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Innovative Implementation of Post-combustion Carbon Dioxide Elimination Technology

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ABSTRACT: The increasing amount of anthropogenic carbon dioxide (CO₂) emissions in the atmosphere in recent years became the major concern among not only scientists and environmentalists but also among the commonwealth. This study puts forth an innovative technique for post combustion CO₂removal from atmosphere necessarily at the source itself. The technique proposes integration of an array of filters in the air-conditioning unit of public & private transportation vehicles for removal of CO₂& particulate matter (being main cause of health concerns)from surrounding air while in use. Also estimated is the potential of this filtration unit for carbon dioxide removal.

I. INTRODUCTION

Earth has had a history of climate change that stretches back more than 800,000 years without much contribution from humanity. While more recently, it took planet earth 5000 years to warm up just 5⁰C as stated by the NASA Earth observatory's paleoclimate report and the predictions are that the rate is going to be at least 20 times faster over next 100 years. Computer models have estimated that the earth will witness an average global temperature rise of about 2⁰C which is undisputedly a result of anthropogenic greenhouse gases emissions like CO₂(carbon dioxide), N₂O (nitrous oxide), MH₄ (methane), O₃ (ozone) & water vapours. CO₂has the highest percentage among greenhouse emissions being 76% [1][5].

The sources of CO₂emissions are mainly industries, electricity & heat production, buildings, transportation vehicles running on fossil fuels and other energy generation processes where the transportation alone contributes to about 14% of worldwide CO₂emissions. A typical passenger vehicle emits about 4.6 metric tons of carbon dioxide per year with an average of about 2.35 kilograms per litre of gasoline. The number is even higher in case of diesel-powered vehicles. The world bank recorded annual CO₂emissions by the petroleum-based fuel consumption to be 12 billion tons in 2014 where the main contributors are countries like US, China, India, Japan, etc. with ever-increasing emission curve since [3].

In recent years, an equally concerning factor has arisen having adverse health effects on humans that is air pollution by particulate matter (PM). Besides CO₂, the atmosphere can also be polluted by particulate matter catalogued as 'floating dust' which includes dust, dirt, soot, smoke, etc. Particulate matter of size about 10 microns (PM₁₀) are comparatively heavier and get settled by gravity within minutes or hours. But, particulate matter of size less than 2.5 microns (PM_{2.5}, PM₁, PM_{0.1}) being comparatively lighter can remain suspended in the air for days or even weeks. Inhaling such air can have negative impacts on humans. Carbon dioxide and particulate matter combinedly have highly hazardous effects on human health & also eventually on other animals as a result of global warming [4].

While driving, we are exposed to high carbon dioxidesaturated air as the post-combustion CO₂concentration is highest on roads due to vehicle emissions. Studies have confirmed that CO₂concentration in vehicle cabins on-road typically exceed 1000 ppm which can make the driver feel sleepy & fatigued. During a study in Hong Kong, Chan found that CO₂concentration aboard a bus reached 1900 ppm when traveling on highway & 2500 ppm in the city while the safe amount of CO₂concentration is 350 ppm beyond which it becomes unsafe for humans to even breathe in [6].

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Breathing in air with such a high concentration of CO₂ for a prolonged period can cause serious health problems like migraines, dizziness, difficulty in breathing, restlessness, increased heart rate, elevated blood pressure, asphyxia & convulsions [8].

On the other hand, air quality survey conducted by Greenpeace in Delhi found that PM_{2.5} levels were 10 times higher than the safety limit prescribed by the World Health Organization. The case is even worse on city streets [7].

Breathing in air with a high concentration of PM_{2.5} can affect both your lungs & your heart. Studies have shown that excessive exposure to particulate matter can result in a variety of health problems including increased respiratory & cardiovascular symptoms like irritation of airways, coughing & difficulty in breathing, irregular heartbeat, aggravated asthma, decreased lung function, nonfatal heart attacks & even premature death in people with heart & lung diseases [2].

Particulate matter is having detrimental effects on human health while on the other hand major greenhouse gas emissions like CO₂ having irrecoverable ramifications on the earth's physique besides air pollution like melting ice caps, rising sea level, warming of the ocean surface, etc. Increased sea level will leave the coastal areas of all continents uninhabitable with seawater flooding the coastal cities while warmer water temperature will alter the water quality and accelerate water pollution. By the end of the century, the global temperature rise is estimated to be 4⁰C which will completely melt all ice caps and glaciers rendering both poles uninhabitable for the polar animal species which will ultimately result in their extinction. Increased global temperature will also increase the number of heat deaths over droughty summers.

As a result, keeping the earth healthy & making the atmosphere we live in breathable has become of crucial importance with ever-increasing pollution rate. Addressing the pollution sources & mitigating its effects have become the need of the hour. Thus, the objective of this study is to propose an innovative filtration technique for removal of anthropogenic CO₂ and particulate matter from air necessarily at the source itself. Secondly, the potential of the proposed filtration unit is also investigated and estimated in the study.

II. PROPOSED METHODOLOGY

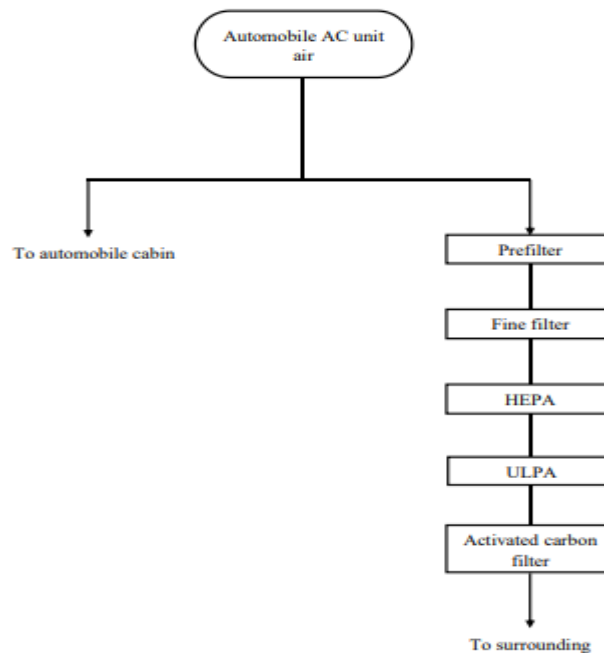


Fig: Proposed Filtration System

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Even when we are currently using filters for screening post-combustion compounds, a single automobile is contributing to about 9 kilograms of carbon dioxide per gallon. As a result, the carbon dioxide concentration is highest on roads post-combustion. And as we have already established, it is necessary to cut-off these high concentrations on the road itself. Automobiles being the largest element of on-road transportation, they are used as a host for the proposed filtration system.

The unit is mounted in parallel with the automobile cabin air-conditioning system using the same intake fan. Part of the intake air is taken in the filtration process as the cabin air conditioning (AC) system is usually fed more air than it actually needs. Also, intake fan velocity can be regulated as per required intake and efficiency of air-conditioning or filtration.

The filtration unit includes an array of gradually refining filters in series. Incoming particles are refined to the size of particulate matter PM_{10} with the help of prefilter & then stepwise filtration of particulate matter PM_{10} , $PM_{2.5}$, PM_1 & $PM_{0.1}$ is carried out by the array of high-efficiency filters. Lastly, an activated carbon filter is used for carbon dioxide elimination as activated carbon has high carbon dioxide adsorption efficiency.

1. Filter Selection

1.1. Prefilter

As the flow diagram shows the air is taken into the filtration unit just before entering the automobile cabin, the air will be already filtered by the AC unit. A normal automobile AC unit uses a filter size of about 10 microns to 100 microns depending on the automobile manufacturer. Hence, the study uses a prefilter to keep out any PM_{10} entering further into the system.

Prefilter selected: Grade – F5
 Size – 5 microns
 Efficiency – 95%
 Airflow capacity – 944 litres per second
 Initial pressure-drop – 6 mm of water column
 Final pressure-drop – 18 mm of water column

1.2. Fine Filter

The air after passing through the prefilter has particles of sizes less than 5 microns i.e. mainly $PM_{2.5}$ which is one of the particle sizes able to remain suspended in the air for weeks and causing detrimental effects on the human cardiovascular system. These are the most important ones to be filtered. A filter of size 1 micron is selected for $PM_{2.5}$ capture. These filters can block particulate matter with an efficiency of more than 90%.

Fine filter selected: Grade – F9
 Size – 1 micron
 Efficiency – 95%
 Air flow capacity – 944 litres per second
 Initial pressure-drop – 15 mm of water column
 Final pressure-drop – 45 mm of water column

1.3. HEPA filter

The air still contains dust particles of size 1 micron (PM_1) which one more factor affecting human health over the long term. Trapping of these particles needs incorporating a higher efficiency filter than the formers. Special purpose industrial filters are manufactured to acquire efficiencies as high as 99.99%. These are called High-Efficiency Particulate Air (HEPA) filters. A HEPA filter of size 0.3 micron is selected to obtain the required efficiency. HEPA filter also helps clear out pollen, dust mites, and even some bacteria. It yields a microscopic-level cleaning.

HEPA filter selected: Grade – H9
 Size – 0.3 micron
 Efficiency – 99.97%
 Airflow capacity – 944 litres per second
 Initial pressure-drop – 25 mm of water column
 Final pressure-drop – 75 mm of water column

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1.4. ULPA filter

Even finer floating dust sizing about ten-millionth of a meter can still manage to pass even through such high-efficiency filters. Ergo, Ultra Low Particulate Air (ULPA) filter is incorporated to terminate such particles. A ULPA filter traps any particles of size 0.12 micron and above. As the name advertises, such filters provide air with ultra-low particulate air content. ULPA filter also keeps smog, oil smoke and carbon black from entering the activated carbon filter which needs zero dust for most efficient working.

ULPA filter selected: Grade – U15
 Size – 0.12 micron
 Efficiency – 99.9995%
 Air flow capacity – 944 litres per second
 Initial pressure-drop – 25 mm of water column
 Final pressure-drop – 75 mm of water column

1.5. Activated Carbon filter

Carbon dioxide has to be effectively eradicated for mitigating its malevolent effects on humans and on the earth. An activated carbon filter is selected for carbon dioxide adsorption. Due to its extremely high porosity, a single gram of activated carbon has surface area more than 3000 m². It has the ability to remove volatile organic compounds (VOCs) from the air and even from water. But the purpose of interest here is its potential to adsorb carbon monoxide (CO), nitrogen oxides (NO_x) and most importantly carbon dioxide (CO₂).

An effective activated carbon filter can yield up to 98% removal of the input carbon dioxide bringing its concentration from 2000 ppm down to 50 ppm. Its efficiency is maximum when incoming dust is necessarily zero being the reason it is installed at the very last in the array sequence.

Activated Carbon filter: Size – 1 micron
 Efficiency – 98%
 Air flow capacity – 944 litres per second
 Initial pressure-drop – 15 mm of water column
 Final pressure-drop – 45 mm of water column

III. RESULTS & DISCUSSION

The potential of the proposed unit is evaluated with the help of intake air velocity, volume discharge, average car speed and cross-section of the filters used and accounting for pressure drop across the filters.

Taking the average speed of the vehicle as 60 km/hr, an average air intake in the automobile cabin through the air-conditioning unit is 180 m³/hr i.e. 0.05 m³/s. The filtration unit takes half of this incoming air through the array for filtration. Consequently, the discharge of air passing through the unit is 0.025 m³/s. Cross-section area of the test filter is taken as (10cm x 10cm) i.e. 0.01m² [10].

By Bernoulli's principle, pressure drop across each filter and final velocity is calculated and tabulated below: -

Filters	Avg. Pressure Drop (mm of water column)	Pressuredrop (N/mm ²)	Velocity drop (m/s)	Output velocity (m/s)
Prefilter	12	0.1177	0.0387	2.4613
Fine filter	30	0.2942	0.0996	2.3617
HEPA filter	30	0.4903	0.1761	2.1856
ULPA filter	50	0.4903	0.1956	1.99
Activated Carbon filter	30	0.2942	0.12	1.87

The system is emitting air to the surrounding at a rate 1.87 m/s which gives a volume discharge of 18.7 litres/s for 0.01m² cross section.

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According to Ford's driving habits survey conducted in 2014, an average car runs about 12000 kilometres per year and average car speed is 60 km/hr which means about 200 hours of ride time per year [9].

Taking this into account, about 13.46 Megalitres of air can be filtered out by this unit per annum. The air around road proximities have carbon dioxide concentration of about 2.5 ml/l. This gives CO₂removal potential of the unit about 33660 litres or 60 kilograms by a single automobile annually. Taking about 1 billion active cars in the world into account, the estimated amount of CO₂removal capacity of the filtration system is about 3.6 million metric tons per year.

On the other hand, HEPA and ULPA being highly efficient filters can block almost every particulate matter particle passing through it.

IV. CONCLUSION

The study shows that implementation of the proposed filtration methodology can yield unprecedented results in favour of humans and betterment of earth's atmosphere and global temperature. The system can capture about 3.6 million metric tons of carbon dioxide worldwide with the help of automobiles as host without taking any extra efforts. It is widely believed that post combustion control technologies have greatest potential for reduction of CO₂emissions. The purpose served here is elimination of the post-combustion CO₂emissions by transportation media necessarily at the source itself being road proximities. The same unit can be retrofitted to existing fossil fuel power plants and other industrial emitters of CO₂.

Thus, the high efficiency particulate matter removing HEPA & ULPA filters and the carbon dioxide capturing activated carbon filters working in synergy has tremendous potential of not only cleaning the air in road proximities but also eliminating the CO₂emissions from fossil fuelled power plants.

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