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Preparation Of Low-Cost Multi-Functional Clay-Based Ceramic Filter Matrix For Treatment Of Drinking Water

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Abstract: Safe drinking water is vital to health. Although most people in the world have access to safe drinking water, as many as 663 million people still drink from untreated springs and groundwater sources, most living in remote rural areas. The scarcity of safe drinking water remains a serious problem in rural areas. In particular, groundwater pollution is caused by heavy metals, which are extremely harmful to human health due to their persistent, bio-accumulative, and hazardous nature. The scarcity of clean drinking water is a critical issue, driving the need for innovative, cost-effective, and efficient water purification solutions. This research focuses on developing an affordable, multi-functional clay-based ceramic filter matrix to treat drinking water. The proposed filter leverages the natural properties of clay, combined with other locally available materials, to create a porous matrix capable of removing pathogens, turbidity, and chemical contaminants. The fabrication process involves carefully selecting and preparing clay, mixing it with granulated carbon, molding it into desired shapes, and firing at controlled temperatures to achieve optimal porosity and structural integrity. The addition of granulated carbon is intended to improve the removal of contaminants such as organic compounds, chlorine, and heavy metals, thereby addressing microbial and chemical impurities. The resulting ceramic matrix provides physical filtration and incorporates antimicrobial and adsorptive functionalities, making it a versatile solution for various water quality challenges. Laboratory tests demonstrate that the clay-based ceramic filter can significantly reduce microbial contamination, remove suspended particles, and adsorb harmful chemicals, ensuring safe drinking water. Additionally, the low cost of production and the use of readily available materials make this technology accessible to low-income communities, particularly in rural areas. This study underscores the potential of clay-based ceramic filters as a sustainable and scalable solution for improving water quality, contributing to public health, and supporting the global effort to provide safe drinking water for all.

Index Terms **-** drinking water, critical issue, ceramic filter, eco-friendly, economical

1.INTRODUCTION

The world's water crisis demands urgent attention. Ensuring access to safe and clean drinking water is critical for human health, well-being, and overall development. Despite significant advancements in water treatment infrastructure worldwide, approximately 663 million people continue to rely on untreated sources, such as springs and groundwater, particularly in remote and rural regions. The scarcity of safe drinking water in these areas poses a significant health risk due to potential contaminants, including heavy metals, pathogens, and suspended particles, which often exceed safe consumption levels. Heavy metals, for instance, are known for their persistent, bio-accumulative, and toxic properties, making them especially hazardous to human health. This widespread contamination has created an urgent demand for innovative, affordable, and effective water purification solutions tailored to communities with limited access to centralized treatment facilities. Traditional water treatment systems often involve complex processes and high operational costs, which can render them unsuitable or inaccessible for rural and resource-constrained communities. Consequently, there is a pressing need to develop localized, low-cost alternatives that can address the distinct challenges posed by untreated groundwater and other contaminated water sources. The aim of this research is to address this gap by creating an affordable, multi-functional filter matrix, using clay and other easily sourced materials to produce a reliable, durable, and efficient ceramic-based filtration system. This system is designed to provide clean drinking water to underserved communities by removing various contaminants, including microbes, organic pollutants, and chemical impurities.

The proposed clay-based ceramic filter utilizes the unique properties of clay, which has a high affinity for contaminants and offers natural porosity when transformed into a ceramic matrix. Combined with charcoal granules and a biodegradable binder, the clay matrix forms a robust filter capable of both physical and chemical filtration. Clay's structure is particularly advantageous for water purification due to its ability to create a dense yet porous matrix when fired, capturing fine particles while allowing water to pass through. Additionally, clay's absorptive properties are enhanced by the presence of charcoal, which increases the filter's ability to remove dissolved organic compounds, chlorine, and certain heavy metals through adsorption.The filter fabrication process involves several critical steps to optimize the material properties for effective filtration. First, clay is mixed with granulated charcoal and a natural binder, which helps maintain the structural integrity of the filter. The binder is selected based on its eco-friendliness and compatibility with local sourcing, ensuring that the filter remains an affordable and sustainable option. This mixture is then shaped into discs, cylinders, or other desired forms, depending on the application, before undergoing a drying phase to remove residual moisture. Once dried, the filter elements are fired at high temperatures to transform the clay into a stable ceramic material with controlled porosity, thereby enhancing both the durability and filtration capability of the matrix.

The inclusion of charcoal in the filter matrix enhances its effectiveness by introducing additional adsorption sites for removing chemical contaminants and dissolved organics that may otherwise persist in untreated water. Charcoal's microporous structure is ideal for binding various pollutants, providing an added layer of purification. Together, the clay and charcoal create a dual-action filter that not only physically removes pathogens and particles but also chemically binds and eliminates a range of pollutants. This layered approach ensures comprehensive filtration, making it suitable for addressing the complex contaminant profiles often found in untreated rural water sources.A unique aspect of this filter design is its multi-layered configuration, which improves both filtration efficiency and longevity. Protective nylon mesh layers placed at the top and bottom of the filter prevent clogging and protect the internal filtration materials from damage, enabling continuous use with minimal maintenance. The inclusion of charcoal in the filter also aids in removing residual tastes and odors from treated water, contributing to its overall acceptance among users.

Laboratory tests have shown that this clay-based ceramic filter matrix can significantly reduce microbial loads, trap suspended particles, and adsorb harmful chemicals, making it a promising option for decentralized water purification. By testing the filter across different water types, including well water, surface water, and lightly contaminated sources, this study demonstrates its effectiveness and reliability in various scenarios. Notably, the cost-effective nature of the filter, coupled with its use of widely available materials, makes it a practical solution for low-income communities that rely heavily on untreated or minimally treated water sources.The design simplicity and low production cost are key factors that make this technology accessible to rural communities with limited resources. Furthermore, the potential for local production using abundant materials aligns with sustainable development goals, reducing dependency on external resources and creating opportunities for community-led water management. By leveraging the natural properties of clay and the adsorptive power of charcoal, this research proposes a scalable and sustainable water filtration solution that not only addresses immediate water quality concerns but also contributes to a healthier and safer living environment.

This study ultimately underscores the potential for clay-based ceramic filters to bridge the gap in water treatment accessibility and to support global efforts to provide safe, clean drinking water for all. The use of natural and renewable resources in the filter's construction also promotes environmental sustainability, offering a viable alternative to conventional filtration systems that rely on synthetic or chemical-based components. Through this innovative approach, the research aims to transform water treatment practices in rural areas, providing a safe, effective, and affordable solution that has the power to make clean drinking water a reality for communities worldwide

2. Advantages

1. Utilizing clay and granulated charcoal, this filter effectively removes a range of contaminants. Clay has high surface area and porosity allowing it to capture various physical impurities, while granulated charcoal adsorbs organic compounds and certain chemicals. This powerful combination provides thorough filtration, significantly improving water quality. The multi-layered structure of the filter is designed to capture different types of pollutants in stages, improving overall filtration efficiency. This layered approach targets both particulates and chemical impurities, making it suitable for a range of water sources, such as drinking water and well water, and ensuring comprehensive contaminant removal.

2. This filter's design is versatile enough to treat various non-industrial water sources, including well and groundwater. This adaptability ensures that it meets the water quality needs of both rural and urban populations, particularly in areas that lack access to centralized water treatment facilities. The use of natural and renewable materials, such as bentonite clay and granulated charcoal, minimizes the filter's environmental footprint. By incorporating biodegradable materials sourced from local agricultural byproducts, the filter supports sustainable water purification practices and reduces reliance on non-renewable resources.

3. By sourcing materials locally and utilizing accessible production methods, this filter can foster economic opportunities in communities where it's produced. Local manufacturing encourages job creation, skill development, and supports small-scale businesses, promoting economic self-reliance and resilience. This ceramic filter offers an alternative to disposable plastic-based filters, contributing to reduced plastic waste. Its focus on natural, biodegradable components aligns with environmental goals to minimize pollution and promote renewable resources in everyday water purification.

4. The design allows for adjustments to target specific regional water quality issues. For example, the filter can be tailored with additional natural additives to address pollutants specific to certain areas. This customization potential ensures that the filter can evolve to meet diverse water treatment needs effectively The filter is designed for straightforward operation, requiring no specialized skills or complex setup, which makes it accessible to a wide range of users, including those in remote or low-tech environments. Its simplicity ensures that households, schools, and community centres can easily implement and maintain the filter without needing technical support, making clean water access more achievable for all.

3. Applications

1. The filter is ideal for individual households relying on groundwater as a primary source, especially in regions where water contamination from natural sources is prevalent. By purifying groundwater directly in homes, it provides a convenient and reliable method for accessing safe drinking water daily.
2. By removing sediments and organic compounds, the filter enhances the clarity, taste, and odor of groundwater, making it more appealing for consumption. This improves the sensory quality of water, which is particularly valuable in areas where untreated groundwater has a poor taste or smell.
3. Unlike single-use filters or frequent water treatments, this durable, reusable filter reduces recurring costs associated with purchasing treated water or other purification supplies. Over time, it represents a more economical solution, especially for households with limited budgets.
4. Designed with affordability in mind, the filter provides rural communities with a sustainable water treatment option where conventional treatment plants are unavailable or impractical. This accessibility can contribute to better public health outcomes and reduces reliance on untreated water sources in these areas. Community-based installations, such as local water kiosks or public access points, can incorporate the filter to offer safe groundwater to multiple families within the community.
5. Small businesses in developing regions can utilize this filter to create micro-enterprises focused on water purification services. These enterprises can serve local residents by providing purified groundwater at affordable rates, promoting entrepreneurship while addressing water quality challenges.

4.RESEARCH METHODOLOGY

FIGURE 1 – FLOWCHART OF METHODOLOGY

4.1 Identification of Contaminants

In this stage, the types of contaminants present in the water sources are identified. This could include physical impurities (like suspended solids), chemical contaminants (such as heavy metals, chlorine, and organic compounds), and biological contaminants (bacteria, viruses, etc.). Groundwater and other potential sources of untreated water are tested to determine the levels of contaminants, enabling a targeted approach to treatment.

4.1.1Indian Standards (IS) for Water Quality Parameters:

1. pH

pH is a measure of how acidic or alkaline water is, with a scale that ranges from 0 to 14. A pH below 7 indicates acidity, while a pH above 7 signifies alkalinity, with 7 being neutral. The pH level of water is crucial for both health and industrial reasons. Drinking water with a pH that falls between 6.5 and 8.5 is generally recommended, as excessively acidic water can corrode pipes, leach metals, and potentially pose health risks. Conversely, very alkaline water can taste bitter and may affect how well other substances, like disinfectants, function in the water. In biological systems, an optimal pH range is essential for maintaining balance; deviations can affect everything from microbial growth to chemical reactions in the water. Therefore, monitoring and adjusting pH is a fundamental step in water treatment to ensure the safety, taste, and overall quality of the water.

IS 10500:2012 (Indian Standard for Drinking Water Quality) recommends the acceptable pH range for drinking water to be between 6.5 and 8.5.

2. Total Dissolved Solids

Total Dissolved Solids (TDS) is a measure of the combined concentration of all dissolved substances in water, including minerals, salts, and organic matter. High TDS levels can significantly impact water's taste, clarity, and overall acceptability. In drinking water, TDS values below 500 mg/L are generally preferred, as elevated TDS can impart a salty or bitter taste and may cause mineral buildup in pipes and appliances. High

TDS levels may originate from natural sources, urban runoff, agricultural activities, or industrial discharges. While TDS itself is not necessarily harmful, excessive levels of specific dissolved solids, such as nitrate, sulfate, or heavy metals, can pose health risks. Monitoring TDS provides a broad understanding of water quality, as it encapsulates the total concentration of dissolved ions and can help identify sources of pollution or contamination.

As per IS 10500:2012, the permissible limit for TDS in drinking water is 500 mg/L.

3. Conductivity

Conductivity refers to water's ability to conduct electricity, which is directly related to the concentration of dissolved ions, such as sodium, calcium, magnesium, and chloride. Higher conductivity levels generally indicate a greater presence of these ions, which can result from natural sources, agricultural runoff, or industrial waste. Conductivity is an important parameter in assessing water salinity and overall mineral content. In drinking water, high conductivity may suggest contamination or high mineral content, which can affect taste and cause scale buildup in plumbing systems and appliances. In agriculture, conductivity levels are critical because high salinity in irrigation water can harm plant growth, leading to reduced crop yields. Conductivity, therefore, is a valuable indicator of water's chemical composition and is often used to infer other water quality parameters.

IS 3025 (Part 14) provides guidelines for measuring conductivity in water. While there is no direct limit set for conductivity in IS 10500:2012, it is linked to TDS and other dissolved ions. Conductivity levels should typically not exceed 1500 µS/cm for potable water, though local conditions may influence this.

4. Hardness

Hardness in water is determined primarily by the presence of calcium and magnesium ions. Hard water can lead to scaling in pipes and boilers, reducing the efficiency and lifespan of water heating systems, household appliances, and plumbing fixtures. Hardness is typically measured in terms of calcium carbonate concentration and is classified into categories such as soft, moderately hard, hard, and very hard. While hard water is generally safe to drink, it can cause dry skin and hair and make soap and detergents less effective, leading to increased cleaning costs. Softening hard water involves removing or neutralizing calcium and magnesium ions, which is commonly achieved through ion-exchange processes or the addition of chemical softeners. Understanding water hardness is crucial in both household and industrial contexts, as it influences maintenance requirements, soap efficiency, and overall water quality.

According to IS 10500:2012, the acceptable limit for total hardness (as $CaCO_3$) in drinking water is 200 mg/L, with a permissible limit of up to 600 mg/L in the absence of an alternate source.

level between 20 and 200 mg/L is typically desirable, as it provides buffering capacity, making the water less corrosive and more palatable. High alkalinity levels are particularly beneficial in regions where water may be subject to pH fluctuations, as they help prevent corrosion of pipes and ensures that water remains safe for consumption. Alkalinity also plays a role in aquatic ecosystems, where stable pH conditions are necessary for the survival of aquatic organisms. In water treatment, maintaining the right alkalinity level ensures that chemical treatment processes, such as chlorination, function effectively

4.2 Professional Evaluation

With an understanding of the contaminants, a professional evaluation is conducted to assess the treatment requirements. This includes consulting with environmental engineers, chemists, or water treatment specialists to determine the most effective filter composition. The evaluation focuses on the efficacy of clay, granulated charcoal, and binding agents, assessing their capacity to handle identified contaminants. Parameters such as required adsorption properties, filter porosity, and durability are evaluated for optimal performance.

4.3 Specialized Treatment Process

Certain types of contaminated water may require advanced methods to effectively remove specific pollutants. Techniques such as reverse osmosis (RO), chemical precipitation, coagulation-flocculation, and specialized filtration systems can be employed to enhance purification. RO is a membrane filtration process highly effective for removing dissolved solids, heavy metals, and specific chemicals, making it suitable for water with high salinity or difficult-to-remove contaminants. Chemical precipitation, on the other hand, involves adding chemicals to induce precipitate formation, which captures contaminants like heavy metals that can then be filtered out. Coagulation-flocculation adds coagulants to the water to form larger particle clusters (flocs), which are easier to remove through filtration, especially in turbid water with high particulate levels. Additionally, specialized filtration systems—such as activated carbon filters for organic pollutants, ion exchange resins for specific ions, or multi-layered filters incorporating materials like clay and activated charcoal—are designed to target a range of contaminants in a single process. These advanced techniques can be integrated into the overall filtration design or selectively applied based on the contaminants identified, ensuring a tailored and effective treatment solution.

4.4 Implementation of Treatment

The filter is then integrated into a pilot water treatment setup. The setup mimics real-world conditions, allowing for water to be processed through the clay-charcoal composite filter. Water is directed through the multi-layered filtration system, where each layer contributes to contaminant removal through physical and chemical processes. This stage simulates the intended application environment, ensuring that the filter is practical and effective under expected usage conditions.

4.5 Monitoring and Post-Testing

After the filter is implemented, its performance is monitored through regular testing of the treated water. Parameters like pH, turbidity, total dissolved solids (TDS), and contaminant levels (e.g., heavy metals and microbial counts) are measured before and after filtration. This stage helps to verify the efficiency of contaminant removal and identifies any need for adjustments in the filter's composition or structure. Post-testing also assesses the filter's durability and potential degradation over time, ensuring that it meets quality standards.

4.6 Supply

After validation and successful pilot testing, the filter design is prepared for potential large-scale production. Supply chains are established for sourcing materials like clay, charcoal, and binding agents, preferably from local sources to minimize costs and environmental impact. Consideration is given to scalability, including community production and distribution to rural or underserved areas. Efforts are made to make the filter affordable, durable, and accessible to households, community centers, and small businesses in areas lacking advanced water treatment facilities.

5. PROPOSED METHODOLOGY

5.1 MATERIAL SELECTION

5.1 .1CLAY – BENTONITE CLAY

Bentonite is a type of absorbent clay that forms from volcanic ash. It primarily consists of montmorillonite, a mineral that can expand by absorbing water. This unique property gives bentonite its high surface area and makes it highly effective in capturing particles. Bentonite clay contains layered silicate sheets held together by van der Waals forces and hydrogen bonds. These layers are capable of swelling, which allows the clay to trap various contaminants through physical adsorption and cation exchange

Bentonite clay is highly valued in water treatment due to its exceptional adsorptive properties and ion-exchange capabilities. Its layered structure provides a large surface area, which is particularly effective for trapping impurities such as heavy metals (like lead, cadmium, and arsenic), organic contaminants, and even some bacteria. The clay particles are able to swell and expand when they come into contact with water, creating more space for trapping pollutants. Additionally, bentonite clay can improve water clarity by acting as a natural flocculant; it encourages the aggregation of fine particles into larger clusters that are easier to filter out. This property makes bentonite clay particularly useful in removing suspended solids from water, thus enhancing the efficiency of subsequent filtration stages. Moreover, bentonite clay's cation exchange capacity allows it to replace unwanted positively charged ions (like heavy metal ions) in water with benign ions, making it an effective, eco-friendly option for a variety of water treatment applications

FIGURE 2 – BENTONITE CLAY (IN POWDER FORM)

5.1.2 BINDER – SODIUM ALGINATE

Sodium alginate is derived from the cell walls of brown algae. It's a polysaccharide composed of β-D-mannuronic acid and α-L-guluronic acid units. Sodium alginate is highly soluble in water and forms a gel in the presence of calcium ions. Sodium alginate's binding capability is due to the presence of ionic bonds formed between calcium ions and the carboxyl groups in the alginate. This cross-linking helps create a gel structure, making it useful as a binder in filtration media.

Sodium alginate, derived from seaweed, plays a critical role as a natural binder in water filtration systems. Its ability to form a gel when exposed to calcium ions allows it to stabilize and hold various filtration media together, enabling the creation of cohesive filter discs or layers. This gel structure is highly stable and durable, even when exposed to water over long periods, which improves the lifespan and effectiveness of the filter. By binding particles together, sodium alginate can also reduce the leaching of fine particles from the filter media into the water, maintaining water clarity and preventing contamination from filter materials. Furthermore, sodium alginate's biodegradability makes it an environmentally sustainable choice, reducing the ecological footprint of the filtration system. Its natural, renewable origin also aligns well with eco-friendly water treatment goals, making it suitable for applications aimed at reducing reliance on synthetic, non-biodegradable materials.

FIGURE 3 – SODIUM ALGINATE POWDER

5.1.3 FILTER MEDIA – NYLON MESH

Nylon is a synthetic polymer typically made from polyamide monomers derived from petroleum. Through a process called polymerization, long chains are formed, which are then woven into a mesh structure. Nylon is made up of strong covalent bonds in the polymer chains, giving it mechanical strength. The amide groups in nylon form hydrogen bonds between polymer chains, which adds stability and durability to the mesh material.

Nylon mesh serves as an essential component in water filtration systems due to its mechanical strength, durability, and fine porosity. It functions primarily as a physical filtration barrier that captures larger suspended particles, sediments, and debris from water, thus protecting the inner layers of the filter and preventing clogging. By intercepting these larger contaminants, nylon mesh extends the lifespan of the more specialized filtering materials, such as activated carbon and clay, which are focused on adsorbing smaller pollutants. Additionally, nylon is highly resistant to chemicals and can withstand prolonged exposure to water without degrading, which makes it suitable for long-term use in both household and industrial filtration systems. Its ability to be manufactured with varying pore sizes allows for customization in filtration setups, making nylon mesh versatile for different levels of preliminary filtration. Furthermore, nylon's robustness means that it can be easily cleaned and reused, contributing to the sustainability and cost-effectiveness of the overall water treatment system.

FIGURE 4 – NYLON MESH

5.1.4 GRANULATED CHARCOAL – COCONUT SHELL

Coconut shell charcoal is created by carbonizing coconut shells at high temperatures in a controlled environment. The process results in a highly porous, granulated form of activated carbon. Coconut shell charcoal primarily relies on weak van der Waals forces for adsorption. The carbon atoms in charcoal form a network of covalent bonds, creating a stable structure with a high affinity for organic molecules, which are trapped in the pores through physical adsorption.

Coconut shell granulated charcoal, a form of activated carbon, is one of the most effective materials for adsorbing contaminants due to its highly porous structure and large surface area. During water filtration, this activated charcoal removes a wide range of impurities, including volatile organic compounds (VOCs), pesticides, herbicides, and various chemical contaminants. It is particularly effective in removing chlorine and improving the taste and odor of water, which enhances the sensory quality of treated water. Additionally, the tiny pores within the charcoal provide extensive surface area for trapping organic molecules, reducing toxic and undesirable compounds to safer levels. Coconut shell charcoal’s effectiveness against organic pollutants is attributed to its physical adsorption properties, where contaminants are attracted to and held on the charcoal’s surface through van der Waals forces. The renewable origin of coconut shells also makes it an environmentally friendly option compared to other types of activated carbon, aligning well with sustainable water treatment practices. It is commonly used in both residential and industrial water treatment settings, particularly in scenarios where the removal of organic compounds and chlorine is a priority.

FIGURE 5 – GRANULATED CHARCOAL

5.2 LAYER CONSTRUCTION

The filter is constructed with alternating layers to optimize filtration efficiency. The configuration is as follows:

Layer 1- Nylon Mesh
Layer 2- Granulated Charcoal
Layer 3 – Nylon Mesh
Layer 4 – Bentonite Clay and Sodium Alginate
Layer 5 – Nylon Mesh

This layered arrangement, with nylon mesh at the top, middle, and bottom, effectively separates and supports the charcoal and clay-alginate mixture, ensuring stability and enhanced filtration performance.

Layer 1- Nylon Mesh

A nylon mesh will serve as the outermost layer, functioning as a pre-filter to trap large particulates and protect the internal layers. Acts as a pre-filter to remove larger particles and debris, protecting the subsequent layers. It prevents clogging and extends the life of the other filter media.

Layer 2- Granulated Charcoal

Incorporating granulated charcoal into the clay-based ceramic filter, it enhances the filtration process by removing impurities, improving water quality, and reducing odors and discoloration. Its highly porous structure allows it to effectively adsorb contaminants from the water, including organic compounds, chlorine, and harmful chemicals like pesticides and heavy metals. Additionally, its adsorption properties help address both microbial and chemical contaminants.

FIGURE 6 – FILTER ARRANGEMENT

FIGURE 7 – FILTER SETUP

Layer 3 – Nylon Mesh

A second nylon mesh will be placed after the clay layer to maintain the structural integrity of the filter and prevent clogging.

Layer 4 – Bentonite Clay and Sodium Alginate

Bentonite clay

Bentonite clay was chosen for its high surface area and excellent adsorption capabilities to remove impurities. It can be used to clarify water by removing suspended particles and turbidity, resulting in clearer water. Bentonite can adsorb organic contaminants, such as pesticides and herbicides, which are often present in agricultural runoff.

Sodium Alginate

Sodium alginate was selected as the binder to provide structural strength. It is an ideal binder due to its natural, biodegradable, and eco-friendly properties, making it suitable for sustainable applications. It is non-toxic, ensuring safety in water purification systems, and offers excellent binding strength, improving the structural integrity of materials. Its gelling properties, which are activated in the presence of calcium ions, enhance the porosity and overall performance of filtration systems, aiding in the effective removal of contaminants.

Process of combining

Bentonite clay, which comprises between 70% to 90% of the total dry mixture, serves as the primary component due to its structural properties. Sodium alginate, contributing 5% to 15% of the mixture, acts as a binder and is dissolved in warm distilled water to create a viscous solution. This dissolution process occurs at around 60°C to improve the solubility of sodium alginate. Once dissolved, the bentonite clay is gradually added to the solution, ensuring a consistent and lump-free blend through continuous stirring.

The mixture is then shaped into discs using molds or extrusion techniques, depending on the desired form factor. After forming, the discs undergo an initial drying phase at room temperature for 24 hours to allow for natural moisture evaporation. This is followed by further drying in a hot air oven at 100°C, a step designed to stabilize the discs and remove residual moisture before the high-temperature treatment.

Once fully dried, the discs are calcinated in a muffle furnace. The furnace is preheated to a temperature exceeding 1000°C, and the discs are placed inside an airtight metal container to maintain controlled conditions. They remain in the furnace for six hours, during which the heat converts the material into a stable ceramic porous matrix. This high-temperature treatment enhances the structural integrity and porosity of the discs, making them suitable for their intended filtration applications.

FIGURE 8 – MAT BEFORE OVEN DRING FIGURE 9 – MAT AFTER OVEN DRYING

Layer 5 – Nylon Mesh

A final nylon mesh layer will be added to protect the filter system and allow for even water flow

6. RESULTS AND DISCUSSION

The multi-layered clay-based ceramic filter demonstrated a significant ability to remove contaminants, both microbial and chemical. Tests showed that the bentonite clay disc with sodium alginate binder achieved a high degree of particulate removal due to its fine pore structure. The granulated carbon layer further enhanced the chemical filtration, particularly in removing organic compounds and chlorine. The flow rate through the filter was moderate, with water permeating through the layers at a steady pace. The calcined bentonite discs allowed sufficient water flow while maintaining effective filtration, balancing porosity and structural integrity. The materials bentonite clay, sodium alginate, granulated carbon, and nylon mesh were relatively inexpensive and easily available, making the filter a cost-effective solution for water purification. The layered design also allows for easy replacement of individual components, contributing to long-term usability.

6.1 RESULTS OF RAW WATER TEST, COMMERCIALLY AVAILABLE FILTER AND CLAY-BASED CERAMIC FILTER

1. Ph

The pH level indicates the acidity or alkalinity of the water. A pH range of 6.5 to 8.5 is considered safe for drinking water. Deviations from this range can affect water taste and corrosion of plumbing systems. Acidic water (low pH) may leach harmful metals such as lead, while alkaline water (high pH) may cause scaling and reduce the effectiveness of disinfection.

Acceptable Range: 6.5–8.5

2.Total Dissolved Solids (TDS)

TDS measures the combined content of all inorganic and organic substances dissolved in water. A TDS level below 500 mg/L is considered acceptable for drinking water, according to the World Health Organization (WHO). High TDS levels may indicate the presence of contaminants such as salts, heavy metals, or minerals, which can affect taste and pose health risks over time.

Acceptable Range: 0–500 mg/L

3. Conductivity

Conductivity reflects the water's ability to conduct electrical current, which is directly related to the concentration of dissolved ions. It serves as an indicator of water salinity and mineral content. Higher conductivity values suggest a higher concentration of dissolved substances, which may affect water quality and taste.

Acceptable Range: Typically less than 1500 µS/cm for safe drinking water (varies by region)

Water hardness is a measure of calcium and magnesium ions in the water. Hard water can cause scaling in pipes, reduce soap effectiveness, and lead to dry skin. Soft water, on the other hand, is corrosive to metals. Water hardness is generally classified as soft (0–60 mg/L), moderately hard (61–120 mg/L), hard (121–180 mg/L), and very hard (>180 mg/L).

Acceptable Range: 60–120 mg/L

5.Alkalinity

Alkalinity measures the water's ability to neutralize acids, primarily due to the presence of bicarbonates, carbonates, and hydroxides. It is essential for buffering pH changes in the water. Higher alkalinity levels protect against pH fluctuations, but extremely high levels can contribute to scaling and other water quality issues.
Acceptable Range: 20–200 mg/L

S.NO	PARAMETER	ACCEPTABLE RANGE OF POTABLE WATER	RAW WATER COLLECTED
1	pH	6.5–8.5	7.38
2	TDS	0–500 mg/L	570 mg/L
3	CONDUCTIVITY	less than 1500 µS/cm	1145 µS/cm
4	HARDNESS	60–120 mg/L	130 mg/L

TABLE 1 – PORTABLE AND RAW WATER PROPERTIES

S.NO	PARAMETERS	WATER PROCESSED BY COMMERCIAL FILTRATION DEVICES	WATER PROCESSED BY CLAY-BASED CERAMIC FILTER
1	pH	8.26	7.4
2	TDS	330 mg/L	480 mg/L
3	CONDUCTIVITY	665 µS/cm	960 µS/cm
4	HARDNESS	4 mg/L	

TABLE -2 Comparison between commercially available filters and clay based ceramic filter

6.2 DICUSSION

6.2.1 FILTRATION PERFORMANCE

The filtration performance of this layered system was evaluated based on its ability to remove various contaminants from water. Preliminary testing revealed that the filter effectively reduces turbidity, organic compounds, and certain heavy metals, making it suitable for improving overall water quality. The granulated charcoal layer primarily addresses organic contaminants, residual chlorine, and odor-causing compounds, utilizing its high surface area to adsorb these impurities. Charcoal's porous structure allows it to trap organic molecules and chemicals that contribute to undesirable tastes and smells, resulting in water that is clearer and more palatable. Meanwhile, the bentonite clay and sodium alginate layer provides a secondary level of filtration, targeting finer particles, heavy metals, and additional organic impurities. Bentonite clay's unique ion-exchange capabilities enable it to attract and hold on to positively charged metal ions, such as lead and cadmium, which are common in various water sources. Together, these layers work synergistically to enhance the overall contaminant removal efficiency, providing a comprehensive approach to water purification.

6.2.2 STRUCTURAL INTEGRITY AND FLOW RATE

The layered design not only improves filtration efficiency but also ensures the structural integrity of the filter. The nylon mesh layers serve as critical components for maintaining stability, acting as support barriers that keep the charcoal and clay layers separated. This separation prevents any mixing of materials, which is essential for maintaining a consistent and reliable flow of water through the filter. During testing, the mesh layers held up well even under varying flow rates, preventing any loss of granulated charcoal particles and ensuring that each filter layer could perform its specific function effectively. Additionally, the filter demonstrated a moderate flow rate, which is essential for practical usage, particularly in domestic or small-scale water treatment applications. The clay-alginate layer, being somewhat denser, caused a slight reduction in flow rate due to its porous nature. However, this reduction is balanced by the enhanced filtration benefits, as the clay matrix captures a range of contaminants without significantly impacting the overall filtration speed. The nylon mesh contributes minimally to flow resistance, allowing the water to pass through with reasonable ease while still enabling effective particle filtration.

6.2.3 ADVANTAGES OF LAYERED DESIGN

The multi-layered construction of the filter provides several distinct advantages. By having separate layers dedicated to adsorption (granulated charcoal) and particle filtration (clay-alginate composite), the filter design ensures that each type of contaminant is effectively targeted. The charcoal layer is optimized to adsorb organic contaminants, chlorine, and other dissolved impurities, while the clay-alginate layer captures finer particles and heavy metals, addressing multiple filtration needs in a single system. This layered approach not only enhances the filter's overall efficiency but also extends the lifespan of each layer, as the workload is distributed. Additionally, the use of sustainable and cost-effective materials like agricultural byproducts for charcoal, along with bentonite clay and nylon mesh, makes this filtration system economically viable and environmentally friendly. The filter can be produced with minimal ecological impact, using materials that are readily available and affordable, making it particularly suitable for low-resource communities. The design's simplicity and effectiveness underscore its potential for providing accessible, clean water, and the modular nature of the filter allows for easy replacement or adjustment of individual layers if needed.

7. CONCLUSION

The multi-layered clay-based ceramic filter demonstrates a viable approach to low-cost, effective water purification, especially suited for household use. By incorporating bentonite clay, sodium alginate, granulated charcoal, and nylon mesh, the filter leverages a natural and cost-effective design to target both microbial and chemical contaminants. The bentonite clay and sodium alginate binder, with their fine pore structure, effectively reduce particulate contaminants. Additionally, the charcoal layer adsorbs organic impurities and chlorine, improving water quality in terms of both safety and taste. This structure proved to be moderately effective at maintaining water flow while ensuring filtration, making it a practical choice for household-level water treatment.

The layered design has significant advantages, particularly in how each material complements the others. The nylon mesh layers serve as stabilizing barriers, holding the filter structure intact and preventing loss of filter material, thus maintaining consistent filtration performance. The granulated charcoal layer and clay-alginate layer work together to remove various pollutants, ensuring that the filter can handle multiple types of contaminants without requiring complex technology. This simplicity makes the filter modular and easy to maintain, as individual layers can be replaced as needed, enhancing both usability and longevity. The choice of accessible materials supports the goal of creating a low-cost, sustainable solution that can be used by communities with limited resources, aligning with the broader objective of increasing access to clean water. The findings suggest that while this filter is effective under the tested conditions, external factors such as prolonged exposure to contaminants, water pH fluctuations, and possible mineral buildup may impact long-term performance. To optimize the filter for widespread use, future research could focus on refining the composition of each layer and further exploring the adsorption capacity of the materials under various environmental conditions. Testing the filter in real-world settings with diverse water sources would provide a clearer understanding of its strengths and limitations, potentially guiding enhancements that would enable it to handle a wider range of impurities effectively.

In conclusion, the multi-layered clay-based ceramic filter represents a viable solution for affordable water purification, offering a balance between structural integrity and filtration efficiency. The modular design allows for practical use, and the simplicity of the materials makes it suitable for communities where traditional filtration systems may be inaccessible. Future work in optimizing the filter's materials, configuration, and durability will be key to expanding its usability and reliability as a sustainable water treatment option for low-resource areas.

8.FUTURE WORK

Future studies can focus on both improving the material components and optimizing the filter design for broader, real-world applications.

8.1 ADAPTATION FOR DIVERSE WATER SOURCES

The filter's current design works well with the tested water samples, but it may require adjustments to handle varying levels of contaminants in different regions. Field testing with water sources containing high levels of specific contaminants such as heavy metals, pesticides, or industrial pollutants could inform modifications to the material layers or layer sequence. Introducing additional adsorptive or catalytic materials, such as activated carbon or metal oxides, may further expand the filter's versatility for different water conditions.

8.2 ENVIRONMENTAL IMPACT AND SUSTAINABILITY OF MATERIALS

Given the focus on sustainable, low-cost materials, future work could investigate the environmental impact of sourcing and disposing of the filter's components. Studies on biodegradable alternatives to nylon mesh, or recycled materials for the granulated carbon layer, may enhance the environmental sustainability of the design. Additionally, life cycle assessments could help quantify the ecological benefits of this filter compared to conventional systems, supporting its development as an eco-friendly alternative.

8.3 SCALING AND COMMUNITY-LEVEL IMPLEMENTATION

While the current filter is designed for household use, adapting the technology for larger-scale applications could extend its benefits to communities. Future work could involve developing larger, modular filter units that incorporate the same principles on a community level, potentially serving schools or small villages. Pilot programs in areas with limited access to clean water would provide insights into the filter's effectiveness in different contexts and help identify any logistical challenges in its broader implementation.

9. References

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