Reduction of Carbon Dioxide Emission from Diesel Engine Fuelled with Plastic Pyrolytic Oil Using Modified Charcoals

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Abstract. Carbon dioxide is one of the greenhouse gases majorly contributing to the global warming and greenhouse effects. Combustion of fossil fuels such as coal, petroleum products and natural gas for power production, transportation and industrial applications produce maximum amount of carbon dioxide. Hence, reduction of CO2 emission is mandated to avoid additional add on to the atmosphere and control global warming. A new low cost carbon trapper using modified charcoals has been designed and tested in a stationary diesel engine for the reduction of carbon dioxide emission and results were reported in this article. Normal wooden charcoal was produced and impregnated with NaOH and KOH. These two modified charcoals, Normal wooden charcoal and commercially purchased activated charcoal were tested individually and compared with each other. Also the effect of amount of different charcoals at 100 grams, 200 grams and 300 grams on carbon dioxide reduction were also tested. The potassium hydroxide (KOH) impregnated wooden charcoal with 300 grams mass shows the best result of 63.92% CO2 reduction at 75% engine load and sodium hydroxide (NaOH) impregnated charcoal shows 62.89% reduction in CO2 at the same engine load due to increased adsorption along with absorption and high porosity.

Keywords: Activated charcoal, Impregnated charcoal, CO2 capturing, Engine emission reduction, Plastic oil.

1. Introduction
CO2 emission due to the fossil fuel combustion from the anthropogenic sources such as coal combustion in power generation, diesel combustion in transport and power sectors is major reason for radiative energy imbalance and global warming in the earth. This increase in level of CO2 leads to 2°C raise in average global temperature which causes glazier melting, acid rain, adverse climatic changes in the earth surface and pollution of water resources. It is mandatory to reduce the CO2 level on the earth surface for safeguarding the human beings and other living things in the earth from many vulnerable defects. The developed countries in the globe have formed many regulatory bodies and
stringent emission norms for automotive and power industries to control CO\textsubscript{2} emission and other harmful pollutants. Hence it has become mandatory to develop new technological solutions for greenhouse emission capture. There are three major CO\textsubscript{2} capturing methods widely recommended for fossil fuel combustion systems namely pre-combustion, oxy-combustion and post-combustion out of which post-combustion is identified as well matured, economic, flexible and effective method. Among the several technologies used, CO\textsubscript{2} adsorption technique at ambient and high pressure using activated carbon employed in post-combustion method is most efficient and cost effective with low energy requirement. However the efficiency of this technique is mainly depends on the quality of the adsorbent used. The desired properties of the adsorbent for effective CO\textsubscript{2} adsorption are (i) capacity of adsorption at different temperatures (ii) kinetics of adsorption / desorption (iii) stability of adsorption capacity after repeated cycles and (iv) sufficient mechanical strength to withstand high pressure stream. Activated carbon or activated charcoal derived from biomass solid waste such as wood, coconut shell, date seed and walnut shell etc. have been found to be best suitable adsorbents for CO\textsubscript{2} capture from engine exhaust gas. To improve the adsorption capacity of the activated carbon its surface needs to be modified by chemical treatments with mineral, chemicals and other materials. Because the CO\textsubscript{2} adsorbing capacity of the activated charcoal is mainly based on the porosity of the structure and surface density properties. The adsorbing capacity of the activated carbon can be improved by the impregnation of base solutions on the surface, because of the acidic nature of the CO\textsubscript{2}. Yong et al. reported that calcium oxide and magnesium oxide impregnation on carbon based adsorbents have been recorded with increased adsorption capacity of 0.22 and 0.28 mmol/g respectively. They also reported that adsorption capacity has been enhanced due to the strong interaction between CO\textsubscript{2} and impregnated adsorbent [19]. Somy et al. studied the effect of Cr\textsubscript{2}O and ZnCO\textsubscript{3} impregnated activated carbon on CO\textsubscript{2} adsorption and reported that the adsorption capacity has been increased by 25% due to the impregnation [24]. The higher adsorption capacity has been reported for cation impregnated activated carbons in comparison with normal raw activated carbons due to the combined action of physical and chemical adsorption due to metal ion groups [25]. The effect of NaOH, KOH and Na\textsubscript{2}CO\textsubscript{3} impregnated zeolite on the CO\textsubscript{2} adsorption was studied and reported by Lillo-Rodenas et al. They reported that Na\textsubscript{2}CO\textsubscript{3} impregnated zeolite showed the better performance. In the present study two base components namely KOH and NaOH are impregnated on the surface of commercially available activated charcoal and tested for the CO\textsubscript{2} reduction from the exhaust emission of diesel engine fuelled with plastic pyrolysis oil and results were compared with the normal wooden charcoal and commercially available activated charcoal.

2. Materials and Methodology

2.1. Preparation of plastic oil through pyrolysis

The waste plasctics of different kinds collected from various sources were heated to 300 - 400\degree C in absence of oxygen for about 90 minutes in a fixed bed reactor made up of steel of 25 cm diameter, 30 cm long and 0.5 cm wall thickness with electrical heater of 10\degree C/min rate of rise. Most of the toxic gases are burnt at that high temperature and hot plastic oil will be condensed and collected. Fractional distillation process was used to get the different categories of fuel from the waste plastic oil in further stage. The fatty acid components of plastic pyrolysis oil is presented in the table 1. The physiochemical properties of waste plastic pyrolysis oil are estimated and compared with diesel and given in table 2. The photographic views of crude and distilled plastic pyrolysis oil are shown in figure 1.

2.2. Preparation of modified charcoal

The normal wooden charcoal and commercial activated charcoal used in this study were purchased from the local market in Chennai India. The activated carbon was made in to small particles
approximately into 2 mm size and filtered from the dust particles, further it was washed using deionized water and dried in the furnace at 100 °C for about 2 hours. 100 grams of the laboratory grade KOH and NaOH were weighted exactly and thoroughly dissolved in 1000 ml of deionized water. 100 grams of charcoal (1:1 weight ratio) was mixed with alkaline solution. The mixing was performed in a water bath shaker for 60 minutes at room temperature. Then the solution was filtered and impregnated charcoal was dried in the oven at 100 °C for 48 hours [17]. The process flow of impregnation is given in figure 2.

### Table 1. Components found in plastic pyrolysis oil.

| Sl.No. | Name                  | Formula  | RT (min) | MW  |
|-------|-----------------------|----------|----------|-----|
| 1     | p-Xylene              | C₈H₁₀    | 3.138    | 91.1|
| 2     | Styrene               | C₆H₈     | 3.242    | 104.1|
| 3     | Benzene, propyl-      | C₆H₁₂    | 3.555    | 91.1|
| 4     | Benzene, 1-ethyl-2-methyl- | C₆H₁₂  | 3.591    | 105.1|
| 5     | Benzene, 1,2,4-trimethyl- | C₆H₁₂  | 3.64     | 105.1|
| 6     | Indene                | C₆H₈     | 4.211    | 116.1|
| 7     | p-Cresol              | C₇H₈O    | 4.289    | 107.1|
| 8     | Acetophenone          | C₆H₈O    | 4.337    | 105.1|
| 9     | 2-Methylindene        | C₁₀H₁₀   | 5.178    | 130.1|
| 10    | Naphthalene, 1,2-dihydro- | C₁₀H₁₀ | 5.378    | 130.1|

### Table 2. Comparisons of important properties of test fuels.

| Sl.No. | Properties                | Standard Method | Diesel          | Plastic Pyrolysis Oil |
|--------|---------------------------|-----------------|-----------------|-----------------------|
| 1      | Density (g/cm³)           | ASTM D941       | 0.8359          | 0.793                 |
| 2      | Calorific Value (kJ/kg)   | ASTM D240       | 44500           | 42000                 |
| 3      | Kinematic Viscosity (Cst) | ASTM D613       | 2.12            | 2.52                  |
| 4      | Flash Point (°C)          | ASTM D445       | 65              | 62                    |
| 5      | Fire Point (°C)           | ASTM D92        | 75              | 70                    |
| 6      | Cetane Number             | ASTM D93        | 53              | 48                    |
| 7      | Aromatic Content          | ASTM D5186      | 20              | 55                    |
| 8      | Oxygen Content (wt. %)    | ASTM D4530      | 0.03            | 4.31                  |
| 9      | Carbon Residue            | ASTM D4530      | 0.20%           | 0.01%                 |
| 10     | Sulphur Content           | ASTM D4294      | <0.05           | -0.02                 |
| 11     | Colour                    | ASTM D1500      | Orange          | Pale Black            |
2.3. Design of CO2 capture unit
The CO2 capture unit was designed as two parts namely inner core and outer shell and assembled. The inner core unit was designed for filling the carbon particles in three different mass of 100 grams, 200 grams and 300 grams. Three compartments of steel cylindrical vessels surrounded by wire mesh on top and bottom faces and one small hole with lid on each vessel to fill the charcoal granules were welded 200 mm apart each to make inner core. The outer shell was made by steel pipe of 4 inch diameter as shown in figure 3. The 3D CAD model of CO2 capture unit is shown in figure 4. The photographic views of the unit is shown in figure 5. Each compartment in the inner unit is capable of filling 100 grams of charcoal. For 200 grams test two compartments will be filled and for 300 grams test 3 compartments will be filled and used. The space between two compartments is designed in such a way that the back pressure will not shoot up and affect the engine performance.
2.4. Design of CO$_2$ capture unit

The experimental engine setup consists of a 5.2 kW single cylinder, rated speed, direct injection, naturally aspirated, water cooled Kirloskar make engine equipped with eddy current dynamometer and load cell. The engine is also coupled with a data acquisition system, pressure, temperature and crank angle position sensor for accurate measurements. Well calibrated AVL 444 digas analyzer and AVL smoke meter are attached in the engine tailpipe for the measurement of CO, CO$_2$, NO, HC and smoke opacity emissions. The schematic diagram of the experimental setup, photographic views of the experimental setup and exhaust gas analyzer are shown in figure 6, figure 7 and figure 8 respectively.
The detailed specification of test engine is given in table 3 and accuracy and percentage of uncertainties of different instrument are given in table 4. The total percentage of uncertainty for the instruments is ±1.4%.

The engine is started after the confirmation of level of lubricating oil and flow of cooling water circulation. Once the engine attained stability the required engine performance related readings are noted at different loads from 0% to 100% of full load with 25% increment. The repeatability of the engine results are ensured by conducting each trial thrice and average value is considered for further analysis. The effect of each charcoal at different mass proportions on CO₂ reduction are analyzed and compared.

Table 3. Engine specification

| Description                | Values                       |
|----------------------------|------------------------------|
| Make & Model               | Kirloskar & TV1              |
| Rated Power                | 5.2 kW @ 1500 rpm            |
| Number of Cylinders        | One                          |
| Combustion chamber         | Hemispherical                |
| Piston bowl                | Shallow bowl                 |
| Compression ratio          | 17.5:1                       |
| Rated Speed                | 1500 rpm                     |
| Bore Diameter              | 87.5 mm                      |
| Stroke Length              | 110 mm                       |
| Injection Pressure         | 220 bar                      |
| Injection Timing           | 20 deg CA BTDC               |
| Fuel Injection type        | Direct                       |
| Number of holes in nozzle  | 3                            |
| Spray hole diameter        | 0.25 mm                      |
| Spray cone angle           | 110                          |
| Cubic Capacity             | 661.45 cc                    |
| Loading type               | Electrical Load              |
| Cooling type               | Water cooling                |

Figure 6. Schematic representation of the experimental setup.
3. Results and Discussions

3.1. Effect of different charcoals on CO₂ reduction

The variation of CO₂ emission at different loads for plastic oil fuelled diesel engine with and without CO₂ capturing unit are compared with that of diesel. The experimental results for three different mass proportions (100 grams, 200 grams and 300 grams) of charcoals filled in the CO₂ capturing unit are plotted and shown in figure 9, figure 10 and figure 11 respectively. It is clearly noted from the figures that KOH impregnated charcoal recorded lower CO₂ emission than that of other charcoals at all three mass proportions. This is due to that the KOH impregnation on charcoal surface would have enhanced the adsorption process along with the regular absorption of CO₂ by charcoals. The NaOH impregnated charcoal recorded second best results at all loads and all mass proportions. The major reason is the base chemical impregnation on the surfaces of charcoals may favours the sorption performance due to

![Figure 7. Photographic view of the experimental setup.](image)

![Figure 8. Photographic view of the exhaust gas analyzer.](image)

| Equipment                  | Parameter Measured | Range of Measurement | Accuracy | % uncertainties |
|----------------------------|--------------------|----------------------|----------|-----------------|
| AVL Digas 444 analyzer     | NOx                | 0 - 5000 ppm         | ±10 ppm  | ±0.53           |
|                            | HC                 | 0 - 20,000 ppm       | ±10 ppm  | ±0.11           |
|                            | CO                 | 0 - 10% vol          | ±0.03%   | ±0.32           |
|                            | CO₂                | 0 - 100% vol         | ±0.5%    | ±1.0            |
| AVL 437C smoke meter       | Smoke opacity      | 0 - 10 BSU           | ±1%      | ±1.1            |
| Speed sensor               | Engine speed       | 0 - 10,000 rpm       | ±10 rpm  | ±0.1            |
| Stop watch                 | Time               | -                    | ±0.6 s   | ±0.2            |
| Burette                    | Fuel quantity      | 0 - 50 cc            | ±0.1 cc  | ±1.0            |
| Thermocouple               | Temperature        | 0 - 1000°C           | ±1°C     | ±0.1            |
| Crank angle encoder        | Crank angle        | ±0.5 CA              | ±0.2 CA  | ±0.2            |
the acid nature of CO\textsubscript{2} emission. The experiments beyond 300 grams of charcoals are not recorded here due to the increase in stagnation pressure in the capturing unit leads to increase in the back pressure in the tail pipe of the engine which will affect the performance of the engine.

![Figure 9](image9.png)

**Figure 9.** Variation of CO\textsubscript{2} at different loads for 100 grams of different charcoals packed in CO\textsubscript{2} capturing unit.

![Figure 10](image10.png)

**Figure 10.** Variation of CO\textsubscript{2} at different loads for 200 grams of different charcoals packed in CO\textsubscript{2} capturing unit.
4. Conclusion
An attempt was made to design and develop a cost effective CO2 capturing system for the reduction of diesel engine CO2 emission with KOH and NaOH impregnated activated charcoal. Experiments were conducted in the single cylinder diesel engine fuelled with plastic pyrolysis oil at different loading conditions to assess the effectiveness of the CO2 trapping system and the following conclusions were made.

- The KOH impregnated charcoal showed highest adsorption capacity followed by NaOH impregnated charcoal at all loading conditions.
- The maximum percentage reduction of CO2 is 63.92% recorded for 300 grams of KOH impregnated charcoal at 75% engine load followed by 300 grams of NaOH impregnated charcoal at the same load with 62.89%.
- 300 grams mass of charcoal showed better results that other mass proportions at all loading conditions irrespective of type of charcoal.

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