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A Review of Indoor Air Cleaning Technologies

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ABSTRACT

Indoor air quality is one of the major threats for the health of human beings because in this age of technology indoor working spaces have become more prevalent. There are different techniques and technologies for the control and remediation of indoor air pollution. These technologies are based on the principles of biology, physics and chemistry so the review is majorly divided into the two categories Physiochemical Technologies and Biological Technologies. Different techniques and technologies under these categories are reviewed and on the basis of it a brief comparison-based conclusion is drawn. This comparison will explain the type of pollutant being removed, the efficiency of technology and its future in the domain of indoor air pollution as some technologies are not able to remove some particular pollutants or they target only selected pollutants. The best indoor air pollution control technique might include use of one of many technologies as combination, targets a particular category based on the type of pollutant or gives suggestion for some new and innovative technology.

KEYWORDS: Indoor, Air Pollution, Air Quality, Biological, Physiochemical

1 INTRODUCTION

Rapid urbanization and population growth have resulted in a global air pollution crisis, impacting both human health and the environment. It is reported that both indoor and outdoor air pollution are harmful to human health, depending on the duration of exposure and the concentration of the pollutants. According to the World Health Organization (WHO), indoor air pollution especially household air pollution is responsible for an estimated 4.3 million deaths each year [1].

Increase in population and recent urbanization have affected humans and the environment in many different aspects. One of the major drawbacks of it is that it made air pollution a global problem. It is reported that both indoor and outdoor air pollution are harmful to human health, depending on the duration of exposure and the concentration of the pollutants. Air pollution directly affects human, and it also causes other environmental problems.

Indoor air pollution is a significant public health concern, affecting millions of people worldwide. It is characterized as more dangerous than outdoor because of less ventilation causing the air to be more concentrated. This makes it a leading environmental risk to health, comparable to the risks of outdoor air pollution.

The type of air pollutants found in outdoor and indoor air are more or less same, but their quantity and concentration differ. The indoor air pollution concentration can reach upto 10 times the concentration of the outdoor air pollution[2]. Indoor air pollutants can originate from a number of sources, including:

- **Building materials and furniture**: Formaldehyde, VOCs, and other hazardous substances can be released.
- **Personal hygiene and household cleaning products**: Phthalates, ammonia, bleach, and VOCs are common culprits.
- **Tobacco smoke**: Highly carcinogenic and even more potent indoors.
- **Cooking and heating appliances**: Nitrogen dioxide and carbon monoxide are potential hazards.
- **Outdoor contaminants**: Particulate matter, ozone, and others can infiltrate enclosed spaces.

Indoor air pollution has a number of health impacts on human beings some of them are:

- **Respiratory infections:** Pneumonia, bronchitis, and asthma are among the most common ailments.
- **Allergic reactions:** Indoor pollutants can trigger allergies and sensitivities.
- **Increased cancer risk:** Formaldehyde and radon are particularly concerning in this regard.
- **Heart disease and stroke:** Exposure can exacerbate existing conditions or increase the risk of developing them.
- **General health issues:** Headaches, nausea, dizziness, and fatigue are also common symptoms.

There are a number of different techniques that can be used to control indoor air pollution. These techniques can be broadly classified into two categories:

- **Source control:** This involves reducing or eliminating the sources of indoor air pollution. For example, using low-VOC paints and cleaning products, quitting smoking, and ventilating homes properly.

- **Air cleaning:** This involves removing pollutants from the air after they have been emitted. This involves the use of different technologies and techniques which will be reviewed in this paper.

This paper targets the air cleaning and not the source control. Air cleaning is majorly divided into two types of Physiochemical technologies and biological Technologies.

2 PHYSIOCHEMICAL TECHNOLOGIES

Table 1: Physiochemical Technologies

Filtartion	A HEPA (high efficiency particulate air) filter coated with CuBTC/TiO2/PS composite nanofiber. Due to the large surface area of nanofibers and high absorption capacity which allows them to effectively capture toulene gas and PM 2.5 particle from the indoor this filter also consists of a UV light self-cleaning system. The average levels of indoor PM 2.5 decreased significantly following the air filtration intervention in the house [3].
	Uses a nylon mesh decorated with two-dimensional titanium carbide (Ti3C2) MXene nanosheets as an air filter. This MDNM filter uses static electricity to trap particulate matter (PM 2.5) which is less than 2.5 micrometres in diameter [5]. Removal Efficiency 90.05% for PM 2.5 (MDNM filter) 91.03% for PM 2.5 (HEPA)
	Use of non-woven fabric membranes as air filters for indoor air quality (IAQ) monitoring. The non-woven fabric membranes are prepared using a dip coating method, resulting in uniform hierarchical porous air filters. These filters have a high filtration efficiency for particulate matter (PM2.5) reaching 96.8% [5].
Adsorption	Activated carbon-based adsorption is commonly used to remove indoor air pollutants, including formaldehyde. Due to ordinary van der waal forces a stronger hydrogen bond between oxygen functional groups and four multiplied occurs but surface oxygen modification of activated carbon increases its adsorption capacity for formaldehyde [3].
	Adsorption is an effective approach for the removal of fine particulate matter (PM2.5) and volatile organic compounds (VOCs) in indoor air pollution. For VOC absorption traditional biochar and metal organic framework are emerging porous material are used. [4]

Photocatalytic Oxidation (PCO)	Photocatalytic oxidation technology is an approach for removing Semi volatile organic (SVOCs) compounds and volatile organic compounds (VOCs) photocatalytic oxidation technology is in development and will promote future advances in elimination of indoor air pollutants[5].
	Natural palygorskite clay produces nanocomposite 4 photocatalytic air pollution control when combined with TiO_2 nanocrystals. Three types of palygorskite clay were synthesized: untreated (P), Zn-modified (Zn-P), and Cu-modified (Cu-P) palygorskite. Palygorskite based nanocomposite catalyst he's effective for indoor air purification along with the nor demand of TiO2 [6].

3 BIOLOGICAL TECHNOLOGIES

Table 2: Biological Technologies

Botanical Filters	Effectively removes formaldehyde and toluene. Increases the relative humidity by 20%. The filter also increased the supply air relative humidity by 20% in winter conditions 15% of the relative humidity with no filtration in summer conditions [7].
	Effectively removes formaldehyde and toluene. Increases the relative humidity by 20%. The filter also increased the supply air relative humidity by 20% in winter conditions 15% of the relative humidity with no filtration in summer conditions [8].
	PM1, PM2.5, PM10 and VOC were removed using slow flow rate. It removes PM1 (2.9 - 3.0 mg m^{-3}), PM2.5 (2.9 - 3.0 mg m−3), and PM10 (3.6–3.7 mg m^{-3}) [9].
	CO2 level of indoor can be reduced to such that of outdoor or even lower [10]. **Removal Efficiency** CO2: 12% - 17% PM2.5: 8% to 14% Temperature: 0.13°C Humidity increased by 3.1-6.4%
Microalgal Air Purification	Use of biosmotrap reduced: nitrogen dioxide from 565 µg/m3 - 188 µg/m3, PM 2.5 from 3200 µg/m3 - 60 µg/m3, carbon monoxide from 1,423,992 µg/m3 - 76,756 µg/m3, and nitric oxide from 71,128 µg/m3 - 9982 µg/m3. It also eliminates 60–80% of indoor air contaminants that come from smoking cigarettes [11].

	Micro Algae based purifier were used to remove PM2.5. These purifiers use microalgae for air cleaning here Chlorella pyrenoidosa specie of microalgae is used. The results show reduction in O_2 production (< 30 mg h^{-1}) and 60 % removal of PM2.5 [12].

4 CONCLUSIONS

This review explores the diverse range of indoor air pollution control technologies encompassing both physiochemical and biological methods. Each technology is beneficial for the air pollution control they have some drawbacks as well. Physiochemical technologies like filtration, adsorption, and photocatalytic oxidation are the most reliable and have high efficiency but require energy for their process. On the other hand, biological technologies which uses Plant-based and microbial systems present a sustainable and energy-efficient alternative, effective for a wide range of pollutants. It also offers additional benefits like CO2 reduction and humidity control. However, their performance can be slow and requires careful maintenance. Combining different technologies in a system holds great efficiency and benefit for comprehensive pollutant control and addressing diverse contaminants.

For future advancements use of new materials for filters, adsorbents, and catalysts can boost efficiency while reducing energy consumption. Integrating smart systems like using sensors and automation into air purification systems can enable real-time monitoring, dynamic adjustments, and personalized Indoor air quality management. Moreover Evaluating the environmental and health impacts of each technology across its entire lifecycle is crucial for responsible development and implementation.

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