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Improvement of Indoor Air Quality Using Bio-Based Solutions: A Review on Green Systems to Reduce Indoor CO2 Levels

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Abstract- Poor air quality is a major concern in today's world, particularly indoor air quality, because most women and children spend the majority of their time indoors and are more severely affected by respiratory disorders than men. Indoor CO2 concentrations are primarily dependent on the occupancy level and outdoor air supply rate. CO2 is the most significant anthropogenic greenhouse gas contributing to global warming. This paper provides an overview of the applications of carbon anhydrase, bacteria, and microalgae in CO2 capture.When it comes to indoor CO2 levels, our bodies are the primary source. Other sources include cooking, smoking, wood stoves, and fires. Carbon dioxide emissions drastically increased from 1990 to 2000 by 13% and are expected to increase by 30–50% until 2050. Humans are harmed by CO2 exposure in a number of ways, including respiratory acidosis, which is caused by an acid–base imbalance in the blood. It may be well tolerated but can also cause memory loss, sleep disturbances, excessive daytime sleepiness, and personality changes.Algal photobioreactors have the highest CO2 collection capability of the developed methods. Algae-based CO2 conversion offers a cost-effective option for reducing our carbon footprint. In addition, an algae-based CO2 mitigation strategy has the potential to obtain valuable products at the end of the process. One of the potential solutions for anthropogenic CO2 conversion is algae-based CO2 reduction.

Keywords- Poor indoor CO2, Climate change, CO2 sequestration, Microalgae and Green methods.

I. INTRODUCTION

CO2 is the anthropogenic greenhouse gas that contributes the highest percentage to global warming. Climate change has become one of the most important environmental and energy policy issues of the 21st century, and the rise in CO2 emissions is considered the main cause of it (Vale et al. 2020). Humans are harmed by CO2 exposure in a number of ways, including Respiratory acidosis, which is caused by an acid–base imbalance in the blood, may be well tolerated but can also cause memory loss, sleep disturbances, excessive daytime sleepiness, and personality changes (Nisitha et al. 2022).

Around 300–400 ppm is normal and will not cause any harmful effects. Inhalation exposure to 1000 ppm CO2 for a short term caused marked changes in respiratory movement amplitude, peripheral blood flow increases, and the cerebral cortex functional state, and also affected decision-making and problem-solving skills. Blood pressure rises above 2500-5000 ppm, causing headaches, drowsiness, and fatigue. Exposure to > 50000 ppm of CO2 causes unconsciousness, and long-term exposure can cause coma and death. Exposure to >100,000 ppm CO2 causes death in a minute (Balasubramani et al. 2022).Over the last several decades, great efforts have been made to reduce CO2 emissions through the use of carbon capture, storage, and use (CCSU) technology. A major system frequently used for carbon capture comprises precombustion, post-combustion, oxy-fuel and chemical looping combustion. Several techniques have been examined worldwide for reducing CO2 emission levels based on chemical, physical and biological methods including solution absorption, adsorption, membrane separation, and cryogenic methodsshown in Fig.1(Mata et al. 2021, Dębowski et al 2021).

Absorption and adsorptionare an excellent method among these options because to its low energy consumption, affordable equipment, and simple implementation. However, it has been indicated that chemical absorption with amines, although technically feasible, does not represent an attractive solution for CO2 separation from flue gases in a global scale (Klinthong et al. 2015). Aside from the CO2 emissions associated with the amine production process, there are several drawbacks to using amines as an absorption solvent: high toxicity, corrosiveness, degradability, high volatility, and the large amount of energy required to regenerate the solvent and recover the CO2 (Fernández et al. 2021).

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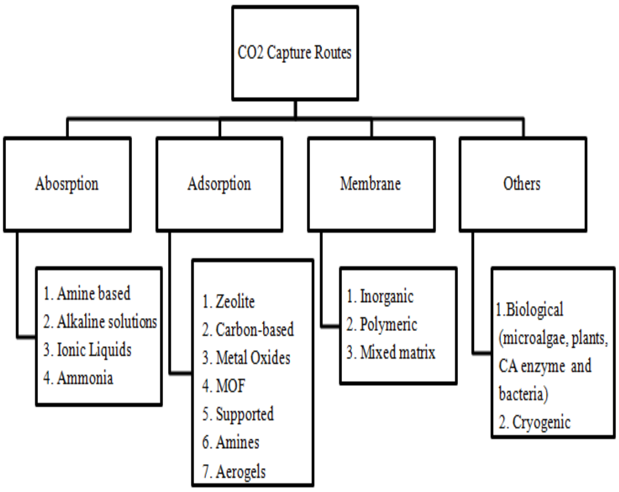

Fig 1. CO_2 capturing technologies.

To overcome the drawback of CO_2 capture using amine functionalization, CO_2 bio-fixation via the photosynthetic procedure is considered one of the most effective approaches for CO_2 capture. There have been promising studies on fixing CO_2 in algae growth and cultivation systems, indicating that the technology may potentially be used to curb the emissions of carbon dioxide and other pollutants present in flue or exhaust gas (Mountourakis et al. 2021). One of the significant benefits of microalgae is that they develop quicker and more effectively than other photosynthesizing organisms such as terrestrial plants.

Another current trend to capture or reduce CO_2 levels is the use of carbonic anhydrase because it catalyzes the reversible hydration reaction of CO_2. Therefore, the main aim of this critical review is to analyze and discuss the biological methods using microalgae, carbon anhydrase, and bacteria to reduce indoor CO_2 levels.

II. GLOBAL CO2 EMISSION STATUS

More than half of the rise in atmospheric CO_2 concentration happened in the last 30 years, from 280 ppm in 1850 (Debowski et al. 2021) to more than 417 ppm in 2021. An interesting fact is that CO_2 levels are higher than they have been for at least 800,000 years. Over the past few decades, carbon dioxide emissions have steadily increased due to population expansion and global economic development (Prasad et al.2021).

Global average surface temperature rises as a result of rising CO_2 levels in the atmosphere, which has direct and indirect effects on global weather and climatic phenomena (e.g., excessive rainstorms, drought). Between 1990 and 2000, carbon dioxide emissions increased by 13%, and it is predicted that they would rise by 30–50% until 2050, which will have a severe impact on the environment and on human health care. Additionally, during the previous fifty years, the amount of carbon dioxide in the atmosphere increased up to 20 times, while the earth's surface temperature increased by 1°C.(Prasad et al. 2021, Vivek Vidhyadharan et al. 2016, Fernandez et al. 2021).

The major sources of carbon dioxide and its percentage are mentioned in Fig 2. The leading polluters were China, the United States, India, the United Kingdom, Russia, and Japan, according to the Emission Database for Global Atmospheric Research (EDGAR). Even though innovative and globally integrated carbon capture, utilization, and storage (CCUS) technologies are being investigated, there are still major financial, economic, and environmental problems (Global Carbon Sequestration Project 2020). Current predictions indicate that worldwide carbon dioxide emissions from cement and fossil fuels will increase by 1.0% in 2022, hitting a new high of 36.6 billion tons of CO_2 ($GtCO_2$).

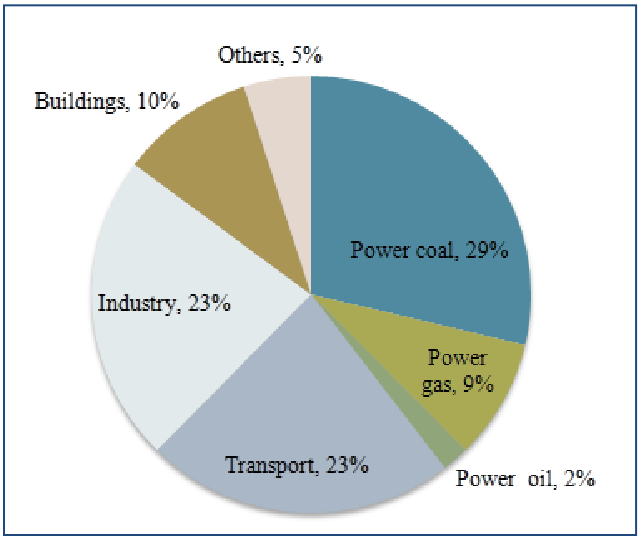

Fig 2. Global CO_2 emission by sector (source: IEA).

III. MICROALGAE

Microalgae are microscopic organisms found in both freshwater and saltwater (Vale et al. 2020). More than 25,000 species have been identified and characterized as prokaryotic cyanobacteria (blue-green algae) or eukaryotic microorganisms. The oceans, which are responsible for approximately 70% of the Earth's atmospheric O_2, mainly phytoplankton, play an important role because 50% of global carbon assimilation has been stated in the literature, and 1.0 kg of cultivated microalgae may assimilate 1.83 kg of CO_2. Photosynthesis is an important natural method for decreasing CO_2 levels in the atmosphere.

The planet's fastest-growing photosynthetic creatures are microalgae, which may grow up to 50 times more quickly than terrestrial plants. They consume significantly less fresh water and don't need agricultural land (Fernandez et al. 2021). However, every cell in microalgae is photoautotrophic and capable of directly absorbing

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nutrients; they do not need a vascular system for the transportation of nutrients like higher plants do. Microalgal cells are photosynthesis-driven cell factories that may use carbon dioxide (CO2) as a source of energy to create biofuels (such as biohydrogen, biodiesel, and bioethanol), animal food chemical feedstocks, and high-value bioactive chemicals (such as docosahexaenoic acid (DHA)) (Klinthong et al. 2015).

Depending on the amount of energy and carbon available, microalgae can grow in one of three ways: autotrophy, heterotrophy, or mixotrophy. In autotrophic growth, microalgae use CO2 as a carbon source and sunlight as an energy source to create the necessary organic matter and energy. Most autotrophic cultivation is done in closed photobioreactors and open pond systems (Prasad et al. 2021). Organic substances are utilized in heterotrophic growth as both energy and carbon sources. Mixotrophy is a growth mode in which heterotrophic and autotrophic modes coexist, resulting in the use of inorganic and organic carbon in the presence of light. During autotrophic growth, microalgae absorb CO2, providing biomass for a variety of purposes, including bioenergy generation. As a result, as the integration of microalgae production increases, it may become an essential solution for CO2 capture (Vale et al. 2020).

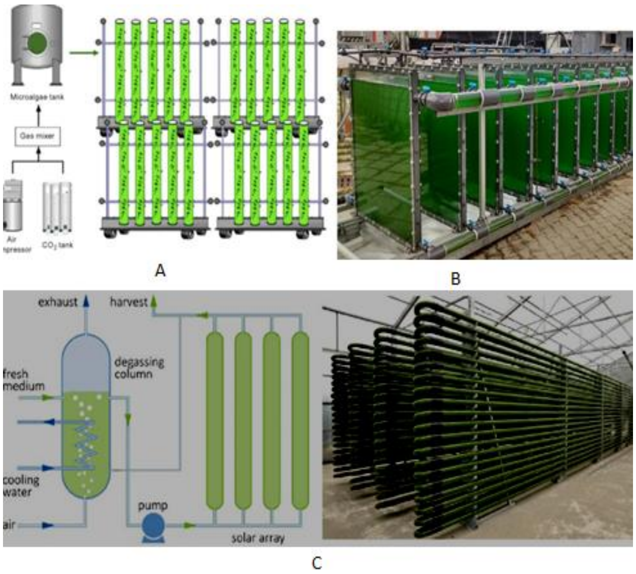

Fig 3. A) Vertical column photobioreactor B) Flat plate photobioreactor C) Horizontal-tubular photobioreactor.

The efficacy of CO2 capture by algae varies depending on algal physiology, pond chemistry, and temperature. Under ideal conditions, carbon-dioxide collection efficiency of 80% to 99% is possible (Sayre et al. 2010). The efficacy of CO2 fixation via microalgae and biomass production is dependent on growing parameters (e.g., temperature, light, pH, and nutrient availability), microalgae species, CO2 concentrations, and harmful contaminants in flue gas. CO2 fixation by microalgae offers numerous advantages over alternative carbon capture and storage (CCS) systems, including a high photosynthetic rate, a quick growth rate, good environmental adaptation, and an inexpensive operating cost. After CO2 extraction, biomass from microalgae is offered for energy consumption as an added benefit. One of the significant benefits of microalgae is that they develop quicker and more effectively than other photosynthesizing organisms, such as terrestrial plants (Debowski et al. 2021).

Microalgae can be grown in the laboratory or outside, in closed or open environments. Open systems for microalgal development are less expensive, but they are more susceptible to external variables and contamination, limiting the ability to maintain microalgal growth for extended periods of time. Closed culture systems, on the other hand, are more expensive but allow for complete control of cultivation parameters, supporting suitable circumstances for microalgal development. Microalgae cultivation methods range from open ponds with varying levels of control to photobioreactors with varying geometries (Dębowski et al. 2021, Fernández et al. 2021, Lim et al. 2021). Microalgae absorb CO2 during photosynthesis, which involves two primary types of reactions. The first reactions (light-dependent reactions) involve the capture of light energy and its conversion into nicotinamide adenine dinucleotide phosphate (NADPH2) and adenosine triphosphate (ATP).

The second corresponds to a series of reactions that fix and reduce inorganic carbon (CO2) into organic carbon, with these reactions being light independent. Photobioreactors are specialized bioreactors used to cultivate photoautotrophic organisms. In the right circumstances, practically any algae, cyanobacteria, seaweed, or plant cell may grow efficiently in a photobioreactor. PBRs are closed systems that do not allow a direct exchange of gases between the algal culture and the atmosphere (Jaganmoha et al. 2021). PBR tubes are typically constructed of glass or acrylic since they must be clear to enable light to pass through. There are different shapes of photobioreactors available, such as vertical columns, airlifts, flat plates, horizontal tubular systems, etc.

IV. BACTERIA AND CARBON ANHYDRASE ENZYME

Biological systems for CO2 conversion provide a potential path forward owing to their high application selectivity and adaptability. Higher plants and microalgae are well known for their ability to fix CO2; however, bacteria have many advantages over these species, including a significantly faster rapid growth rate and life cycle, the ability to exist in a high-density culture, and the ability to be genetically engineered more easily (Anguselvi et al. 2019). Many bacteria can utilize CO2 as their only carbon source and convert it into value-added compounds. A lot of effort has lately gone into developing possible CO2 fixation mechanisms using synthetic biology, protein engineering, and metabolic engineering. Synthetic biology focuses on rebuilding and repositioning innate CO2 fixation pathways, changing CO2-fixation pathways to improve CO2 supply, and generating and improving CO2 fixation enzyme efficiency and durability to enable successful CO2 fixation. Bacteria, namely E. coli are the first genetically engineered prokaryotic creatures (Jaganmoha et al. 2021). 2.7 billion years ago, cyanobacteria were the only oxygenic photosynthetic microorganisms on the planet. During that period, the gaseous composition of the environment changed, with CO2 decreasing and O2 rising (ebowski et al. 2021).

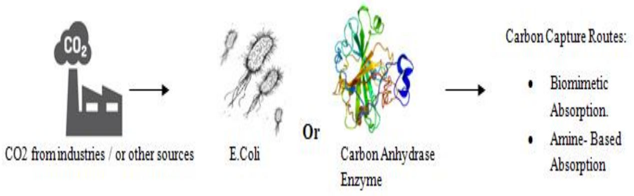

Fig 4. Carbonic anhydrase enzyme and its CO2 sequestration.

Carbonic anhydrase (CA; carbonate hydro-lyase) a metalloenzyme containing zinc (Zn++) metal ion in its active site, encoded by almost all organisms including eukaryotes and prokaryotes, and catalyzes the reversible hydration of carbon dioxide (CO2) into bicarbonate ions (HCO− 3) shown in fig 5 (Fu et al. 2018). By using CA's capacity to catalyse the reversible hydration of CO2, an eco-friendly and cost-effective strategy to CO2 sequestration has been developed. (Ajam et al. 2012). It is an excellent candidate for novel biocatalytic processes based on the capture and utilization of CO2. In Eukaryotes, CAs is involved in the transport and supply of CO2 or HCO3–, pH homeostasis, secretion of electrolytes, biosynthetic processes, and photosynthesis.

CAs is essential for the survival of the microbes and their pathogenicity and virulence. CA carries out two types of enzymatic equilibrium processes. Firstly, as a "hydrase," it catalyzes the equilibrium hydration and dehydration reactions of CO2 (aq) or CO2 to bicarbonate interconversion. Secondly, as an "esterase," it hydrolyzes substrates such as para-nitrophenylacetate (p-NPA) to paranitrophenol (p-NP). Immobilization of carbonic anhydrase in any polymer or in a bioreactor is the best way to capture CO2.

$$\mathrm{CO2 + H2O} \xrightarrow{\text{Carbon Anhydrase}} \mathrm{HCO3 + H^{+}}$$

Fig 5. CO2 reduction by CA reaction.

V. RESULT AND DISCUSSION

CO2 is the anthropogenic greenhouse gas that contributes the highest percentage to global warming. Carbon dioxide emissions increased by 13% between 1990 and 2000 and are expected to grow by 30-50% until 2050, causing global warming and affecting the environment and human health. Furthermore, carbon dioxide levels in the atmosphere have grown up to 20 times in the last fifty years, and the temperature of the Earth's surface has risen by 1 degree Celsius (ebowski et al. 2021). To address this issue, CO2 sequestration is an effective method of lowering the ambient CO2 level.

One promising way to address those issues is to use bioreactors using microalgae or carbon anhydrase. Despite the fact that green solutions are more expensive, the outcome is more efficient than conventional carbon capture technology. Algae-based carbon dioxide (CO2) sequestration has gained popularity due to its capacity to utilize CO2 as a carbon source, better photosynthetic efficiency, high CO2 fixation capabilities, ideal culture conditions, faster growth rates than conventional crop plants, and biomass generated that may be utilized as a feedstock for various value-added products such as ethanol and chemicals.Many studies have focused on microalgae production for CO2 reduction.

Table 1. Microalgae and its CO2 reduction range.

Microalgae	CO2 reduction percentage	Reference
Chlorella Vulgaris	84.48% - 89%	Mata et al. 2021, Mathin Jaikua et al. 2018
Oscillatoria	70-80%	Anguselvi et al. 2019
Spirulina sp	100%	Shen et al. 2021
Scenedesmus Obliqus Biofilim	65.05%	Guo et al. 2019
Botryococcus braunii	73%	Pooja et al. 2014

For example, (Mata et al. 2021) examined the contribution of microalgae to energy generation, CO2 bio fixation capability, and land preservation, while evaluating two potential microalgae species: Chlorella vulgaris and Dunaliellatertiolecta, the result shows that chlorella vulgaris sequestered 89% more CO2 than Dunaliellatertiolecta, with a panel inclination of 750. (Mountourakis et al. 2021) investigated the green algae chlorella vulgaris in entirely autotrophic settings at various light intensities (0-400 mol m2 s 1) and CO2 concentrations (0.04-60% CO2) and found that 100 mol m2 s 1 light intensity appears to be the only one suited for microalgal adaptation, even at 60% CO2. (Anguselvi et al.

2019) identify Botryococcus braunii, Chlorella sp., Chlorella vulgaris, Scenedesmus obliquus, and Scenedesmus sp. as potential microalgal strains capable of absorbing large amounts of CO2 while producing significant amounts of lipid for biodiesel production.

In a bubble column photobioreactor, (Pourjamshidian et al. 2019) investigated the CO2 bio fixation of the microalgae Chlorella sp. at various CO2 concentrations (1.75% and 9.45% v/v) and gas flow rates (30, 50, and 70 ml/min). 100% CO2 bio fixation occurred at a 1.75% CO2 air ratio and 30 mL/min flow; however, a considerable and high efficiency of the growth rate was not seen due to a shortage of carbon dioxide. Consequently, the microalga Chlorella sp. has a high potential for biofuel generation and CO2 capture, therefore mitigating the detrimental effects of greenhouse gas emissions and global warming. A research study on chlorella vulgaris undertaken by (Mathin Jaikua et al. 2018) shows the greatest effectiveness of CO2 reduction was 84.48% when using a flow rate of 100 mL/min and a concentration of 1.9 x 107 cells/mL of C. vulgaris culture, while methane in the biogas effluent increased to 89.40%. (Shen et al. 2021) designed a parallel spiral-flow column photobioreactor (PSCP) made up of eight spiral-flow columns and two pipe headers for increasing microalgae cultivation using spirulina sp. to trap CO2, the CO2 fixation rate of Spirulina sp. in PSCP was 100%.

These studies showed that microalgae may absorb more CO2 than traditional technologies.Carbon anhydrase, which is found in cyanobacteria, may also decrease CO2 by converting it to bicarbonates. Recent research has demonstrated by (Dębowski et al 2021) on bacterial isolates (Bacillus altitudinis) with positive carbonic anhydrase (CA) activity from mangrove sediments in India had significant CO2 sequestering potential, with a decrease of 97%. CA immobilized membranes are capable of selective and efficient CO2 removal from fuel gas (containing CO, H2, H2O, and H2S) or flue gas (containing N2, O2, H2O, SO2, NOx, and HCl), which could have significant economic value. (Fu et al. 2018) used carbon anhydrase to create an ultra-thin hydrophilic nonporous membrane that can reduce CO2 by 50%. Immobilized CO2 on cotton fibre textile packing materials using chitosan entrapment resulted in up to 76% CO2 reduction (Jialong Shen et al. 2022). This demonstrates that carbon anhydrase immobilization can decrease CO2 more effectively than its liquid form.

VI. CONCLUSION

Carbon dioxide (CO2) is a greenhouse gas emitted into the atmosphere as a result of anthropogenic activity such as fossil fuel burning and industrial production. As a result, concerns about catastrophic global warming and climate change have grown more intense. Several technologies for capturing CO2 have been developed, including adsorption, absorption, membrane separation, microalgae, bacteria, and others; however, the majority of them are expensive and have low capturing effectiveness. Algal photobioreactors have the highest CO2 collection capability of the developed methods. Algae-based CO2 conversion offers a cost-effective option for reducing our carbon footprint. In addition, an algae-based CO2 mitigation strategy has the potential to obtain valuable products at the end of the process. One of the potential solutions for anthropogenic CO2 conversion is algae-based CO2 reduction.

While microalgal cultivation is costly, microalgal biomass may be used to create cash by producing a number of high-value commercial goods (algal fuel, protein-rich algal food, animal feed, algae-based medications, and so on). Botryococcus braunii, Chlorella vulgaris, Chlorella sp., Oscillatoria, Scenedesmus obliquus, Scenedesmus sp., and Spirulina sp. are examples of microalgae and cyanobacteria species often used for CO2 mitigation. I'm concluding that spirulina sp., which has a higher tolerance for temperature and CO2 concentration than the carbon anhydrase enzyme bioreactor, could grow effectively and produce a high CO2 concentration of up to 100%.

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