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Advanced Lightweight Photocatalytic Composite Membrane to Remove Biological Pollutants from Wastewater

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Abstract

The objective of this study is to design a novel lightweight photocatalytic composite membrane which can be utilized to remove biological contaminants from wastewater. The developed membrane is not only safe and economical but also environmentally friendly. The photocatalytic composite membrane is made up of zinc oxide (ZnO), titanium oxide (TiO_2), copper oxide (CuO), silver nitrate ($AgNO_3$), and hydraulic cement as a binding agent. TiO_2, ZnO, $AgNO_3$, CuO, and sand were mixed in the ratio of 4:2:2:25:67, respectively. The biological pollutant (BP) inactivation test with the photocatalytic composite membrane reduced the total number of bacterial colony forming unit (CFU) by 96.37%, 97.25%, and 97.78% immediately after filtration in 15 minutes at an initial concentration of 523, 400, and 225 CFU/ml, respectively. In under 15 minutes, at a concentration of 225 CFU/ml, this photo catalytic composite membrane eliminated 97.78% of all bacterial colonies, making the sample sterile. The experimental analysis reveals the suitability of sustainable, cost-effective, and environmentally friendly approach to purify wastewater. The developed membrane takes only 15 minutes to kill or disinfect around 98% of bacteria that were born as a result of biomedical or other contaminants.

Keywords

Photocatalytic, Lightweight, Membrane, Colony forming unit, Wastewater, Composite

Introduction

The quality of water is crucial for all living things. 70% of the planet's surface contains water, but just 2.5% of total available water is clean and only 1% of this fresh water is fit for human consumption without risk to human health [1]. Due to the increasing growth of the world's population and large-scale pollution, the availability of fresh and clean water has been a major challenge for modern society [2]. Other contributors include a growth in the number of chemicals used in agriculture and industry, as well as human activities. Human activities diminish the quality of ground water [3]. About one-sixth of the world's population does not drink clean and fresh water [4]. These harmful contaminants in the water limit the amount of hygienic drinking water that can be preserved. Through the soil, microbiologically harmful microorganisms gain access to ground water. These bacteria are responsible for a wide range of disorders. Aeromonas bacteria present in the water are particularly dangerous for human health [5]. Since the chemical run off from agricultural, industrial, and home operations has not been consistently monitored and recorded therefore water bodies are being continuously contaminated [6]. Current water purification technologies include chlorination, ozonation, aeration, reverse osmosis, and Ultraviolet irradiation (UV ray). The existing technologies not only require extra energy but also produce secondary pollutants. In addition to this these methods are not effective in removing the heavy metals present in water [7]. Photocatalytic composite membranes can be used to remove biological contaminants from wastewater. Visible light causes photocatalytic effect, which increases the reaction rate without using any material in the redox reaction. Examples of photocatalytic chemicals are TiO_2 and ZnO [8]. Photocatalytic compounds become active when exposed to sunlight's ultraviolet-A (UVA) rays. When this radiation strikes photocatalytic material electron jumps from the valance band to the conduction band. In this procedure, the electrons that jumped from the valance band to the conduction band will recombine in the valance band. The bulk of conduction band free electrons (e) will mix with oxygen and water to form highly reactive superoxide (O_2-), hydroxyl radical (OH-), and hydrogen peroxide (H_2O_2). These reactive free radicals are responsible for the destruction of the bacterium [9]. Due to the energy band gap, the photocatalytic cannot function in visible light; thus, to reduce the energy band gap, high-conducting silver (Ag) must be added [10]. This minimizes the energy band gap, allowing it to operate in visible light, while Ag's antibacterial characteristic kills more bacteria [9].

Procedure for Preparing Advance Lightweight Photocatalytic Composition

The corresponding weight ratios of TiO_2, ZnO, $AgNO_3$, CuO, and sand in the advanced lightweight photocatalytic composite membrane were 4:2:2:25:67. Initially TiO_2 and ZnO were combined in the right proportion and mechanically mixed, followed by the addition of $AgNO_3$ and further mixing.

After fully mixing the CuO, the mixture is placed in a location where it will be exposed to sunlight for 2 to 3 hours. After this it was kept for two to three hours in an oven at temperatures between 250 and 350 °C for the calcinations process. This calcinated mixture is re-exposed to the exposed zone for two hours. After incorporating this cementing binder and CuO powder into the mixture, water has been added and it has been completely mixed. From this mixture, a number of little porous solid spherical balls will be created. Figure 1a depicts a visual representation of the filtration process, whereas figure 1b depicts the material employed in the photocatalytic membrane. The CuO is used for its antibacterial properties and its ability to retain free electrons in the conduction band. The Ag is also antimicrobial, and it reduces the energy band gap for the semiconductors such as TiO_2 and ZnO to enhance the photocatalytic activity for low to high wavelengths (the UV to visible light spectrum) The application of the lightweight photocatalytic mixture TiO_2-ZnO-Ag-CuO in the continuous cleansing of dirty water [9]. The complete procedure for making this photocatalytic membrane is shown in figure 2. The physical parameters of photocatalytic membrane are shown in table 1.


(a) (b)

Figure 1: (a) From left TiO_2 and UF membrane and **(b)** Pictorial view of process of filtration Micro filter, mineral cartilage.

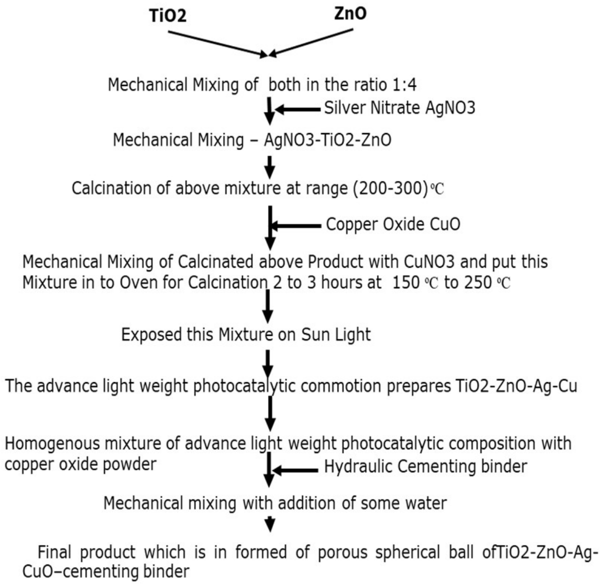

Figure 2: Block diagram of preparation advance light weight photocatalytic composition.

Materials

i. ZnO is used for removing harmful bacteria and viruses [10].

ii. TiO_2 produces free electron, this free electron decomposes water into hydroxyl radical and H_2O_2 [9]. TiO_2 possesses not only self-cleaning capability but also it has a good photocatalytic property. Therefore, the cost of maintaining the photocatalytic membrane will be reduced. A variety of photocatalytic materials comprising of ZnO, SnO_2, and Fe_2O_3 have been used earlier. In long period all these combinations required major cleaning operation for their continuous use. This increases the maintenance cost as well as reduces the performance of the filter during its usual operation. So, use of TiO_2 is preferable compared to other photocatalytic materials.

iii. U.F. membrane filter water in range 200 - 350 nm [4].

iv. Ag: Antibacterial agent, good conductor, optical property,

Table 1: The physical parameters of photocatalytic membrane.

Physical parameters	Value
Pore size	15 - 50 micron
Density	1450 kg/m^3
Thickness	3 cm
Filtration rate	40 liter/h
Water socking capacity	0.002 liter

chemical stability, photocatalytic activity, good mechanical property, reduce energy band gape anticorrosive, and semiconductor [10].

v. CuO: High corrosive resistance, good conductor of heat and electricity, antibacterial property, holding property of electron, and stable in nature [11-13].

Methodology

When visible light strikes a photocatalytic material, a positive hole (P^+) is created on the valance band and an electron is removed (e^-). Which jump from the valance band to the conduction band, produces electrons and holes that react with the pollutant to form oxides and precipitate. This method involves redox reactions (oxidation-reduction relation). The hole produced by photocatalytic reaction reacts with water. It decomposes water into hydroxyl free radical OH^* and H^+ free radicals with strong reduction potential, but semiconductor or photocatalytic reactions are not involved, hence TiO_2 and ZnO do not dissolve in water [9].

$$\text{Photocatalytic composition + light} \longrightarrow P^+ + H^-$$

In natural condition free radical hydroxyl ion is produce in fallowing reaction

$$P^+ + H_2O \longrightarrow OH^- + H^*$$

$$P^+ + OH^- \longrightarrow OH^*$$

Under alkaline condition hydroxyl free radical directly produce in fallowing reaction

$$P^+ + \text{pollutant} \longrightarrow \text{pollutant}^+$$

In alkaline condition hydroxyl free radical will more reactive

$$e^- + O_2 \longrightarrow O_2^{*-}$$

$$O_2^{*-} + P^+ \longrightarrow OOH$$

Acidic condition has more H^+, this H^+ will be reactive with electron which is free is produce H^*

$$H^+ + e^- \longrightarrow H^*$$

$$H_2O_2 + \text{Sun light} \longrightarrow 2OH^-$$

$$\text{Pollutant} + (OH^-, P^+, OOH, O_2^{*-}) \longrightarrow \text{degradation of pollutant}$$

$$H^* + OH^* = H_2O$$

In acidic condition photocatalytic activity will decrease [12].

It is evident from the above equation that the photocatalytic process generates OH^-, which reduces pollutants, heavy metals, germs, etc. in water. It also precipitates heavy metals such as arsenic and kills germs. After this free electron, superoxide (O_2^{*-}) will react with water to generate hydrogen peroxide (H_2O_2).

Analysis of bacterial growth

After the bacteria grow on the agar plate, we calculate the total number of CFU developed in that sample. For this, we have to check the Petri plate and take a minute sample from it then place it on slides for microscopic analysis.

Finally, we need to watch the end results for the dilution of waste spread on agar media. For this, we need to check the Petri plate and take for a moment test from it at that point place it on slides for microscopic analysis. The direct observation which can be made from the Petri plate is as shown in figure 3a. Figure 3b reduction of bacteria and germs the testing of the wastewater sample in both treated and untreated stage. From the microbiological testing is concluded that the photocatalytic membrane treated wastewater is free from bacterial growth in comparison to the treated sample.

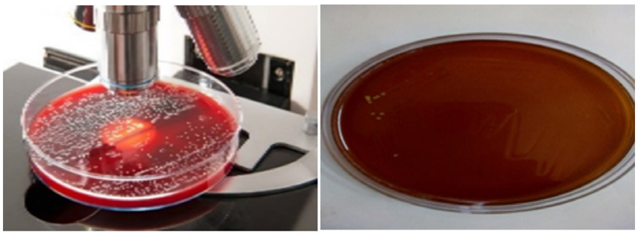
(a) (b)

Figure 3: **(a)** Calculate the total CFU and **(b)** Reduction of bacteria and germs.

Results and Discussion

This study focuses primarily on the existing technologies, the selection of the most effective method of disinfection, and the microbial testing of wastewater filtered by a photocatalytic composite membrane. Before and after the wastewater was filtered in the presence of sunshine, visible light, and dark light, the total amount of biochemical waste, and bacteria that were born in the biological pollutant were estimated. The CFUs are used to quantify all bacterial counts. In this experiment, a one-milliliter sample of wastewater is collected whenever a different concentration is studied. Prior to analyzing or examining the data, the Petri dish was placed in an incubator at a temperature of 35 degrees Celsius for 48 hours. Using three different concentrations of 523, 402, and 225 CFU/ml, the efficiency of this photocatalytic membrane in disinfecting wastewater was assessed. 15-minute independent time periods.

Reduction percentage of biological pollutant in water after filtration

In 15 minutes, the results indicate that a photocatalytic composite membrane may successfully and sustainably reduce the quantity of bacteria formed from BP. Table 1 displays the average number of microorganisms counted at different time intervals for a photocatalytic composition including TiO_2-ZnO-Ag-Cu that was exposed to sunshine, visible light, or dark light. In 15 minutes, the concentration of bacteria and viruses has considerably decreased. Because an advanced photocatalytic composition filtering mechanism generates OH^- in sunlight, visible light, and dark light, so reducing pollutants, heavy metals, microorganisms, and so on [9-

Table 2: Biological pollutant in the wastewater culture report.

Sr. No	Treated Time in min	Sample 1 Micro Bacteria Count CFU/ml	Sample 2 Micro Bacteria Count CFU/ml	Sample 3 Micro Bacteria Count CFU/ml
1.	Pre-treated	523	400	225
2.	Treated 5 min	162	150	75
3.	Treated 10 min	83	50	17
4.	Treated 15 min	19	11	5

10]. Sample number 1, which was given treatment with a photocatalytic composite membrane, had a concentration of bacteria that was 523 CFU/ml, which was relatively high in comparison to the other samples given at the beginning of the process. After filtration takes place in sample 1, the results show that the concentration of bacteria rapidly drops from 523 CFU/ml to 19 CFU/ml as shown in table 2. In a similar manner, the concentration of bacteria dropped considerably from 400 CFU/ml to 11 CFU/ml and from 225 CFU/ml to 5 CFU/ml, respectively, in samples 2 and 3. Bacteria reduction percentages for samples 1, 2, and 3 with varying concentrations were 96.37%, 97.25%, and 97.78%, respectively. As the degree of pollution drops, the quality of the filtering system improves. This is due to the fact that at lower levels of pollution, the quantity of bacteria is significantly lower when compared to other samples. The definition of the percent decrease of BP is the ratio of the difference between the initial and final value of CFU to the value of CFU at the beginning. The presence of nascent oxygen and hydroxyl free radical in the sample was the cause of the decrease in the concentration of the bacteria [11-12].

Conclusion

The objective of this study is to develop a cost effective, simple, and environmentally friendly advance light weight photocatalytic (semiconductor) composite membrane for water purification. The developed membrane contains TiO_2, ZnO, Ag, CuO, hydraulic cementing binder in the weight ratio of 4:2:2:25:67, respectively. The membrane could reduce the pollutant, bacteria, dissolved heavy metal and water turbidity. Experimental data shows that it was effective in reducing BP borne bacteria in a closed chamber. Over 97.78% of BP borne bacteria were disinfected/killed after filtration. It was observed that for three different water samples with initial concentration of 523, 400, and 225 CFU/ml, bacteria got reduced by 96.37%, 97.25%, and 97.78%, respectively. Thus, its disinfection proficiency is better than the autoclaving procedure and incineration.

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None.

Conflict of Interest

No potential conflict of interest.

Credit Author Statement

Sanjay: Conceptualization, Methodology, Experimentation, Writing - original draft preparation, Writing - review and editing; Dhirendra Pratap Singh: Conceptualization, Data validation, Writing - original draft preparation, Writing - review and editing; Sanjay Mishra: Supervision, Writing - original draft preparation, Writing - review and editing; Tabish Alam: Data validation, Writing - original draft preparation, Writing - review and editing. All the authors read and approved the manuscript.

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