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Development of A Multi-Layer Herbal Water Filter for Bacterial Removal

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Abstract:
This study comprehensively evaluated the performance of various low-cost and locally available adsorbents for iron removal from water, focusing on their adsorption capacity, practical applicability, and limitations. Adsorption has emerged as the most effective, economical, and user-friendly technique for iron removal, offering advantages like longer filtration runs, shorter ripening times, and improved filtrate quality, though requiring periodic backwashing to maintain efficiency. Sand, as the most abundant and cost-effective adsorbent, exhibited excellent iron removal efficiency and high filtration rates, but biofilm formation during prolonged usage necessitated regular maintenance. Tulsi leaf powder, despite its medicinal value, demonstrated poor adsorption performance for iron removal, attributed to its limited surface area and lack of functional groups, making it unsuitable for practical applications. Untreated neem leaf powder showed minimal effectiveness; however, when modified by mixing with chuna ($Ca(OH)_2$), it displayed improved adsorption efficiency due to enhanced surface reactivity, albeit at the expense of reduced filtration rate. Aluminium hydroxide-coated rice husk ash (RHA) emerged as a promising adsorbent, where the coating increased surface roughness and provided additional active sites for effective iron adsorption. Sugarcane bagasse, although an abundant agricultural waste, exhibited limited iron removal capacity due to larger particle sizes and lower specific surface area, indicating the potential for performance improvement through finer grinding. The study emphasizes the importance of selecting and modifying locally available natural materials for sustainable and efficient iron removal, while also highlighting the need for further research into particle size optimization, surface modification techniques, and regeneration methods to enhance long-term performance.

Keywords: Herbal Water Filter, Bacterial Removal, Bioactive Compounds, Sustainable Filtration, Water Purification.

I. INTRODUCTION

Access to safe and clean drinking water is a fundamental human right and a cornerstone of public health. However, in many developing and rural regions across the globe, including parts of India, access to microbiologically safe water remains a persistent challenge. Contamination of water sources with pathogenic bacteria such as Escherichia coli, Salmonella, and Vibrio cholerae leads to the spread of waterborne diseases like diarrhea, cholera, typhoid, and dysentery, contributing significantly to morbidity and mortality rates, particularly among children under five. According to the World Health Organization (WHO), nearly 2.2 billion people globally lack access to safe drinking water services, and a significant portion of this burden falls on marginalized communities with limited access to water treatment facilities. Conventional water purification technologies, such as chlorination, UV disinfection, and membrane filtration, although effective, often involve high capital and operational costs, dependence on electricity or chemicals, and regular maintenance—factors that make them unsuitable for widespread deployment in rural or low-resource settings. In contrast, the use of natural, herbal materials with inherent antimicrobial properties offers a promising, sustainable, and cost-effective alternative for water purification. Many plant-based materials like neem (Azadirachta indica), tulsi (Ocimum sanctum), and moringa (Moringa oleifera) have been extensively documented in traditional medicine systems for their antibacterial, antifungal, and antiviral properties. These materials are widely available, renewable, and biodegradable, making them an attractive option for developing low-cost, eco-friendly water filtration solutions. The concept of a multi-layer filter system integrates physical filtration through sand, gravel, and charcoal, with herbal antibacterial action, offering a holistic approach to water treatment that is both effective and sustainable. This study aims to harness the antibacterial potential of herbal materials to develop a multi-layer herbal filter that can significantly reduce bacterial load in contaminated water, providing a practical solution for improving water quality in underserved regions.

II. PROPOSED METHODOLOGY

2.1 MATERIALS USED

In the proposed design of the model, the prefabricated water of known iron concentration was passed through the inlet pipe above. Inside the bottle cylinder, different adsorption media of specified thickness were placed with proper gravel support. Then after filtration, the filtered water was collected through the outlet part in a beaker and the final concentration was measured in the Atomic Absorption Spectrometer (AAS).The rate of filtration was noted and for each adsorption media, three or four samples were tested and average concentration was considered for analyzing filter effectiveness.

Here we have manufactured a simple cylindrical filtration bottle with the Following dimension

- Length=15 cm.
- Internal diameter = 7.3 cm.
- Base and top is covered with a sponge of 2 cm thickness.
- From the base, outlet pipe is extended to collect water with a tap to regulate filtered water.
- Top of the cylinder filter bottle was covered with a cap of 0.5mm thickness.
- A hole of 12mm diameter was made to connect with the inlet pipe.

Materials:

1. Plain Sand
2. Tulsi Leaves Powder
3. Neem Leaves Powder
4. Rice Husk
5. Sugarcane Bagasse

2.1.1 Plain Sand

Sand is also used in the water filter as a filtering agent for the removal of the suspended particles in the untreated and waste water sample. Fine sand and gravel are naturally occurring glacial deposits high in silica content and low in soluble calcium, magnesium and iron compounds are very useful in sedimentation removal. But here the media is used for iron removal from drinking water. Here for the experimentation plane sand passing through 600 Micron IS sieve were used.

[Fig.2.1: Fine Aggregate 4.75 mm Size]

Sand of size 4.75 mm was sieved from the 4.75 mm sieve using manual method. Sand being a very good filtering agent is very useful in the filtering water from its impurities. Sand filters are used as a step in the water treatment process of water purification. Sand filtration is used for the removal of suspended matter, as well as floating and sinkable particles. The wastewater flows vertically through a fine bed of sand and/or gravel. Particles are removed by way of absorption or physical encapsulation. If there is excessive pressure loss on the filter, it must be rinsed. A distinction can be made between continuous and discontinuous filters. In continuous filters (often upward-flowing filters), the polluted sand is removed, rinsed and re-used continuously, without interrupting the filtration process.

Discontinuous filters (often downward-flowing filters) are stopped, and a rinse takes place in the opposite direction. Air bubbles are blown into the sand bed to make it swirl around. Filtered water then flows through the filter bed.. The polluted matter is released and flows away along with the rinse water. The filtration process can then resume. The main benefit of a sand filter is the simple system which, in many cases, can be used to obtain considerable yields. A sand filter can be placed in various phases of water management - as a pre-treatment, as side-stream filtration and as a polishing filter. A sand filter often provides an effluent with potential for re-use. However, chemicals sometimes need to be added to improve the yield of the sand filter. A disadvantage of sand filtration is the rinse water that is created when the sand filter is cleaned. This heavily polluted water must be treated and disposed of. To limit the load on the filter, a preliminary sedimentation step is implemented for heavily loaded wastewaters (a lot of suspended and sinkable matter). This helps to avoid repetitive re-rinsing of the filter. Discontinuous sand filters are often placed in parallel set-up in order to keep the process running when one of the filters is being cleaned. Sand filters are used in various sectors and processes, where far-reaching removal of suspended matter from water or wastewater is required. Sectors where sand filtration is implemented include drinking water production, swimming pools, car washes, groundwater treatment, RWZI, slaughterhouses, fruit and vegetable processing industry, drinks, food industry, surface treatment of metals, Cooling water production, drinking water preparation, pre-filtration in active carbon treatments and membrane systems, and the filtration of swimming pool water.

2.1.2 Tulsi Leaves Powder

The scientific name of Tulsi is Ocimum Tenuiflorum, Holy basil or Ocimum Sanctum Linn. Leaves are dropped in drinking water for purification and for medication. In all Hindu temples, water mixed with Tulsi leaves are offered to devotees every day since the herbal plant is an excellent medicinal plant found all over India and is considered sacred. The leaves, seeds and root of this plant have been used in ayurvedic medicine. Chemical composition is highly complex, containing many nutrients and other biological active compounds. It can remove fluoride levels in drinking water. Recently it's used have been found in fighting fluorosis.

[Fig.2.2: Tulsi Leaves]

They are mainly two types of Tulsi. First is Shyam Tulsi having dark coloured stems and leaves and second Rama Tulsi have whitish stem and green leaves. Here Tulsi leaves powder was used for removal of iron from water. Tulsi leaf powder was purchased from the local market of Wardha.3.1.3 Neem Leaves Powder The scientific name of neem is Azadirachta indica. Neem leaf powder was purchased from the local markets of Wardha. Neem leaves powder was taken for removal of toxic element from water. Here, two methods were adopted. First method was only neem powder used but second method was mixed thoroughly with calcium hydroxide (chuna) 1:10 ratio. Chemical formula of calcium hydroxide is Ca(OH)2. It is springily soluble in water and forms a solution called lime water.

[Fig.2.3: Neem Leaves]

Neem leaf is used for leprosy, eye disorders, bloody nose, intestinal worms, stomach upset, loss of appetite, skin ulcers, diseases of the heart and blood vessels (cardiovascular disease), fever, diabetes, gum disease (gingivitis), and liver problems. The leaf is also used for birth control and to cause abortions. The bark is used for malaria, stomach and intestinal ulcers, skin diseases, pain, and fever. The flower is used for reducing bile, controlling phlegm, and treating intestinal worms. The fruit is used for hemorrhoids, intestinal worms, urinary tract disorders, bloody nose, phlegm, eye disorders, diabetes, wounds, and leprosy. Neem twigs are used for cough, asthma, hemorrhoids, intestinal worms, low sperm levels, urinary disorders, and diabetes. People in the tropics sometimes chew neem twigs instead of using toothbrushes, but this can cause illness; neem twigs are often contaminated with fungi within 2 weeks of harvest and should be avoided. The seed and seed oil are used for leprosy and intestinal worms. They are also used for birth control and to cause abortions. The stem, root bark, and fruit are used as a tonic and astringent. Some people apply neem directly to the skin to treat head lice, skin diseases, wounds, and skin ulcers; as a mosquito repellent; and as a skin softener. The leaf extract is used to reduce tooth plaque and to treat lice. Neem contains chemicals that might help reduce blood sugar levels, heal ulcers in the digestive tract, prevent pregnancy, kill bacteria, and prevent plaque from forming in the mouth. Drinking neem juice first thing every morning will help to relieve your digestive issues. Its astringent properties reduce the formation of gas, and thus help with bringing down bloating, flatulence and abdominal issues. This potent drink also helps to get rid of constipation and other problems. They are most effective when consumed in the form of new leaves and on an empty stomach in the morning. This is to ensure that the nutrients of the neem are absorbed fully without being diluted with other food or drinks.

2.1.4 Rice Husk

Rice husk are the hard protecting covering of grains of rice. Around 20% of the paddy weight is Husk. Scientific name for rice is oryza sativa. The chemical composition of Rise husk is similar to that of many common organic fibres and it contains of cellulose 40-50%, lignin 25- 30%, ash 15-20% and moisture 8-15 %(by Hwang and Chandra 1997). After burning, most evaporable components are slowly lost and the silicates are left. Low value agricultural by rice husk can be made purification of water. Rice husk was collected from a local mill in Wardha, Maharashtra. The rice husk was sieved in the mesh in the range of 600 micron in order to increase its surface area. This was used as and adsorbent along with sand as a base material. Rice hulls (or rice husks) are the hard protecting coverings of grains of rice. In addition to protecting rice during the growing season, rice hulls can be put to use as building material, fertilizer, insulation material, or fuel. Rice hulls are part of the chaff of the rice.

2.1.5 Sugarcane Bagasse

Bagasse is sugarcane fiber waste left after juice extraction. Bagasse contains mainly cellulose, hemi cellulose, pentosans, lignin, sugars, wax and minerals. Sugarcane bagasse was collected from Wardha, Maharashtra. It was first washed thoroughly with tap water and again washed with distilled water to remove dirt and metallic impurities and after which it was dried in the oven at about 105 degree Celsius for 3 hours and 24 hours dried in sun light. The dried bagasse was grounded and made like fine particles to increase its surface area and 0.1M HCL was added in 100gram bagasse. This was used as an adsorbent along with sand as a base material.

2.2 METHODOLOGY

For removal of iron broadly four herbal materials had been used in the experiments i.e. Tulsi leaves powder, neem leaves powder, rice husk and sugarcane bagasse has been adopted. The following adsorption media had been experimented here for removal of iron from drinking water.

Procedure for preparation of Standard Solution:

- Standard solution of the toxic element will be prepared by mixing toxic element with the water.
- Filter model will prepared consisting sponge, sand and different herbals.
- Then standard solution will pass through the filter model and final solution obtained is the purified solution.
- Finally the content of toxic element remaining will be calculated.
- Toxic element used was iron.
- First made the iron 1000ppm standard solution.
- 3.5713 g of ferric sulphate (Fe2 (So4)3) was dissolved in 1 L of water to make 1000ppm of iron solution as 1000 ppm = (1000 mg / L Fe) * (1 g Fe / 1000 mg Fe)* (398.88 g Fe/2*55.845g Fe) *X* 1 L = 3.5713 grams. For 10ppm of iron mixed with 500ml of water, 5ml of 1000ppm solution because 1000*x=10*500 => x=5ml.

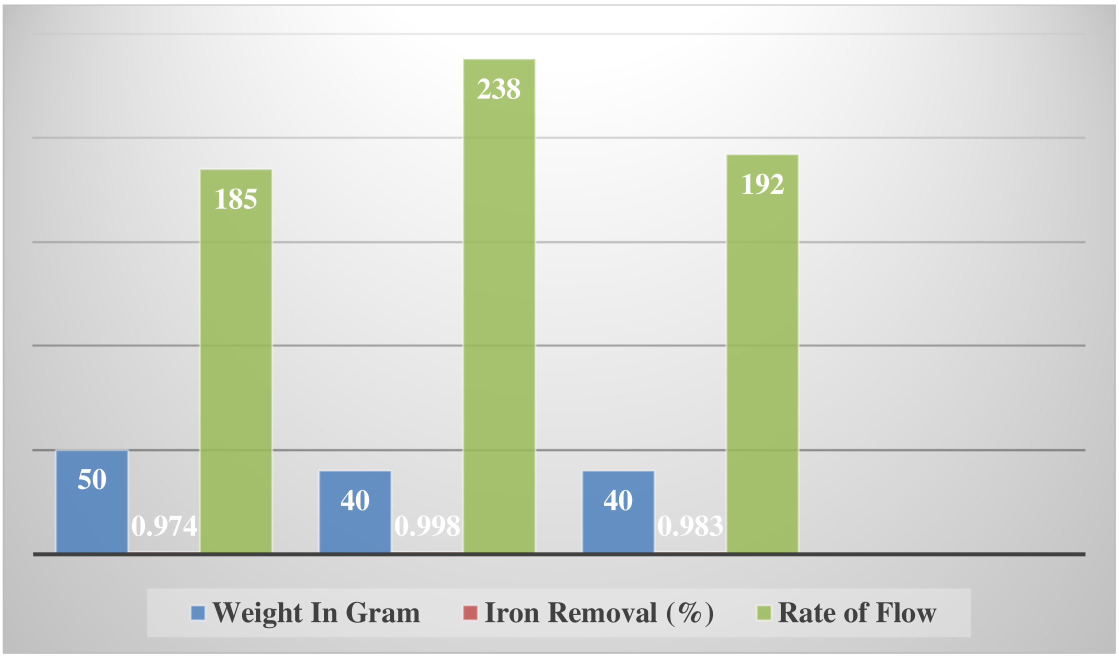
III. RESULTS & DISCUSSION

3.1 RESULTS OF FILTRATION IN TULSI LEAVES POWDER

The results obtained from the experimental study focusing on the removal of iron using Tulsi leaf powder as an adsorbent, as elaborated in the methodology section, demonstrate the potential application of this herbal material in water purification processes. The experimental setup involved passing water contaminated with iron through a filter bed containing Tulsi powder, and both the rate of filtration and the efficiency of iron removal were carefully measured and recorded. The initial concentration of iron in the water sample was 1.053 ppm, which served as the baseline for assessing the treatment performance. Among the three samples tested, Sample 1 exhibited the highest iron removal efficiency, achieving the best reduction in iron concentration when compared to the other samples. However, this higher removal efficiency was accompanied by a relatively lower rate of filtration, suggesting that the water flow slowed down due to increased retention time or denser packing of the adsorbent material, which allowed for more effective adsorption of iron ions. This trade-off between filtration rate and removal efficiency highlights an important consideration in designing filtration systems — balancing adequate contact time with acceptable flow rates for practical use. The detailed numerical data on the initial and final iron concentrations, removal percentages, and filtration rates are compiled in Table 3.1, which provides a clear quantitative overview of the experiment. Moreover, Figure 3.1 presents a graphical representation of these results, visually illustrating the superior performance of Sample 1 in terms of iron removal and the associated filtration characteristics. These findings suggest that Tulsi leaf powder can be a viable low-cost, eco-friendly adsorbent for reducing iron contamination in water. Nonetheless, the reduced filtration rate indicates that optimization of parameters such as adsorbent particle size, packing density, and flow rate may be necessary to enhance the practical applicability of this treatment method. Overall, the study provides valuable insight into the effectiveness of Tulsi powder as a natural adsorbent, supporting its potential use in sustainable water treatment technologies, especially in regions where access to advanced treatment infrastructure is limited.

Table 3.1 Results of filtration in Tulsi leaves powder

Sample No	Thickness of Sand Layer (in cm)	Amount of Tulsi Leaf powder (gram)	Initial iron content (ppm)	Final iron content (ppm)	Rate of filtration (ml/min)
1	Top layer=2cm Bottom=3cm	50 gm	1.053	0.974	185
2	Top layer and Bottom=2cm	40 gm	1.053	0.998	238
3	Top layer and bottom=3cm	40 gm	1.053	0.983	192



[Fig.3.1: Iron removal in Tulsi leaves]

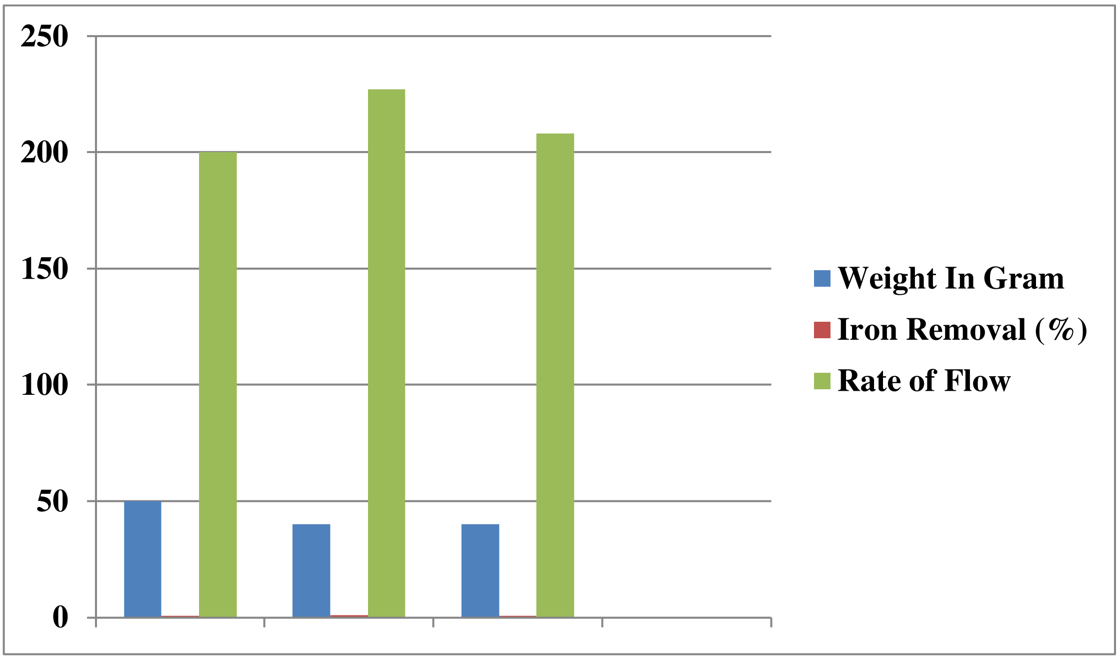
3.2 RESULTS OF FILTRATION IN NEEM LEAVES POWDER

3.2.1 The results obtained from the experimental analysis for the removal of iron using Neem leaf powder as an adsorbent, as detailed in the methodology section, showcase the potential of this natural, herbal material in water treatment applications. The performance of Neem leaf powder was evaluated by conducting batch filtration experiments, and the rate of filtration, as well as the iron removal efficiency, were systematically measured and recorded. The initial iron concentration in the contaminated water sample was 1.317 ppm, which served as the baseline for assessing the performance of the adsorbent. Among the three samples tested, Sample 3 exhibited the highest iron removal efficiency, achieving an iron removal percentage of 47%, which was notably higher compared to the other two samples. However, it is important to highlight that while Sample 3 achieved the best removal performance, the corresponding filtration rate in this case was relatively lower, indicating a trade-off between contact time and adsorption capacity. This suggests that longer retention time of water within the Neem leaf powder filter bed may enhance adsorption and improve contaminant removal. Additionally, a comparative analysis between Neem leaf powder and Tulsi leaf powder revealed that Neem leaf powder consistently demonstrated better removal efficiency, indicating its superior adsorption potential for iron ions in water. The detailed numerical data, including filtration rates, initial and final concentrations, and percentage iron removal for each sample, are comprehensively tabulated in Table 3.2.1, providing a clear and structured overview of the experimental findings. Furthermore, the trends and variations in the removal efficiencies across different samples, as well as the corresponding filtration rates, are graphically presented in Figure 3.2.1, offering a visual interpretation of the data. These findings underscore the importance of considering both removal efficiency and filtration rates when evaluating the performance of adsorbent materials. While Neem leaf powder shows promising results for iron removal, further research could explore optimizing the filter design, controlling the flow rate, and combining Neem leaf powder with other adsorbents or coagulants to enhance overall system performance.

Table 3.2.1 Results of filtration in Neem leaves powder

Sample No	Thickness of Sand Layer (in cm)	Amount of Neem Leaf powder (gram)	Initial iron content (ppm)	Final iron content (ppm)	Rate of filtration (ml/min)
1	Top layer=2cm	50 gm	1.317	0.710	200

	Bottom=3cm				
2	Top layer and Bottom=2cm	40 gm	1.317	0.890	227
3	Top layer and bottom=3cm	40 gm	1.317	0.698	208

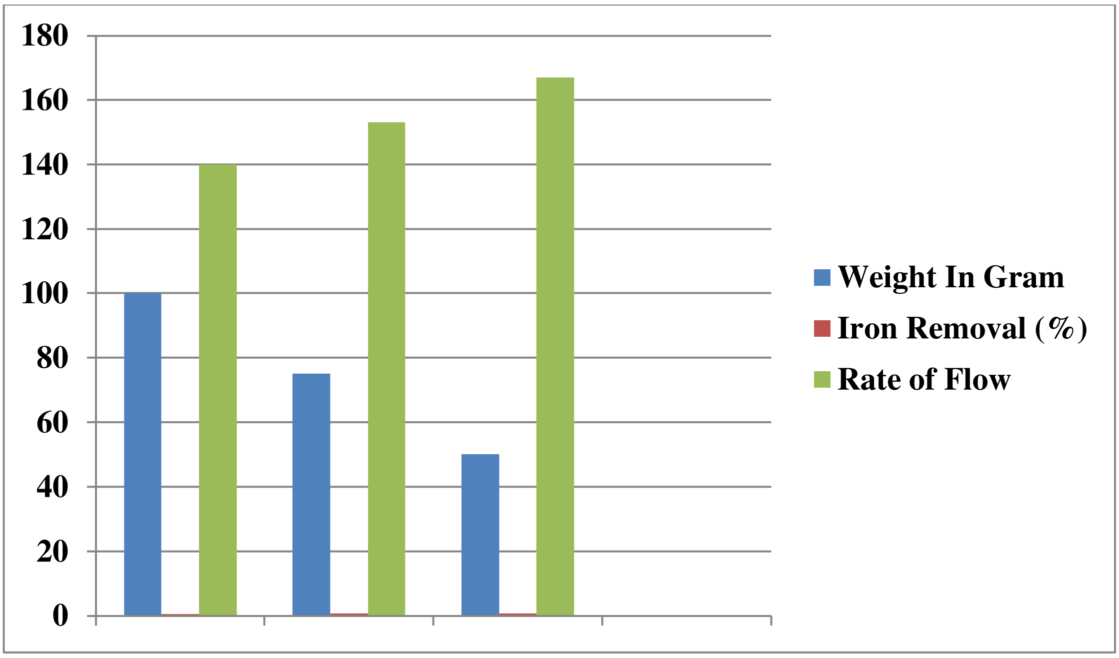


[Fig.3.2.1: Iron removal in Neem leaves]

3.2.2 The results obtained from the experimental evaluation of iron removal using a mixture of neem leaf powder and chuna ($Ca(OH)_2$), as described in the methodology section, demonstrate an enhanced performance compared to the use of neem leaf powder alone. The mixture was tested through batch filtration experiments where both the rate of filtration and the effectiveness in iron removal were carefully monitored and recorded. The initial concentration of iron in the water sample was measured at 1.317 ppm, which served as the baseline for comparison. Among the tested samples, Sample 1 exhibited the highest iron removal efficiency, achieving a remarkable reduction in iron concentration with a removal percentage significantly better than that obtained with neem leaf powder alone. However, this increased removal efficiency came with a trade-off, as the rate of filtration in this case was relatively lower, indicating slower flow rates likely due to the denser packing or increased adsorption interactions in the filter bed. The presence of chuna (calcium hydroxide) alongside neem leaf powder appears to improve the overall adsorption and precipitation mechanisms, facilitating more effective iron removal by possibly altering the pH and enhancing flocculation processes. This synergistic effect suggests that the combination of natural adsorbents with chemical additives can substantially improve treatment outcomes, particularly for iron-contaminated water. The detailed data on filtration rates, iron concentrations before and after treatment, and percentage removal for each sample are systematically presented in Table 3.2.2, providing quantitative clarity on the improvements achieved. Additionally, the graphical representation in Figure 3.2.2 visually depicts the comparative removal efficiencies and filtration rates across samples, highlighting the superior performance of the neem leaf powder and chuna mixture. These findings underline the practical importance of combining herbal adsorbents with alkaline agents to optimize contaminant removal, offering a promising, cost-effective, and environmentally friendly solution for water purification. Future studies may focus on refining the mixture proportions, investigating regeneration potential, and scaling up the system for field-level applications to provide safe and affordable drinking water in areas affected by iron contamination.

Table 3.2.2 Results of filtration in neem leaf powder mixed with chuna

Sample No	Thickness of Sand Layer (in cm)	Amount of Tulsi Leaf powder (gram)	Initial iron content (ppm)	Final iron content (ppm)	Rate of filtration (ml/min)
1	Bottom layer =2cm	100 gm	1.317	0.579	140
2	Bottom layer =2cm	75 gm	1.317	0.632	153
3	Bottom layer =2cm	50 gm	1.317	0.676	167



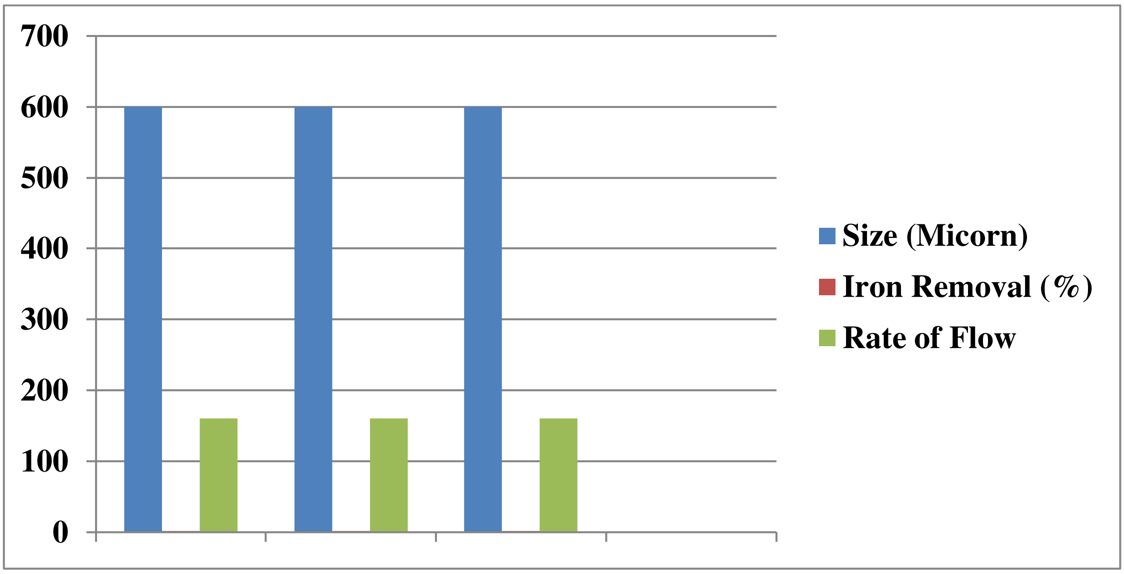
[Fig.3.2.2: Iron removal with Chuna mixed neem powder]

3.3 RESULTS OF FILTRATION IN RICE HUSK

The results obtained from the experimental study for the removal of iron using unmodified Rice Husk as an adsorbent, as detailed in the methodology, highlight the potential of this readily available agricultural by-product in addressing iron contamination in water. The filtration process was carried out under controlled conditions, and the performance was assessed based on the reduction in iron concentration after filtration. The initial concentration of iron in the water sample prior to treatment was measured at 2.378 ppm, which served as the baseline for evaluating the adsorptive effectiveness of the rice husk material. After the filtration process, the average iron concentration across three experimental runs was found to be reduced to 1.611 ppm, indicating a moderate reduction in iron content. This corresponds to an iron removal efficiency of approximately 32%, which, while lower compared to chemically modified adsorbents like $Al(OH)_3$-coated Rice Husk, still demonstrates the viability of raw rice husk as a natural, low-cost adsorbent for partial iron removal. The variations in filtration rates and removal efficiencies across the three samples were influenced by factors such as the porosity of the rice husk, the interaction time between the adsorbent and the contaminated water, and the saturation capacity of the rice husk fibers. The specific rate of filtration and the effectiveness in reducing iron concentrations were meticulously recorded and are presented in Table 3.3, providing a comprehensive quantitative assessment of the filtration performance. Furthermore, the corresponding trends and comparative results are illustrated in Figure 3.3, offering a clear visual representation of the data. The study of rice husk as an unmodified adsorbent for iron removal emphasizes its potential application in rural and resource-limited settings where high-tech water treatment options may not be feasible. However, it also underlines the limitations of unmodified rice husk, indicating that while it contributes to a reduction in iron content, further modifications or combinations with other adsorbents and coagulants may be necessary to achieve higher removal efficiencies and meet stringent water quality standards. Overall, the findings suggest that rice husk, even in its unmodified form, can serve as an eco-friendly, economical, and easily available material for preliminary treatment processes, providing a sustainable option for communities seeking to reduce iron contamination in water sources.

Table 3.3 Results of filtration in unmodified rice husk

Sample No	Size of RH (Micron)	Initial iron content (ppm)	Final iron content (ppm)	Rate of filtration (ml/min)
1	600	2.378	1.593	160
2	600	2.378	1.569	160
3	600	2.378	1.671	160



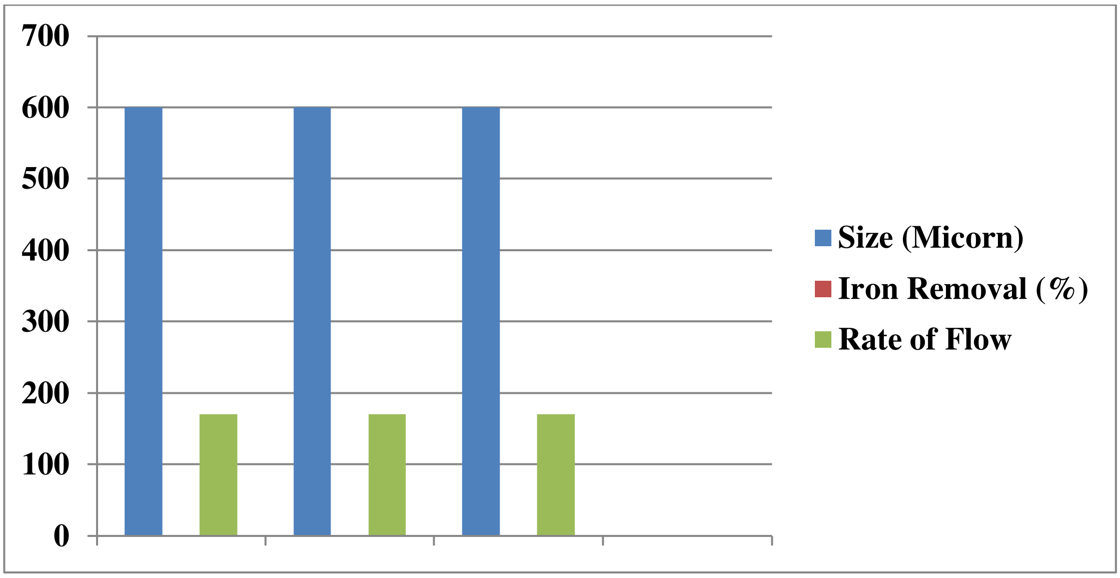
[Fig.3.3: Iron removal in Rice husk]

3.4 Al (OH) 3 COATED RICE HUSK ASH

The results obtained from the experimental investigation for the removal of iron using $Al(OH)_3$-coated Rice Husk Ash (RHA), as described in the methodology section, highlight the potential of chemically modified agricultural waste materials in water treatment applications, particularly for iron removal. The study aimed to assess the performance of $Al(OH)_3$-coated Rice Husk Ash in comparison to unmodified rice husk, and the results demonstrate a notable improvement in iron removal efficiency with the modified adsorbent. The experiments were conducted by passing water containing an initial iron concentration of 2.378 ppm through the filter media packed with $Al(OH)_3$-coated Rice Husk Ash. After filtration, the final iron concentrations across the three samples were recorded, and the average of these values yielded a significantly lower concentration of 0.562 ppm, indicating a substantial reduction in the iron content. This result corresponds to an impressive iron removal efficiency of approximately 76%, which is considerably higher than that observed with unmodified rice husk, as previously documented. The $Al(OH)_3$ modification appears to enhance the surface properties of the rice husk, increasing its adsorption capacity by providing additional active sites for iron ion binding, likely through mechanisms involving chemisorption and surface complexation. The filtration rate during the experiments was also measured and tabulated, providing insight into the practicality and efficiency of the system under realistic flow conditions. The detailed quantitative data, including initial and final concentrations, percentage removal, and filtration rates, are systematically presented in Table 3.4 for clarity and ease of reference. Furthermore, the graphical representation in Figure 3.4 illustrates the trend in iron removal across the different samples, offering a visual confirmation of the superior performance of $Al(OH)_3$-coated Rice Husk Ash compared to its unmodified counterpart. These findings reinforce the potential of value-added agricultural by-products like chemically modified rice husk ash as low-cost, sustainable, and effective adsorbents for the removal of iron and possibly other heavy metals from contaminated water sources. The study also emphasizes the need for further exploration into optimizing the coating process, assessing long-term stability and reusability of the adsorbent, and evaluating the scalability of such systems for practical deployment in water treatment facilities, especially in rural and underdeveloped regions where access to clean water remains a critical challenge.

Table 3.4 Results of filtration in modified rice husk

Sample No	Size of RH (Micron)	Initial iron content (ppm)	Final iron content (ppm)	Rate of filtration (ml/min)
1	600	2.378	0.469	170
2	600	2.378	0.563	170
3	600	2.378	0.656	170



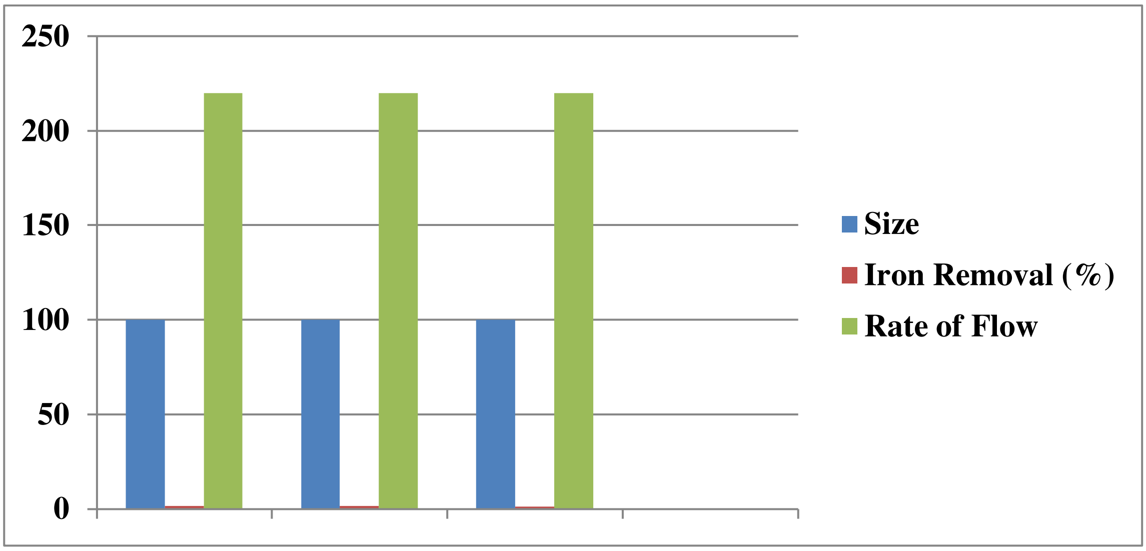
[Fig.3.4: Iron removal in Al (OH)3 coated rice husk]

3.5 RESULTS OF FILTRATION IN SUGARCANE BAGASSE

The results obtained from the experiments for the removal of iron using Sugarcane Bagasse (SB) as an adsorbent material, as outlined in the methodology section, reveal a significant potential of this agricultural waste by-product in water purification applications. The performance of Sugarcane Bagasse was evaluated by conducting batch filtration tests, and the efficiency in iron removal, along with the corresponding filtration rates, were systematically measured and recorded. The initial concentration of iron in the water sample before filtration was found to be 2.378 ppm, representing the baseline contaminant level against which the effectiveness of the filtration process was assessed. Upon treating the water using Sugarcane Bagasse, the iron concentration was reduced significantly across the three experimental runs. By averaging the concentration values obtained from these three samples, it was observed that the final iron concentration decreased to 1.394 ppm, demonstrating a clear reduction in the contaminant levels due to the adsorption capacity of Sugarcane Bagasse. This decrease in iron concentration reflects an average iron removal efficiency of approximately 40%, indicating that while Sugarcane Bagasse may not achieve complete removal, it still offers a valuable and sustainable solution for partial iron remediation, particularly in scenarios where low-cost, natural, and locally available materials are preferred. The variations in the filtration rate and corresponding iron removal percentages across the three samples can be attributed to factors such as differences in the packing density of the Sugarcane Bagasse within the filter column, the contact time between the adsorbent and the contaminated water, and the potential saturation of the adsorption sites during successive filtration cycles. The detailed results, including the rate of filtration, initial and final concentrations, and percentage removal efficiencies, are presented in Table 3.5 for a clear quantitative analysis. Additionally, Figure 3.5 visually represents the data through graphical illustrations, providing a comparative understanding of the filtration performance of Sugarcane Bagasse. These findings highlight the moderate yet promising capacity of Sugarcane Bagasse in removing iron from water sources, supporting its potential role as a cost-effective, eco-friendly material for rural and decentralized water treatment systems. However, it is also evident from the results that for achieving higher removal efficiencies, Sugarcane Bagasse might need to be used in combination with other adsorbents or pre-treatment methods, or it may require modifications to enhance its adsorption properties further. Nonetheless, the current study underlines the utility of agricultural waste materials like Sugarcane Bagasse in addressing the challenges of water contamination, especially in regions where conventional water treatment solutions may not be economically feasible or accessible.

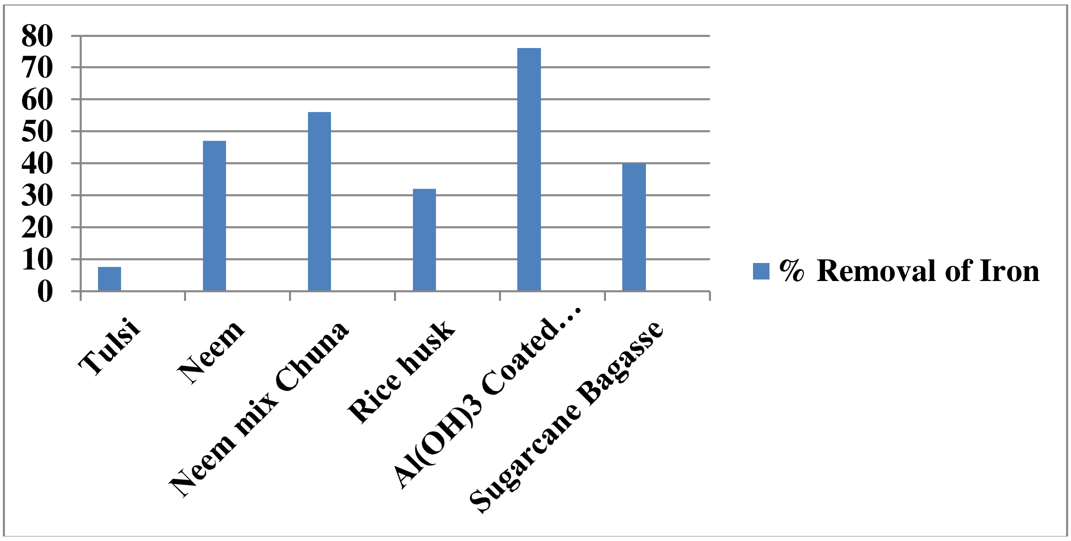
Table 3.5 Results of filtration in Sugarcane bagasse

Sample No	Amount of SB (gram)	Initial iron content (ppm)	Final iron content (ppm)	Rate of filtration (ml/min)
1	100	2.378	1.396	220
2	100	2.378	1.589	220
3	100	2.378	1.297	220



[Fig.3.5: Iron removal in Sugarcane Bagasse]

3.6 COMPARISON OF RESULTS



[Fig.3.6: Variation of % removal of irons with different herbal used]

1. In the case of Tulsi leaf powder as an adsorbent media, the experiment revealed that Sample 1 demonstrated the most effective result in reducing iron concentration. The iron removal efficiency achieved by Sample 1 using Tulsi leaf powder was 7.502%, indicating a relatively lower efficiency compared to other materials but still contributing towards the overall treatment process.
2. For the Neem leaf powder adsorbent, it was observed that Sample 3 exhibited the best performance in iron removal among the tested samples. The iron removal efficiency for Sample 3 using Neem leaf powder was 47.00%, highlighting the potential of Neem as a natural adsorbent with significant efficacy in iron adsorption.
3. When Neem leaf powder was used in combination with chuna (lime) as a coagulant, the efficiency of iron removal improved considerably. Among the tested samples, Sample 1 yielded the most favorable results, achieving an iron removal efficiency of 56%, showcasing the synergistic effect of Neem and chuna in enhancing the filtration process.
4. In the case of unmodified rice husk, the results demonstrated a moderate performance, with an average iron removal efficiency of 32% across the tested samples. However, when the rice husk was modified by coating it with aluminum hydroxide ($Al(OH)_3$), the iron removal efficiency improved substantially. The $Al(OH)_3$ coated rice husk achieved a significantly higher iron removal efficiency of 76%, indicating that chemical modification of natural materials can enhance their adsorption capacity for specific contaminants.
5. For the sugarcane bagasse used as an adsorbent, the experiment showed an average iron removal efficiency of 40% across all three tested samples. This suggests that sugarcane bagasse, an easily available agricultural by-product, can contribute effectively to the iron removal process when used in water filtration systems.

3.7 COST OF THE FILTER

In order to assess the economic feasibility of the proposed multi-layer herbal water filter for bacterial removal, it is essential to evaluate the material costs involved in its development. The cost analysis has been carried out by compiling a detailed chart that includes the prices of all the adsorbent media and materials used during the experimental phase, excluding labor, maintenance, and energy costs, which are assumed to be external operational factors and beyond the scope of this specific assessment. The primary objective of this cost evaluation is to determine the material expenses required for the fabrication of the filter, which is an important factor when considering the potential for scaling up the project for practical applications in rural or economically constrained settings. The materials used in the experiment include sand, Tulsi leaf powder, Neem leaf powder, rice husk, aluminum sulphate, sugarcane bagasse, and a plastic bottle to serve as the filter's outer casing. The costs were calculated based on the quantity of each material consumed during the experimental trials. Specifically, 0.9 kg of sand was utilized at a market rate of ₹15 per kg, contributing a total cost of ₹13.5. Tulsi leaf powder, known for its natural antibacterial properties, was used in a smaller quantity of 0.2 kg at a significantly higher rate of ₹300 per kg, amounting to a total of ₹60. Similarly, Neem leaf powder, also recognized for its potent antimicrobial properties, was incorporated at 0.3 kg, with a unit cost of ₹150 per kg, resulting in a total expenditure of ₹45. Rice husk, an abundant agricultural byproduct with a wide surface area favorable for adsorption, was used at 0.6 kg, costing ₹20 per kg, leading to a total material cost of ₹12. Aluminum sulphate, a common coagulant used to aid in the filtration process, was utilized in a very minimal quantity of 0.05 kg, priced at ₹20 per kg, resulting in a cost of ₹1. Furthermore, sugarcane bagasse, another agricultural waste material contributing to the filter's adsorption capacity, was used at 0.2 kg, priced at ₹20 per kg, with a total material cost of ₹4. The bottle, serving as the container for the filter media, was considered as a one-time investment, priced at ₹2. The cumulative total of all these material costs amounts to ₹137.50 for the entire filter setup, as detailed in Table 4.6. This breakdown of costs demonstrates the low-cost nature of the filter components, especially when considering the use of locally available natural materials and agricultural byproducts.

It is noteworthy that this calculation does not account for recurring operational costs such as labor charges for filter assembly, periodic maintenance costs, and energy requirements, if any, for running the filter in specific applications. Additionally, it is important to consider the scalability aspect, as bulk procurement of materials or local sourcing may lead to even lower costs per unit in a full-scale deployment scenario. Therefore, this cost analysis establishes a foundational understanding of the material expenses associated with the development of the multi-layer herbal water filter, reinforcing its potential as a cost-effective and sustainable solution for bacterial removal in water treatment, particularly in resource-limited areas.

Table 3.6 Material cost of different adsorbent media used in experimentation

Material	Amount used for experiment (kg)	Rate per kg In rupees	Total cost In rupees
Sand	0.9	15	13.5
Tulsi leaf powder	0.2	300	60
Neem leaf powder	0.3	150	45
Rice husk	0.6	20	12
Aluminum sulphate	0.05	20	1
Sugarcane bagasse	0.2	20	4
Bottle	-		2
Total Cost			137.50/-

CONCLUSION

1. Adsorption as a Preferred Technique for Iron Removal:

- Adsorption stands out as the simplest, most economical, and user-friendly technique for iron removal from water.
- Its advantages include longer filtration runs, shorter ripening times, and improved filtrate quality compared to other methods.
- However, a notable limitation is the requirement of periodic backwashing to maintain filter media effectiveness, as the filter tends to clog over time.

2. Effectiveness of Sand as an Adsorbent:

- Sand, being the most readily available and affordable adsorbing surface, has shown excellent potential in removing dissolved iron from drinking water.
- Its high filtration rate makes it suitable for practical applications in large-scale water treatment.

- The major limitation is the growth of bacterial biofilm on the sand media during prolonged usage, which necessitates regular backwashing to sustain performance and prevent secondary contamination.

3. Performance of Tulsi Leaves Powder as an Adsorbent:

- Tulsi (Ocimum sanctum) leaf powder did not exhibit significant potential in iron removal during the study.
- This indicates its limited surface area or lack of functional groups that favor adsorption of iron ions from water.
- Hence, Tulsi leaf powder is not recommended as an effective adsorbent for iron removal.

4. Modified Neem Leaf Powder as an Adsorbent:

- Untreated neem leaf powder demonstrated poor adsorption capacity for iron removal.
- However, when mixed with chuna ($Ca(OH)_2$), the modified neem powder showed improved performance due to enhanced chemical reactivity and increased active surface sites.
- The modification slowed down the filtration rate, suggesting a trade-off between higher adsorption efficiency and filtration speed.

5. Aluminium Hydroxide-Coated Rice Husk Ash (RHA) as an Adsorbent:

- Aluminium hydroxide-coated RHA was found to be an effective adsorbent for iron removal.
- The improved iron removal efficiency is attributed to the roughened and activated surface of RHA due to aluminium hydroxide coating, providing more active sites for adsorption.

6. **Sugarcane Bagasse as an Adsorbent:**

- Sugarcane bagasse exhibited limited potential for iron removal.
- The lower efficiency is attributed to the larger particle size of the material used in the experiment, which results in a lower specific surface area and fewer adsorption sites.
- For future studies, finer grinding of sugarcane bagasse may enhance its performance as an adsorbent.

7. Final Remarks:

- Overall, the study highlights the need for selecting appropriate low-cost and locally available adsorbents for efficient iron removal.
- The effectiveness of natural materials can often be enhanced by chemical modification, as observed with neem leaf powder and RHA.
- Future research should focus on optimizing particle size, surface modification techniques, and regeneration methods to improve the practicality and sustainability of these adsorbents in real-world applications.

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