Development and test of a new carbon capture system using Zeolite with addition of Activated carbon and Monoethanolamine for IC engines

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Abstract. Global warming is one of the major concerns of the modern era. It is caused by the surplus presence of gases like CO₂, CH₄, NOₓ, and SF₆, which can entrap the sun’s warmth within our atmosphere leading to the greenhouse effect. Past surveys show that the atmospheric CO₂ levels, which has been on a steady rise due to burning of fossil fuels as well as incomplete combustion in IC engines, is the key factor to the climate change problem the world is facing right now. One of the ways to reduce this CO₂ crisis is to capture carbon emissions at the source itself. This paper deals with a process to reduce CO₂ levels by employing a combination of zeolite, activated carbon and monoethanolamine (MEA) with the help of Aluminium fine wire mesh. The properties of zeolite 5A have been adapted in capturing the CO₂ due to their high micro porous structure and MEA due to its high CO₂ absorbing characteristics. A slurry is prepared and the aluminium wire mesh is dipped in it, dried and is later kept in the exhaust pipe for the results. A comparison of the carbon emission with and without mesh is tabulated and presented with discussions.

1. Introduction

Over the years air pollution has become a major threat to humankind as well as for the environment. Air pollution exhibits various ailments to living things. One of the common and fortunate reasons for this pollution is the exhaust lines of automobiles which emit toxic gases like CO, CO₂, NOₓ, etc. The overall growth of automobiles has also started to increase at a superior level adding to the crisis. In the total motor vehicle production, majority percentage is covered by passenger vehicles which consist of 74% of total production. As there is a current decline in annual automobiles sales, recent trends suggest that there might be a growth in electric vehicles. Various automobile industries have started to test and model electric vehicles which are significantly less pollutant. The primary objective is to control pollution to an extent and reduce the toxicity of the atmosphere. Post-combustion carbon capture is expected to be an efficient way of reducing pollution as it would separate CO₂ from the fuel gases and convert it into a less harmful gas at the source itself. Post-combustion has been widely equipped in the automobile industry for the past few decades. Standard cleaning, cooling, sorption and mist elimination processes used with PCC units aren’t decent to eliminate the emissions of CO₂ from atmosphere. It may be difficult to additionally make an attempt to eliminate these emissions as the existing market choices to regulate them are restricted. Additional refined ways are needed to capture these emissions. Amine-based PCC method could be chosen as an alternative way to be widely employed in coal-fired power stations. Since MEA, its degradation product and numerous corrosion
reactions within the liquid section are a forerunner of all aerosolized emission, a perfect approach to eliminate emissions would be to maintain an occasional concentration of degradation product within the liquid section, which might additionally cut back the concentration of degradation products in fine droplets. Additional enhancements in this method could be adopted to eliminate vapour emissions [1]. Novel functionalised adsorbents are synthesized by immobilization of varied amines on zeolite 13X. The results discovered that the maximum loading was achieved for methanol-mediated synthesis conducted which used prior to wetted pellets at 29°C and with 15 minutes of shaking time. The sorption capacities that were prior to wetted zeolite 13X, 19.98 mg/g for modified zeolite with monoethanolamine and 22.78 mg/g for zeolite with isopropanol amine [2]. Catalytic converter can help in reducing pollutants but the increase in exhaust back pressure increases fuel consumption. Converter was tested with wire mesh size (16 and 30) substrate which considerably reduced the emissions of HC, CO, CO₂ and NOₓ from the engine [3]. The neem oil blend was analysed in a diesel engine for its emission characteristics and performs with and without CCS. The study shown 100g of wooden charcoal can reduce emission of CO₂ by 18.4% at full condition [4]. Blend of 80% diesel (B20) and 20% of methyl ester of cotton seed oil used in a diesel engine to study perform and emission characterisation of engine with and without CCS using activated carbon and wooden charcoal. It was observed 19% and 32% of reduction in CO₂ emission by using charcoal and activated charcoal respectively [5]. On certain investigation it was evident that X zeolite can be used for CO₂ capturing from post combustion flue gas. Also studies found that enhanced diffraction peak intensity can contribute in the performance of X zeolite in capturing CO₂ [6]. The impregnation of MEA at 0.5-25wt% on absorbent lead to the characterization of surface area, pore size and crystallinity. CO₂ absorption rate is high in MEA loaded absorbents than the absorbents without MEA. Further increase in absorption has been found out in moist environment [7]. Mesoporous carbon sphere (MCS) with impregnation of polyethyleneimine (PEI) is been studied for post-combustion CO₂ capture. The study also extends to the regeneration cycle effect for long period. MCS with PEI impregnated system in the presence of O₂, NO, NO₂ and SO₂ these chemical during regeneration cycle form irreversible chemical reaction. [8]. Absorption isotherm in an experiment of flue gas using activated carbon and zeolite 13X at 25°C and 1bar, revealed that, zeolite 13X is more sensitive towards temperature than activated carbon, hence absorption capacity is more for zeolite 13X at experimental condition. [9]. During the calculation of regeneration heat conducted during parametric analysis on system polyethyleneimine (PEI)/silica absorbent system is found to be 2.46GT/tCO₂ which is lower than advance MEA system (3.3GT/tCO₂) and aqueous MEA system (3.9GT/tCO₂). With more development solid absorbent based capturing system will out weight typical MEA system [10].

2. Experimentation

2.1. Materials

The materials that are used in this experiment are zeolite 4A, activated carbon and carboxymethyl cellulose. The combinations of zeolite and activated carbon have shown absorption of CO₂ in a very high rate. These can be combined with the help of binding agents like carboxymethyl cellulose and a very small ratio of Fe₂O₃ and MnO₂. The binding agent helps the chemical to provide a structural stability by chemically or mechanically using the cohesive force. Zeolite being an efficient way to capture CO₂ than the conventional method of separation by amine scrubbing, pre-combustion and chemical looping. These chemicals are coupled together in such a way that they held to each other. These moulds are encapsulated in steel cases providing extra strength to the mould as in figure 1.
2.1.1. **XRD Analysis of mould.** In the X-ray diffraction experiment conducted on the mould, the signal transmitted from the sample is recorded and graphed. In the graph, peaks are observed related to the atomic structure of the sample. From the diffraction pattern it has been observed that all the chemicals are incorporated in it [11, 12]. The result of the diffraction is represented in figure 2.

![Figure 1. Moulds arranged on a steel rod to be kept at the exhaust.](Image)

![Figure 2. XRD Analysis of mould.](Image)
2.2. Experimental setup
A single cylinder with 4 stroke IC engine fuelled by petrol has been used in the experiment. The details of the engine have been provided in table 1 and figure 3.

| Number of Strokes | 4 |
|--------------------|---|
| Number of Cylinder | 1 |
| Fuel               | Petrol |
| Rated Power        | 2.95HP (2.2kW) @3000rpm |
| Calorific Value of fuel | 45,800 kJ/kg |
| Cylinder Diameter  | 55mm |
| Stroke Length      | 50mm |
| Capacity           | 119cc |
| Method of Loading  | Electrical Loading |
| Manometer Liquid   | Water |

The absorption of CO$_2$ is done with the help of chemical moulding. The selected chemicals are taken in a certain amount and mixed with distilled water. They are mixed for at least 15 minutes to form a solid consistency. This mixture is transferred into a 5cm steel tube fig 5 to form a solid mould. They are supported with iron rods of 8mm to form holes in the middle for the passage of flue gas. They are allowed to dry in atmospheric temperature for 24hrs, without any additional heat supply. These moulds are later fixed into an 8mm threaded mild steel rod in which both sides of the mould are covered using an aluminium mesh. The fixed moulds are placed into the exhaust gas chamber and connect to the exhaust line. Using AVL Digas analyser amount of CO$_2$ is tabulated, also a comparison of both with moulds and without moulds is also noted.

2.3. Experimental observation
Using AVL Digas analyser at the exhaust line amount of CO$_2$ and other flue gases such as CO, HC, O$_2$ and NO$_x$ is tabulated, also a comparison of both with moulds and without moulds at the exhaust line is noted in table 2 and table 3 respectively.

| Sl. No. | BP (kW) | CO (%vol) | HC (ppm) | CO$_2$ (%vol) | O$_2$ (%vol) | NO$_x$ (ppm) |
|---------|---------|-----------|----------|--------------|-------------|--------------|
| 1       | 0       | 4.3       | 248      | 7.7          | 3.98        | 50           |
Table 3. Readings noted down with carbon capture system.

| Sl. No. | BP (kW) | CO (%vol) | HC (ppm) | CO₂ (%vol) | O₂ (%vol) | NOₓ (ppm) |
|---------|---------|-----------|----------|------------|-----------|-----------|
| 1       | 0       | 3.96      | 166      | 2          | 15.04     | 24        |
| 2       | 0.9     | 4.74      | 185      | 2.15       | 14.05     | 35        |
| 3       | 2       | 4.3       | 170      | 1.9        | 13.02     | 59        |
| 4       | 4       | 4.45      | 82       | 2.15       | 12.78     | 63        |
| 5       | 6       | 4.64      | 86       | 2.17       | 12.03     | 76        |

3. Methodology
Zeolite and activated charcoal are currently the best chemicals for the absorption of CO₂ in addition to that monoethanolamine has good absorption properties. A combination of all the three chemicals with the help of binders can able to form a carbon capture mould which is later placed into a carbon steel exhaust chamber (100mm diameter). This attachment is later fixed to the exhaust of petrol and diesel engine. A gas analyser is attached to monitor the emission rate. One probe is connected to the exhaust tube and another to the gas analyser. The basic flow chart for methodology is represented in figure 4.
4. Result and Discussion

4.1. Emission Characterisation

The testing of the experiment is carried out by varying current and voltage on a single cylinder four stroke petrol engine. Initially the readings were taken directly from the exhaust tube and later on the readings were taken with the prepared mould kept on a chamber. Each set of readings have the same variation of current and voltage and the comparison is done in both cases.

4.1.1. Oxides of Nitrogen emission variations. The chemical mould showed reduction in NO\textsubscript{X} when compared to the reading without the mould. From the figure 5, we can observe a reduction in NO\textsubscript{X} with a maximum of 50% and a minimum of 20%.

![Figure 5. Comparison of NO\textsubscript{X} emission (ppm) with Brake Power (kW).](image)

4.1.2. Hydro Carbons emission variations. In the comparison analysis it is also observed that a reduction of emission of HC is observed in the readings with the mould when compared to without the mould. The overall variation between both the readings from figure 6 is used to conclude that chemical mould showed reduction in emission of HC by maximum of 50%.

![Figure 6. Comparison of HC emission (ppm) with Brake Power (kW).](image)
4.1.3. **Carbon monoxide emission variations.** In the comparative analysis of readings with and without mould, from figure 7 we can observe that there is a significant reduction in CO. There is a maximum reduction of 12% and minimum reduction of 5% at the wide range of engine rpm.

![Graph showing CO emission variations](image)

**Figure 7.** Comparison of CO emission (ppm) with Brake Power (kW).

4.1.4. **CO\textsubscript{2} emission variations.** The experiment was mainly conducted to show the reduction in the amount of CO\textsubscript{2} emitted from the petrol engine. The comparison between with and without mould showed a remarkable reduction in CO\textsubscript{2} levels when the mould is placed, a maximum of 72% and a minimum reduction of 65% were observed from figure 8.

![Graph showing CO\textsubscript{2} emission variations](image)

**Figure 8.** Comparison of CO\textsubscript{2} emission (ppm) with Brake Power (kW).

4.2. **FTIR analysis**

The FTIR structure of zeolite 4A, the vibration bands at 1001 cm\(^{-1}\) and 471 cm\(^{-1}\) could be assigned to the stretching vibration of Si-O or Al-O units and the vibration of Si-O-Al units in the zeolite 4A structure, respectively. The peak values here it’s found to be 2356.09 cm\(^{-1}\), 548.12 cm\(^{-1}\). The vibration bands appeared at 668 cm\(^{-1}\) and 556 cm\(^{-1}\) could be assigned to the vibration modes of the zeolite framework. Figure 9 shows the spectrum region of mould.

![Graph showing FTIR analysis](image)

**Figure 9.** FTIR analysis of zeolite 4A.
Figure 9. FTIR spectra of mould.

5. Conclusion
This experimental research was intended to observe the effect of zeolite 5A, activated charcoal, Monoethanolamine combined with binders in exhaust as adsorbents of CO\(_2\) and monitor the performance of IC engine in combustion process.

- The combination of these materials has the ability of lowering CO\(_2\) gas levels to significantly lower level even at exhaust temperature.
- It has also dropped certain levels of other flue gases such as CO by 5%, NO\(_x\) by 20% and HC by 30%.

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6. References
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