 shows the variation of CO emission with relevance to the BP for diesel with and without scrubber. The CO emission changes at different load conditions for both diesel without scrubber and diesel with scrubber. The CO emission was found at 0.06% for diesel without scrubber and 0.056% for diesel with scrubber at eventual load condition. Temperature of the flame at the squat condition was considered as the reason for the poor air quality ratio, which resulted in the CO emission formation. This is one of the reasons for the CO emission level increase along with the disruption due to the oxidation of CO to CO$_2$. 
Smoke emission:

The smoke which is in gas phase react with the liquid phase sodium bicarbonate solution. The subsequent conversion of the sodium bicarbonate solution from the liquid to the solid phase affects the bicarbonate of the soda concentration within the liquid, which is followed by the introduction of the bubble column. Therefore, the amount of supersaturation could also be a function of this liquid within the bubble column. The variation of smoke on the brake power is shown in figure 7. It shows a decrease in value for the diesel with scrubber due to the use of sodium bicarbonate, which reduces the smoke. This is due to the higher adsorption capacity of sodium bicarbonate, which reduces the smoke to a greater extent. The results also revealed a decrease in smoke-level when the scrubbing setup was used. The reason for changes in the values of NO, HC and smoke is due to the sodium bicarbonate reaction. The sodium bicarbonate is a very good absorbent. It is present in solid form, which is very suitable for gas absorption.

![Figure 7: Variation of Smoke emission](image)

4. Conclusions:
In this study, an exhaust gas-treatment setup is fabricated and tested for diesel fuel with and without scrubber. The following conclusions are derived, which are listed below.
1. NO was reduced by 12.35% at full load conditions due to the reaction of sodium bicarbonate solution.
2. Smoke emission decreased by 27.21% at full load conditions due to the settling of the smoke particles at the bottom of the scrubber tank with the help of the sodium bicarbonate solution.
3. The HC and CO emissions were also slightly reduced.

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