Reduction of pollutants from the exhaust gas of diesel engine by dual type wet scrubber technology

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1.ABSTRACT

Wet scrubbing, a relatively new technology, is used on absorption of pollutants such as carbon dioxide (CO_2), unburned hydrocarbons (UHC), oxides of nitrogen (NO_X) and lead and other particulate emissions from the diesel engines. These pollutants are the root cause for the air pollution. Scrubber is a device used to control the solid and gaseous pollutants from industrial exhaust streams. In this project dual type scrubber was designed and fabricated. After that the setup was used in the diesel engine to reduce the pollution by chemical absorption method. The rate of absorption of the pollutants mainly depends on the nature of the absorbent used. Emission rates of CO_2, NO_X, HC, CO of a diesel engine had analyzed and the results were taken. The various chemical absorbents such as Sodium Hydroxide (NaOH), Potassium hydroxide (KOH), Magnesium hydroxide ($Mg(OH)_2$) are used for experimental works. Finally, the results were compared with the performance of diesel engine with and without experimental setup.

Key words:

Scrubber, Pollutants, Emission rate, Absorption, Packed bed, spray tower, Gas analyzer, solution preparation.

2.INTRODUCTION

In present scenario, the environmental pollution is major problem in the world. The vehicle exhausts generate pollutants such as carbon dioxide, unburned hydrocarbon, oxide of nitrogen and lead and other particulate emissions. These pollutants are the root cause for the air pollution. The pollutants prevalent in the atmosphere today is harmful to the health of human particularly children and those with affected with lung diseases. These gases are responsible for acid rain formation. Considering the harmful effects of some pollutants as a severe problem, the research towards the emission control has to reach the peak. Hence emission control devices have been developed by several researchers for simultaneous control of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulphur (SO_x) and particulate in automobile engine exhaust.

Here scrubber technology is used to control the emission from various sources. If the exhaust stream contains both particles and gases, wet scrubbers are generally the only single air pollution control device that can remove both types of pollutants.

In this project wet scrubbers are used when dry dust collection creates excessive explosion hazards, when dust collection is combined with acid gas removal, and chemical reaction takes place and the dust is collected as slurry.

Wet scrubbers are capable of removing the pollutants by the action of the chemical absorbers. Inconvenient are the occurrence of erosion, corrosion, and a wet plume of entrained droplets that can only be eliminated by high-efficiency fibrous mat demisters.

Scrubber systems are a diverse group of air pollution control devices that can be used to remove particles and/or gases from industrial exhaust streams. Traditionally, scrubbers have referred to pollution control devices that used liquid to "scrub" unwanted pollutants from a gas stream. Recently, the term scrubberis also used to describe systems that inject a dry reagent or slurry into a dirty exhaust stream to "scrub out" acid gases. Scrubbers are one of the primary devices that control gaseous emissions, especially acid gases.

Wet scrubber is a term used to describe a variety of devices that use liquid to remove pollutants. In a wet scrubber, the dirty gas stream is brought into contact with the scrubbing liquid by spraying it with the liquid, by forcing it through a pool of liquid, or by some other contact method.

The design of any air pollution control device (wet scrubbers are no exception) depends on the industrial process conditions and the nature of the air pollutants involved. Exhaust gas characteristics and dust properties, if particles are present, are of primary importance. Scrubbers can be designed to collect particulates and/or gaseous pollutants. Wet scrubbers remove pollutant gases by dissolvingor absorbingthem into the liquid. Also, the resultant scrubbing liquid must be treated prior to any ultimate discharge or reused in the plant.

A wet scrubber's ability to collect small sized particulates is often directly proportional to the power input into the scrubber. Spray towers are used to collect particulate matter larger than 5 micrometers. To obtain high efficiency removal of 1 micrometer (or less) particles generally requires high energy devices such as venturis or augmented devices such as condensation scrubbers.

Wet scrubbers, chemical liquids that remove gaseous pollutants are referred to as absorbers. Good gas-to liquid contact is essential to obtain high removal efficiencies in absorbers. A number of wet scrubber designs are used to remove gaseous pollutants, we use the dual type scrubber i.e. combination of packed bed type and spray type.

Wet scrubbers can achieve high removal efficiencies for either particles or gases and, in some instances, can achieve high removal efficiency for both pollutants in the same system. However, in many cases, the best operating conditions for particle collection are the poorest for gas removal. In general, obtaining high simultaneous gas and particle removal efficiencies requires that one of them be easily collected (i.e., that the gases are very soluble in the liquid or that the particles are large and readily captured).

Wet scrubbers can serve two different duties, namely, the absorption of water-soluble gases or vapors, and arresting dust.

Dissolution of soluble gasesis basically driven by:

Contacting surface, available for mass transfer between the gas phase and the liquid, Difference between actual concentration and equilibrium conditions.

Hence, absorption normally requires a very large gas to liquid interface surface. Arresting dust particlesby wet scrubbing proceeds by high velocity impaction of dust particles in their first contact with droplets. After this initial impact the relative velocity becomes too small to create collisions, so that the initial contact of particles and droplets drives almost entirely a successful separation of dust and is little helped by providing supplemental surface.

In spray tower scrubbers, liquid is sprayed through a number of tubes through nozzles. In this scrubber, the gas stream and absorbers are allowed to flow in counter flow direction. Therefore, both gas and liquid phases provide energy for the gas-liquid contact**.** Then chemical reactions take place and the pollutants are collected.

In packed tower or wet-film scrubbers, liquid is sprayed or poured over packing material contained between support trays. A liquid film coats the packing through which the exhaust gas stream is forced. Pollutants are collected as they pass through the packing, contacting the liquid film.

In the dual type scrubber, the spray type to be placed at the top of the packed type in the scrubber. The chemical absorber is first allowed to spray through several tubes and then pass over the packing materials of the packed bed. The exhaust gas first enters the bottom of the packed bed and then against the sprayed absorbers in the spray type. Then pollutant gets deposit at the bottom. The exhaust gas after the removal of pollutants is passing through top.

The various chemical absorbers used in this setup were water, potassium hydroxide, magnesium hydroxide. The results were taken by using these absorbents and compared with the actual readings.

3.EXPERIMENTAL SETUP

3.1 DIMENSIONS OF DUAL TYPE SCRUBBER SETUP

3.1.1 Absorption column1

Diameter of absorption column =20cm

Height of absorption column =75cm

Height of packing bed =70cm

3.1.2 Absorption column2

Diameter of absorption column =20cm

Height of absorption column =75cm

3.1.3 Bottom tank

Diameter of bottom tank =31.8cm

Height of bottom tank = 30 cm

Total capacity of bottom tank =24liters

3.1.4 Column head

Diameter of column head = 19.7 cm

Height of column head = 17.5 cm

3.1.5 Ceramic packing

Height of packing ring = 2.5 cm

Diameter of packing ring = 2.5 cm

Thickness of packing ring = 8 cm

3.2 COMPONENTS

The experimental setup consists of following components:

- Engine
- Dual type scrubber setup0
- Packing material
- Pump
- Engine exhaust gas emission analyzer
- Absorbents

Fig.1 Experimental setup

3.2.1 Engine

This project is selected to reduce the pollution from the environment due to engines in various field. Though engines burnt fuel to give power required by entire world, burning fuel will liberate so many pollutants in both solid and gaseous form.

Solid pollutants include dust particles and other contaminants. And gaseous pollutants are lethal which includes carbon monoxide, nitrous oxides, sulphour oxides, etc. so it is very much important to reduce the environmental pollution as much as possible.

Fig.2 Four stroke diesel engine

3.2.1.1 Engine specification

Number of cylinder	2
Bore	87.5 mm
Stroke length	110 mm
Speed	1500 rpm
B.H.P	10 HP
Compression ratio	17:1

3.2.2 Dual type scrubber setup

The experimental setup is the main element in controlling the pollutants from engine exhaust. So it is very concern to design the experimental setup.

Fig.3 Dual type scrubber setup

This setup consists of following sub-components:

- Absorption column 1
- Absorption column 2
- Bottom tank
- Column head
- Sieve plate

3.2.2.1 Absorption column 1

Absorption column is the filtering component in this experimental setup. It is dumped with ceramic packing material which provides greater gas- liquid contact area.

Fig.4 Absorption column 1

3.2.2.2 Absorption column 2

Absorption column is the filtering component in this experimental setup. It is fitted with spray pipe which provides greater gas- liquid contact area. This will act as a spray type region.

Fig.5 Absorption column 2

3.2.2.3 Bottom tank

Bottom tank is used to store the absorbing liquid. It also gives stability to whole setup by having bottom large surface area. It should be corrosive resistance to store the chemical liquids for larger period. It has ports to supply the absorbing liquid to column head and to easily drain those liquids.

Fig.6 Bottom tank

3.2.2.4 Column head

Column head has a sprayer arrangement to spray the absorbing liquid in the column. It has liquid inlet port with flow controlling valve and one outlet port for exhaust gas.

Fig.7 Column head

3.2.2.5 Sieve plate

Sieve plate is provided in the column for holding ceramic material.

Fig.8 Sieve plate

3.2.3 Packing material

For fabricating the packed bed scrubber technology we are using Rasching rings type ceramic material. Random packing method is used to increase the contact area of absorbent and gas.

Fig.9 Ceramic packing

3.2.4 Pump

The pump is used to circulate the absorbing liquid through pipes to column head and bottom tank.

Fig.10 Pump

3.2.4.1 Pump specification:

Suction	4.5 m
Total Head	15 m

3.2.4.2 Motor Specification:

Rating (drive on load)	0.373 KW
Discharge (Max)	810 lph
Consumption	120 w
Power input	230 V-Ac 50 Hz
Speed	1800 rpm
Duty	Continuous

3.2.5 Engine exhausts gas emission analyzer

Engine exhaust gas emission analyzer is the monitoring device to analyze the amount of pollutants present in the exhaust gases from the engines. It display results in digital form with high precision. It has a probe for measurement.

Fig.11 Engine exhaust gas analyzer

4.SELECTION OF ABSORBENTS

The working absorbent used for the testing purposes were

1. Sodium Hydroxide – NaOH (in diluted form)

2. Potassium hydroxide – KOH (in diluted form)

3. Magnesium hydroxide – $Mg(OH)_2$ (in diluted form)

4.1 SODIUM HYDROXIDE

Sodium hydroxide also known as lye and caustic soda.. It is a white solid and highly caustic metallic base and alkali salt which is available in pellets, flakes, granules, and as prepared solutions at a number of different concentrations. Sodium hydroxide is soluble in water, ethanol and methanol. This alkali is deliquescent and readily absorbs moisture and carbon dioxide in air.

Fig.12 Sodium hydroxide

4.2 POTASSIUM HYDROXIDE

Potassium hydroxide can be found in pure form by reacting sodium hydroxide with impure potassium. Potassium hydroxide is usually sold as translucent pellets, which will become tacky in air because KOH is hygroscopic. Its dissolution in water is strongly exothermic, meaning the process gives off significant heat.

Fig.13 Potassium hydroxide

4.3 MAGNESIUM HYDROXIDE

Magnesium hydroxide is an inorganic compound with the chemical formula of hydrated $Mg(OH)_2$. As a suspension in water, it is often called milk of magnesia because of its milk-like appearance. The solid mineral form of magnesium hydroxide is known as brucite.

Due to the availability of water is high and it has more absorbent properties, it can used as a absorbent .And also other absorbents like KOH and Mg (OH)2 are to be used for analyzing the results**.**

Fig.14 Magnesium hydroxide

4.4 CHEMICAL REACTIONS INVOLVED

The following reactions are occurred when the absorbents react with these gases

i.Potassium hydroxide (KOH)

Potassium hydroxide absorbs carbon dioxide readily from air. This will produce the suspension of potassium carbonate formed:
$2KOH(aq) + CO_2(g) \rightarrow K_2CO_3(s) + H_2O(l)$

ii.Magnesium hydroxide ($Mg(OH)_2$)

Magnesium hydroxide reacts with carbon dioxide to give magnesium carbonate and water:

$Mg(OH)_2\ (aq) + CO_2\ (g) \rightarrow MgCO_3\ (s) + H_2O(l)$

iii.Sodium hydroxide (NaOH)

Sodium hydroxide reacts with carbon dioxide to give sodium carbonate and water:

$2NaOH\ (aq) + CO_2\ (g) \rightarrow Na_2CO_3\ (s) + H_2O(l)$

iv.NO_X Removal

The following chemical reaction occurs when nitrogen dioxide reacts with water:

$2\ NO_2 + H_2O \rightarrow HNO_2 + HNO_3$

Nitrous acid then decomposes as follows:

$3\ HNO_2 \rightarrow HNO_3 + 2\ NO + H_2O$

Where nitric oxide will oxidize to form nitrogen dioxide that again reacts with water, ultimately forming nitric acid:

$4\ NO + 3\ O_2 + 2\ H_2O \rightarrow 4\ HNO_3$

5.RESULTS AND DISCUSSION

5.1 Actual emission rates from the four stroke diesel engine (without setup)

Table.1 Actual emission rate

SPEED (rpm)	CO (%vol)	HC (ppm)	CO_2 (%vol)	NO_x (ppm)
1540	0.14	77	2.9	254
1500	0.13	78	3.0	292
1475	0.10	80	3.2	303
1430	0.09	83	3.5	339

5.2 Emission rates from the four stroke diesel engine by dual type scrubber setup

i. Using (KOH and NaOH) as absorbent:

Table.2 Emission rates using (KOH and NaOH) as absorbent

SPEED (rpm)	CO (%vol)	HC (ppm)	CO_2 (%vol)	NO_x (ppm)
1540	0.05	48	1.2	161
1500	0.04	51	1.3	187
1475	0.04	52	1.3	198
1430	0.03	54	1.4	209

ii. Using (KOH and Mg(OH $)_2$) as absorbent:

Table.3 Emission rates using (KOH and Mg(OH $)_2$)as absorbent

iii. Using (NaOH and Mg(OH $)_2$) as absorbent:

Table.4 Emission rates using (NaOH and Mg(OH $)_2$) as absorbent

5.3 ENGINE EXHAUST GAS EMISSIONS WITH AND WITHOUT DUAL TYPE SCRUBBER SETUP

9.3.1 Various CO_2 emissions from the diesel engine based on engine speed

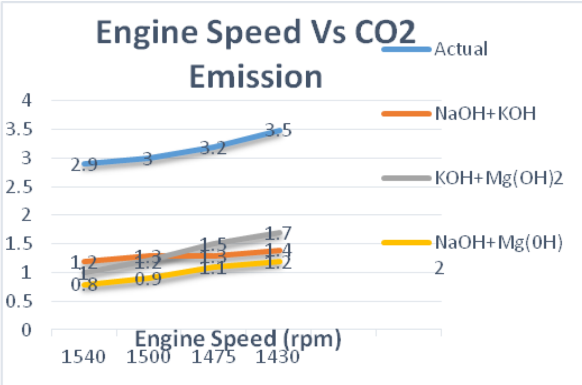


Fig.15 Various CO_2 emissions from the diesel engine based on engine speed

CO_2 emission from the engine was almost constant for higher engine speed conditions. NaOH and $Mg(OH)_2$ absorbed CO_2 comparatively more with other absorbent.

9.3.2 Various CO emissions from the diesel engine based on engine speed

SPEED (rpm)	CO (%vol)	HC (ppm)	CO_2 (%vol)	NO_x (ppm)
1540	0.03	29	1.0	133
1500	0.02	35	1.2	145
1475	0.02	36	1.5	156
1430	0.01	41	1.7	180

SPEED (rpm)	CO (%vol)	HC (ppm)	CO_2 (%vol)	NO_x (ppm)
1540	0.05	34	0.8	121
1500	0.04	41	0.9	128
1475	0.02	48	1.1	136
1430	0.01	57	1.2	154

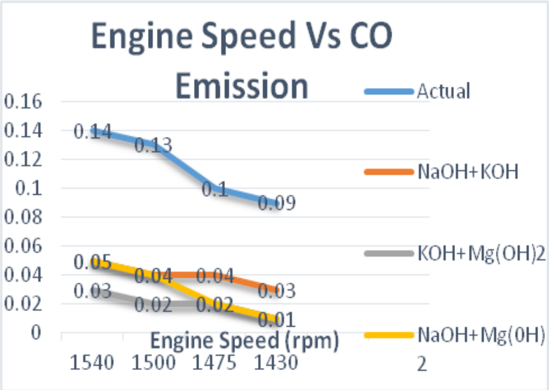


Fig.16 Various CO emissions from the diesel engine based on engine speed

Almost all CO emission from engine at different speed was absorbed by KOH. $Mg(OH)_2$ also absorbs this emission considerably. Water has little that much effect in absorbing CO. After some stages water got saturated with this absorption.

9.3.3 Various NOx emissions from the diesel engine based on engine speed

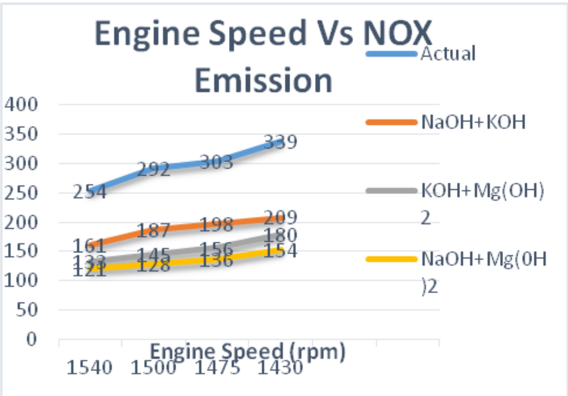


Fig.17 Various NOx Emissions from the Diesel engine based on engine speed

$Mg(OH)_2$ absorbed more NO_X emission from the engine when comparing with other two absorbents. Both water and NaOH had good effect in absorbing this pollutant.

9.3.4 Various HC emissions from the diesel engine based on engine speed

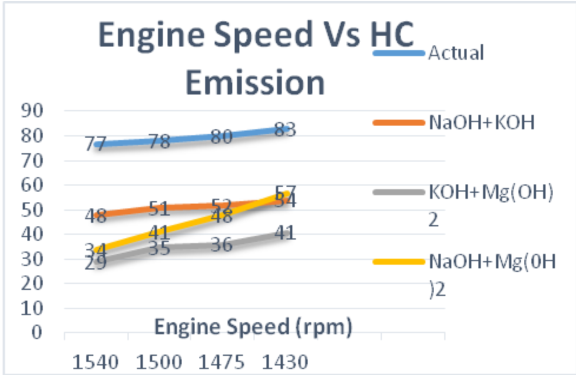


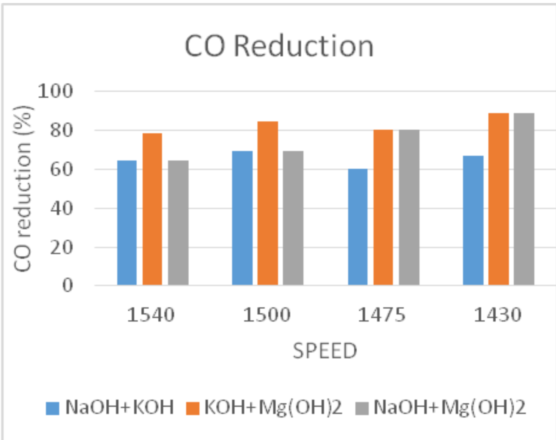
Fig.18 Various HC emissions from the diesel engine based on engine speed

HC emission from engine gradually decreases when engine speed increases. This emission was reduced with more effect by KOH and $Mg(OH)_2$.

5.4 ENGINE EXHAUST GAS EMISSIONS REDUCTION PERCENTAGE WITH DUAL TYPE SCRUBBER SETUP

9.4.1 Various CO emission reduction percentage from the diesel engine based on engine speed

Fig.19 Various CO emission reduction percentage



from the diesel engine based on engine speed

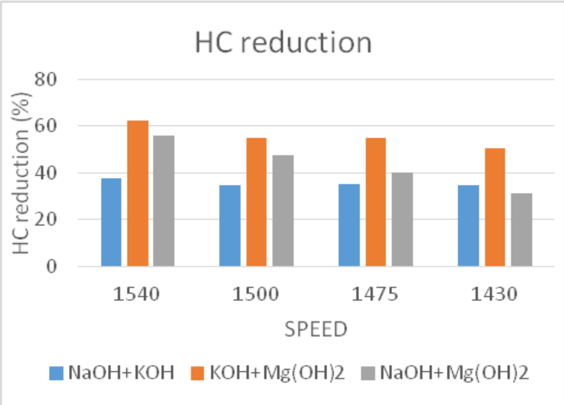
While, comparing the reduction percentage of various combination of chemical solutions the KOH and $Mg(OH)_2$ solution gives maximum CO reduction.

9.4.2 Various HC emission reduction percentage from the diesel engine based on engine speed

Fig.20 Various HC emission reduction percentage from the diesel engine based on engine speed

While, comparing the reduction percentage of various combination of chemical solutions the KOH and $Mg(OH)_2$ solution gives maximum HC reduction.

9.4.3 Various CO_2 emission reduction percentage



from the diesel engine based on engine speed

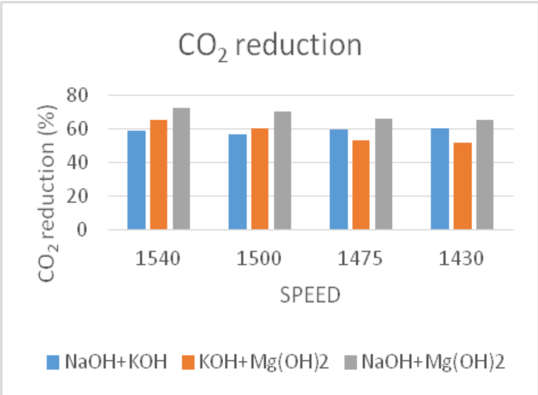


Fig.21 Various CO_2 emission reduction percentage from the diesel engine based on engine speed

While, comparing the reduction percentage of various combination of chemical solutions the NaOH and $Mg(OH)_2$ solution gives maximum CO_2 reduction.

9.4.4 Various NO_X emission reduction percentage from the diesel engine based on engine speed

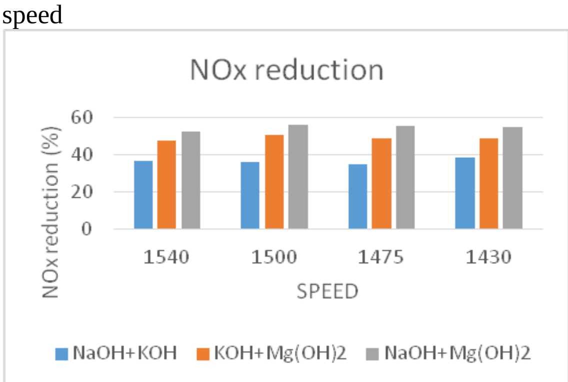


Fig.22 Various NO_X emission reduction percentage from the diesel engine based on engine speed

While, comparing the reduction percentage of various combination of chemical solutions the NaOH and $Mg(OH)_2$ solution gives maximum NO_X reduction.

6.CONCLUSION

In diesel engine various pollutants such as CO, CO2, HC, and NOx are highly emitted. Dual type scrubber setup was designed and fabricated. Then the setup can be used as a source to reduce the various pollutants from the emission and to produce eco friendly environment. The various absorbents such as NaOH, KOH, $Mg(OH)_2$ were used to spray in the dual type scrubber to reduce the emission**.** We found KOH was well suited for reducing the CO and CO_2 emissions after the analyses of various emissions by using different absorbents. We found that the combination of NaOH and $Mg(OH)_2$ solution is the best choice for the removal of NOx and CO_2 emissions and also we found that the combination of KOH and $Mg(OH)_2$ solution is the best choice for the removal of HC and COemissions.

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