Experimental investigation on CO₂ reduction in exhaust gases of CI engine fuelled with neem oil blend

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Abstract. Global warming and climate change problems resulting from the greenhouse gas emissions, particularly CO₂, have paved the way for the need of research in minimizing the accumulation of carbon dioxide (CO₂) in the atmosphere. Though various CO₂ capture technologies have been proposed for post combustion processes, Carbon dioxide capture and storage (CCS) by the absorbent is a simple and better method for CO₂ emission reduction. The neem oil blend was analyzed in a single cylinder, 4-stroke, computerized water-cooled, diesel engine of 3.5 kW rated power for performance and emission characteristics without and with CCS with different quantity. The quantity of wooden charcoal is varied (50g, 100g and 150g) and the analysis is done. Results show that the CCS with wooden charcoal of 100g reduces the CO₂ emission by 18.4% at full load condition. However, the brake thermal efficiency is decreased slightly by 2.4% for CCS due to the back pressure.

Keywords: Mitigation, Neem, Wooden Charcoal, CO₂ emission, Carbon Capture System.

1. Introduction

CO₂ is measured and identified as one of the main providers to the greenhouse effect, causing a major impact on climate change, increasing rainfall, developing storm patterns and increased height of tide and level of sea. The contribution of CO₂ towards global warming is over 60% which is very much significant as compared to other green house gases [1]. Prominent industrial sources of CO₂ emission include power plants, oil refineries, automobile industries, biogas sweetening and production of ethylene oxide, ammonia, steel, iron and cement. There are numerous recent evidences of global warming. The Arctic Sea ice has thinned by 40% in the recent decades [2]. The ice sheets on the planet are shrinking, even the mountainous snow is melting. Overall, the world's glaciers are retreating which induce sea levels to rise. There has been an escalation in the number of severe weather events such as wild fires, heat waves and tropical storms. The Oceans and trees are thought to absorb and are continually absorbing the additional CO₂, which is being released into the atmosphere. The absorption of this extra CO₂ by the Oceans has lowered their pH marine ecosystems and is continuously being
damaged by Ocean acidification, evidenced by the shrinking of marine life. The reduction of CO2 is also significantly affected by deforestation.

The annual emission of CO2 through burning of fossil fuels across the globe has been on the rise by 2.7% in the past few decades and at present it is above 60% of 1990 level which is the Kyoto Protocol reference year [3]. It is alarming to note that the estimated global CO2 emission should be at least brought down by 50% in order to control the rise in average temperature of globe to 2.8°C by 2050. Scientists and researchers across the globe take different measures to mitigate climate change, carbon capture and storage (CCS) is one among the prominent options. However, use of CCS involves barriers both technical and economical in nature which the system should overcome before large scale deployment. In the recent past another alternative option carbon capture and utilization (CCU) has become prominent worldwide owing to the fact that in addition to mitigation of global climate change CO2 emissions could be effectively converted into useful products like fuels and chemicals which would otherwise go as wastes. CCU in comparison with CCS is considered as a profitable activity, as it can fetch profit through sale of products. However, varieties of compatible CO2 capture mechanisms are available to meet the specific industrial requirements. Separation of CO2 from the outgoing exhaust is the post conversion technique which is applicable to industries like power plants, ethylene oxide production, cement, iron and steel manufacturing and biogas sweetening as well. Post-conversion capture includes absorption in solvents, adsorption by solid sorbents, membranes and cryogenic separation as well as pressure and vacuum swing adsorption. Absorption by mono-ethanolamine (MEA) is the most widely used one for CO2 capture.

It is evident by now that CO2 is continually being emitted into the atmosphere and is becoming a cause of concern worldwide. Carbon dioxide has a long lifetime and according to the literature based models, 20-36% of the CO2 remain in the atmosphere following equilibration with the ocean, which takes 2-20 centuries. This is then followed by further neutralization by formation of CaCO3, which again occurs on long timescales of 3000 to 7000 years. Considering all the above aspects of CO2, it is evident that CO2 emission deteriorates the climate not only in the present generation but future generations.

Biodiesel has proved to be a reliable substitute to fossil diesel throughout the world in the recent past. The global supply and demand of biodiesel has been fast rising and this trend will continue to do so in the years to come [4, 5]. The emission of CO2 through biodiesel combustion is considered compensated through absorption of CO2 during the growth of the plants and hence there is no net addition to green house effect and global warming. Absorption of CO2 from the exhaust gases results in further reduction of CO2 level which contributes to environmental protection. The present study investigates the use of neem oil blend as the test fuel along with use of activated carbon (wooden charcoal impregnated in KOH solution) in the exhaust gas as absorbent to absorb and mitigate CO2 emission. The effect of after treatment process on emission and the performance of a direct injection compression ignition engine fuelled with neem oil blend (10% neem oil + 90% diesel) are highlighted in this paper.

2 Experimental setup

2.1. Engine
A single cylinder, naturally aspirated, water-cooled 3.5 kW direct injection CI engine coupled with an eddy current dynamometer was subjected to experimental investigations. To measure the exhaust emissions a gas analyzer of make AVL DiGas 444 was used. The mass flow rate of engine cooling
water and its inlet temperature were kept at 0.083 kg/s and 29°C respectively. Prior to the conduct of experimental trials, the engine was properly checked and the measuring instruments were subjected to calibration. The standard test procedure was adopted for all the fuels tested. The engine emission was studied at different loads for diesel, neem oil blend and with activated carbon, by operating the engine at an average speed of 1500 rpm.

2.2. CO$_2$ absorption
Commercial activated carbon (wooden charcoal) is chosen as the potential materials for Carbon dioxide adsorption. Porous material is used as adsorbents in laboratory conditions. Charcoal being a porous material has a higher surface area and melting point which are essential requirements of the proposed system. Charcoal is cheaper and the system for carbon dioxide reduction in diesel engines is cost effective. Charcoal also adsorbs harmful gases.

Wooden charcoal is impregnated with KOH in laboratories. The samples can be purchased at a cheaper cost. Wooden charcoal is easily available in the market. The size of wooden charcoal should be less to increase the activated zones for adsorption. The adsorption is limited till the system reaches its saturation point beyond which the adsorbent should be replaced or regenerated. The charcoal is packed along with the wire mesh in the pipe to prevent the escape of charcoal out of the adsorption chamber and is shown in Figure 1. When the exhaust gases pass through the chamber, CO$_2$ molecules get attached to the wooden charcoal molecules. Wooden charcoal impregnated with KOH were tested.

![Figure 1. Photographic view of CO$_2$ absorption chamber.](image-url)
3 Test Fuels

Natural neem oil is with color dark brown with a strong odor and bitter taste. Neem is an Indian species found in Burma and other Asian countries and the entire tree is useful for medicine, organic manure and pesticide. It can conveniently grow on rocky, dry and shallow soils. Neem trees are capable of tolerating extreme weather of temperature of 45°C, annual rainfall of less than 35 cm [6]. Matured tree of 10 years old can provide an average yield of 5.25 tonnes per hectare [7]. The average percentage of oil yield and efficiency of oil extraction are 28% and 94% respectively. Based on the energy ratio of 1.64, biodiesel from neem proved to be one of the few promising renewable sources of fuel from environmental protection point of view. The main constituent of neem oil is Azadirachtin with varying proportion of 300 to 2500 ppm based on the extraction method and crushed oil seed quality. The oil has pungent odor due to the presence of sulfur and is considered less clean burn as compared to other vegetable oils. The properties of the test fuel used were given in Table 1.

| Properties                  | Diesel   | Neem Oil | Neem Oil Blend |
|-----------------------------|----------|----------|----------------|
| Density (g/cm³)             | 0.8358   | 0.943    | 0.8465         |
| Calorific Value (kJ/kg)     | 44600    | 39842    | 44124          |
| Kinematic Viscosity (Cst)   | 2-3      | 38.3     | 5.96           |
| Flash Point (°C)            | 75       | 201      | 88             |
| Cetane Index                | 51       | 55       | 51             |

4. Results and Discussion

The influence of wooden charcoal and activated carbon in carbon capturing system for CO₂ emission reduction in a CI engine fuelled with neem oil blend has been experimentally investigated in the present study. Experimental readings pertaining to engine performance and exhaust emission were taken in three different trials and recorded. The analysis is carried out with the average of the trial values.

4.1. Emission characteristics

4.1.1. CO₂ emission variations

Figure 2, depicts the changes in carbon dioxide emission with respect to brake power. The results show that CO₂ emission increases with increase in engine load [8]. The emission of CO₂ for neat neem oil blend increases by 2.38% compared to diesel. The higher inherent oxygen content in the biodiesel could be the reason to promote oxidation. CO₂ emission decreases by 36% with the activated carbon compared to neem oil blend.
Very low flame temperature and very rich fuel air ratio are the prime reasons for CO emissions in the exhaust from the engine. Increased emission of CO emissions is an indication of loss of power in the engine [9]. The variation in emission of CO with brake power is shown in Figure 3. Increased density and higher viscosity of neem oil blend are responsible for poor mixture formation which resulted in high partial burning during the process of combustion process. This leads to increased emissions of CO for neem oil blend in comparison with diesel at all load conditions. CO emission is reduced by 27.75% for CCS with activated carbon in comparison with neem oil blend at full load.
Figure 3. Variation of CO emission with Brake Power.
4.1.3 \textit{HC emission variations}

![Figure 4: Variation of Hydrocarbon emission with Brake Power.](image)

\textbf{Figure 4} Variation of Hydrocarbon emission with Brake Power.
Partially burned or unburned hydrocarbons come out of the exhaust pipe in the form of vapour, fuel drops or products of fuel after thermal degradation [10]. The emission of unburned HC is responsible for the formation of smog, photochemically reactive species and also carcinogens. Figure 4 reveals the changes in unburned HC emission with brake power. Higher viscosity of the neem oil blend and poor quality of mixture formation are responsible for the increased HC emissions. HC emission is reduced by 28.34% for CCS with the activated carbon.

4.1.4. Comparison of Oxygen percentage in exhaust emissions

![Figure 5](image)

**Figure 5** Variation of Oxygen with Brake Power

Figure 5, presents the variation of oxygen percentage with engine brake power. Decrease in oxygen percentage is noted with increase in load for neem oil blend. This could be due to the induction of increased amount of fuel at increased load. Oxygen percentage increased by 4.94% for CCS with activated carbon compared to neem oil blend at full load condition. This increase in oxygen percentage may be due to the decrease of CO$_2$ and other gases like CO and HC.

4.2 Engine Performance Analysis

4.2.1 Comparison of brake thermal efficiency

The changes in brake thermal efficiency (BTE) with respect to brake power at different loads are provided in Figure 6. As the viscosity is higher and the mixture forming tendency is poor for vegetable oils and their blends, the value of brake thermal efficiency is lower for neem oil blend compared to diesel at all load conditions [11,12]. Small reduction in brake thermal efficiency is noted for the engine incorporated with CCS using activated carbon. Brake thermal efficiency is decreased by 2.65% with activated carbon as compared to neem oil blend at full load. CCS system obstructs the free flow of
exhaust gases which leads to back pressure generation in the exhaust pipe leading to small reduction in BTE.

![Graph showing variation of Brake Thermal efficiency with Brake Power](image)

**Figure 6** Variation of Brake Thermal efficiency with Brake Power

5. Conclusions

The performance and emission characteristics of neem oil blend fuelled unmodified CI engine with a CCS system using activated carbon were studied and analyzed. Based on the results derived from the experimental investigation, certain conclusions are drawn as summarized below.

- Wooden charcoal can be used as a surface adsorbent to adsorb CO$_2$, even at higher temperatures and pressures.
- CO$_2$ emission was reduced significantly by 36% for CCS with activated carbon in comparison with neem oil blend at full load.
- Emissions of CO and HC were also reduced by 28.34% and 27.75 % respectively for CCS with activated carbon.
- However, a small drop in value is noted for brake thermal efficiency to the tune of 2.65% for CCS with activated carbon.

Based on the present experimental investigation, it is observed that wooden charcoal and activated carbon absorb significant amount of CO$_2$ emission along with slight reduction in emissions of CO and unburned HC. This simple and reliable method of mitigation of CO$_2$ emission could be employed in large scale in industries for environmental protection.
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