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Comparison of Performance of Point of Use Water Treatment Systems Using Various Low Cost Materials for Production of Drinking Water

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ABSTRACT: Safe drinking water is becoming one of the scarce resources worldwide. Several methods are available to remove chemicals and pathogens from water and thereby making it potable. Most of the treatment methods are not economical to rural communities and are not efficient. Therefore certain low cost and effective treatment methods are to be formulated. Slow sand filtration is a widely used low cost method. But it has also proved to be not very effective. In this paper the performance of various indigenous/ modified materials like sand, sand & crushed brick, iron & pumice stone for treating water for domestic use are discussed. The studies were conducted in filtration unit made up of poly acrylic sheet of size 15cm×15cm×50cm. Short term and long term studies were conducted and the effluent was analyzed for fluoride, turbidity and fecal coliform removal. Conventional sand filter showed an average fluoride, turbidity and fecal coliform removal of 63.40%, 85.77% and 99.60% respectively. The corresponding fluoride, turbidity and fecal coliform removal efficiency for sand with an extra layer of crushed brick media were 80.80%, 94.03% and 99.97% respectively. Sand with metallic iron and pumice stone mixture showed a fluoride, turbidity and fecal coliform removal efficiency of 69.60%, 81.09%, and 99.94% respectively. The long term studies shows that the sand with an additional layer of crushed brick and iron & pumice stone attains quality deterioration after passing 101 & 86 bed volumes respectively.

KEYWORDS: slow sand filtration; effluent; fecal coliform;

I. INTRODUCTION

Water is an essential natural resource for sustaining life and environment that we have always thought to be available in abundance and free gift of nature. However, chemical composition of surface and subsurface is one of the prime factors on which the suitability of water for domestic, industrial or agriculture purpose depends. Natural, readily available waters such as shallow groundwater, surface water, water from the boreholes and springs are the main sources for drinking water production. About 1.1 billion people worldwide lack access to improved drinking water supplies and use unsafe surface and groundwater sources. Even people who have access to "improved" water supplies such as household connections, public standpipes, and boreholes may not have chemically and microbiologically safe water. The World Health Organization (WHO) estimates that diarrheal diseases kill 1.6 million people yearly, mostly children under five years of age. This disease burden falls disproportionately on those in developing countries, where children experience multiple episodes of diarrheal disease each year [1]. Presence of chemical contaminants in groundwater is also a serious problem faced by the decentralized rural communities. Presence of various hazardous contaminants like fluoride, arsenic, nitrate, sulfate, pesticides, other heavy metals etc. in underground water has been reported from different parts of India [2]. Point-of-use (POU) water treatment technology has emerged as an approach that empowers people and communities without access to safe water to improve water quality by treating it in the home. Contemporary reviews estimate 30-40% reductions in diarrheal disease by improving household drinking water quality at the POU, making such treatment more effective than improvements at the source [3] [4] [5]. Several POU technologies are



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available, but, except for boiling, none have achieved sustained, large-scale use. Sustained use is essential if household water treatment technology (HWT) is to provide continued protection, but it is difficult to achieve. Free chlorine, coagulation/ chlorination, and solar disinfection can improve the microbiological quality of water and reduce diarrheal disease, but the available evidence suggests that they do not achieve sustainable, long term, continuous use by populations. For technologies producing relatively small quantities of water, such as solar disinfection and coagulant-disinfectant products, the required time and effort to treat sufficient water quantities for all daily household uses may contribute to declining use rates and consumption of both treated and untreated water, undermining their overall effectiveness [6].

Various studies shows that the chemical and microorganisms removal efficiency of conventional sand filters can be improved by replacing or enhancing the sand media by various low cost filter materials. The low cost materials selected in this study are (i) Sand(ii) sand with extra layer of crushed brick (iii)sand with extra layer of iron and pumice Stone mixture.

II. MATERIALS AND METHODS

This includes the laboratory preparation of materials used for filtration process and methods for assessing the efficiency of materials in removing microorganisms and chemical contaminants from collected well water samples.

A. MATERIALS

1)Sample collection

Well water was collected from a residence near 'Pallimoola', Thrissur. The physicochemical characteristics of the collected well water are presented in table I. The samples were collected in plastic cans and the collected samples were properly refrigerated. Required amount of well water was withdrawn daily from the containers after thorough mixing and brought to room temperature.

Parameter	Value
	*
Alkalinity (mg/L)	20.00
Total Dissolved Solids (TDS)	52 30
(mg/L)	52.50
Dissolved Oxygen (DO) (mg/L)	7.40
Chlorides (mg/L)	74.00
Iron (mg/L)	0.28
Fluoride (mg/L)	1.20
Coliform (MPN/100mL)	15000
Fecal Coliform (MPN/100mL)	9

TABLE ICHARACTERISTICS OF WELL WATER

*Mean of 3 values

2) Different Types of Filter Media Used and Their Preparation

The different types of media use for the study and their specification are enumerated in the table II

B. PERPERATION OF FILETR MEDIA

1)Preparation of Crushed Brick

Bricks of standard size $19 \times 9 \times 9$ cm were selected and were crushed into particles of grain size ranging from 0.25-0.5 mm. These were washed using deionized water till the colour of the wash water disappeared completely. The crushed brick was then dried at room temperature and stored for future use [7]. Fig1 shows the dried crushed brick used in the study.

2)Preparation of Metallic Iron (Fe⁰) and Pumice Stone Mixture

Metallic iron in the form of steel wool was selected for



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the present study. It was then brought to particles of size having an average diameter of 1.2mm by crushing and sieving through 1.2mm size sieve. Pumice stone was crushed and brought to particles having average diameter of 1.2mm. Based on the previous studies done by Noubactep and Care [8] a volumetricFe^o:pumice stone ratio of 51:49 was selected. Fig 2 & 3 shows the metallic iron particles and pumice stone used in the study respectively.



Fig 1 Crushed Brick

TABLE II DIFFERENT TYPES OF MEDIA AND THEIR SIZE

Materials	Size
Gravel	1.5 - 0.8 mm
Fine Aggregate	0.8 - 0.2 mm
Crushed Brick	0.5 - 0.25
	mm
Metallic Iron (Fe ⁰), pumice	Average
stone	diameter
	1.2mm



Fig 2Metallic Iron particles



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Fig 3 Pumice stone

C. EXPERIMENTAL SET UP

A working model of experimental set up is shown in Fig 4. The experimental set up consists of a plastic storage tank of 12 litre capacity which was placed above a filtration unit fabricated in polyacrylic material having a square cross section of 15×15 cm and a height of 50cm. The filtration unit was fitted with a half inch outlet pipe. The treated water from the filtration unit was collected into a plastic basin through a valve. The filtration unit was filled in the following manner: 5cm stone (pebbles) at bottom; above that a 4cm filter gravel of size 0.8mm- 1.5mm and a top layer of 20cm deep filter sand having a particle size of 0.2- 0.8mm. This filter unit was used as the conventional filtration unit for the study. In order to measure the head loss in the media vertical glass tubes were placed at bottom of each media. The filter units with other two additional media were filled in the following manner:



Fig 4 Experimental Setup

1)Sand and Crushed Brick Media

This filter unit was filled in the same way as that of conventional filtration unit except that a 5cm crushed brick (grain size ranging from 0.25- 0.5mm) layer was added between sand bed and gravel bed. 2) Sand and Metallic Iron and Pumice Stone Mixture

The filter unit was filled with 5cm stone (pebbles) at bottom; 4cm filter gravel of size 0.8mm- 1.5mm, 5cm metallic iron and pumice stone mixture (average diameter 1.2mm), and a top layer of 20 cm deep filter sand with a particle size of 0.2- 0.8mm.



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D. METHODS

Down flow column tests were conducted on the polyacrylic model of size $15 \times 15 \times 50$ cm. Water was added to the filter tank continuously for several hours using a storage tank kept above the filtration unit. Before being used in the experiment about 2 bed volumes of deionized water was passed through the column to remove any unbounded materials (metallic oxide/ hydroxide). Samples were passed through the columns using gravity flow. Filter was never allowed to go dry during the entire experiment. The effect of treatment time on the chemical and microorganism's removal of various filter media were studied by varying the treatment time.

Since fluoride and fecal coliform levels in the collected well water sample exceeded the WHO limits, the performance of the media in removing the above contaminants from the sample was evaluated in the present work. In order to get a clear idea about the removal efficiency of the filter media contaminant level in the water sample has been elevated. Fluoride and fecal coliform concentration was made to 5 mg/l and 240×10^3 /100ml respectively.

1)Effect of Treatment Time

Before conducting long duration column tests on performance evaluation of the media, effect of treatment time on turbidity, fluoride and coliform bacteria was studied by operating the experiments in batches under different treatment time of 1, 2, 4, 6, 8 and 10 hours. The well water samples were allowed to pass through all the experimental filter units. The effluents from all the units were analyzed for fluoride, turbidity and fecal coliform.

2) Long duration tests on the media

Long duration column tests were conducted for all the media. Optimum treatment time obtained from the short duration studies was selected as the treatment time for long duration studies. Maximum bed volumes that can be passed through each media were obtained from these studies. The influent and effluent samples were analyzed after every 2 days for turbidity, fluoride and fecal coliform. The filter run was stopped when deterioration in the performance of the filter was observed.

III. RESULTS AND DISCUSSIONS

The results of the short term and long term column studies in removing chemical contaminants and microorganisms from well water by two different media sand, sand with extra layer crushed brick, sand with an extra layer of metallic iron and pumice stone mixture along with discussions are presented.

A. Short term study

1)Effect of treatment time

The effect of treatment time in removing fluoride, turbidity and fecal coliform by various filters containing sand, sand with an extra layer of crushed brick, sand with an extra layer of metallic iron and pumice stone mixture was found by conducting short duration column studies. The effluent concentration of fluoride, turbidity &fecal coliform with time is shown in Fig 5, Fig 6, and Fig 7 respectively.







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It has been observed from the experiment that as the treatment time progressed, all the three selected media showed an increase in the removal of fecal coliform, fluoride and turbidity from the well water. But the increase was marginal beyond 6 hours. So the optimum treatment time for the long duration column studies was selected as 6 hours. Percentage removals of various contaminants by different media are given in table III. Removal of fluoride was found to be maximum (80.8%) in the case of sand with an extra layer of crushed brick. All the media were found to be efficient in removing turbidity.

Deflouridation capacity of brick powder can be explained on the basis of the chemical interaction of fluoride with the metal oxides under suitable pH conditions. Studies done by Yadev et al [9] reveals that maximum adsorption of fluoride will be in the pH range of 6-8, which makes it very suitable for use in drinking water treatment, especially in rural areas. The lower adsorption efficiency offluoride inacidic



medium might be due to the formation of weakly ionized hydrofluoric acid, which reduces availability of free fluoride for adsorption. In alkaline conditions, lower adsorption may be due to the competition of OH^- ions with F^- ions for adsorption because of similarity in F^- and OH^- in charge and ionic radius. This makes crushed brick a good adsorbent of fluoride at normal pH of drinking water.

The conventional sand filter has also showed fluoride removal. This might be due to presence of crystalline minerals such as $Ca=^{+2}Mg^{+2}$, Al^{+3} , etc which could adsorb anions such as fluoride. Exchangeable anions such as OH⁻



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are present in many minerals and the proxy of F^- for OH^- would serve as one of the principal contributing factor for defluoridation[10].

In the case of filter containing sand with an extra layer of iron and pumice stone mixture, the contaminants and microorganism are removed mainly by adsorption, co-precipitation and size exclusion [8].

TABLE III COMPARISON OF THE FILTER PERFORMANCE AT THE OPTIMUM TREATMENT TIME OF 6

HKS					
Parameter	%Remo val by Sand	% Remova l by Sand + crushed brick	% Removal by Sand + Metallic iron & pumice stone mixture		
Turbidity	84.00	94.03	81.09		
Fluoride	58.00	80.80	69.60		
Fecal coliform	99.60	99.97	99.94		

2) Effect of Long Duration Column Studies

In order to find the long term efficiency of the selected filter media's in removing chemicals and microorganisms from well water, long duration column tests were conducted. The results of fluoride, turbidity and fecal coliform removal are shown in Fig 8, Fig 9, and Fig 10 respectively.



Fig 8. Effluent Fluoride concentration Vs Number of bed volume passed

When sand was used as the filter media, the removal may be due to the basic theories of filtration i.e., mechanical straining, flocculation and sedimentation, biological metabolism and electrolytic changes. Filter showed an average fluoride, turbidity &fecal coliform removal of 63.40%, 85.77 % and 99.60% respectively. It has been observed that the performance of the media improved with time but it never matched with that of other filters. This improvement could be due to the formation of a dirty layer called 'schmutzdecke'. This layer might have further helped in absorbing and straining out the impurities. Bacteria, fluoride & turbidity removal was low compared to other filters (Table III). The filter showed quality deterioration after passing 64 bed volumes.



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Fig 9. Effluent Turbidity Vs Number of bed volume passed

When sand with an extra layer of crushed brick was used as the media it showed an average fluoride, turbidity and fecal coliform removal efficiency of 81.80%, 93.63% and 99.90% respectively.Maximum fluoride removal was observed in the case of crushed brick.



Fig 10. Effluent Fecal coliform Vs Number of bed volume passed

The main reason behind this increased adsorption of fluoride is anionic exchange. The brick that is being used in the study contains good adsorbent of anions such as Al (OH)₃, FeO.OH and other metal oxides and hydroxides, which are good ion exchangers with fluoride and others. Furthermore, the heat treatment during the preparation of the bricks may also have contributed to the efficiency of the brick [11].

Studies done by Coetzee et al., [12] proves that clay types containing Al(OH) $_3$ can absorb 0.25-0.4mgof fluoride per gram of clay and Goethite(FeO.OH) can adsorb 0.2 - 0.3 mg of fluoride per gram of clay. Addition of crushed bricks is an added advantage in the case of experimental sand filter because small portion of fluoride can be defluoridated and help the brick from early saturation. Typically, brick powder is a mixture of oxides of silicon, aluminium, iron, calcium, magnesium, etc. In the presence of water these species can be hydroxylated. The specific adsorption reaction can be explained by two-step mechanism as follows:

 $SOH + H^+ \leftrightarrow SOH_2^+$

 $SOH_2^+ + F^- \leftrightarrow SF + H_2O.[9]$

The filter has showed quality deterioration after passing a bed volume of 102.



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In the case of sand with an extra layer of metallic iron and pumice stone the average removal efficiency of fluoride, turbidity and fecal coliform was 71.80%, 85.44% and 99.00% respectively. Contaminants are removed by adsorption, co- precipitation and size exclusion. Removed contaminants could be further chemically transformed (oxidized or reduced). A contaminant that is not removed in the entry zone could be removed in the deeper metallic iron [8]. While intentionally ignoring the interactions between Fe^0 and water, the initial filtration in an iron filter is comparable to slow sand filtration. As expansive corrosion products are generated, the initial pore space in the filter is progressively filled and the system is gradually transformed to an ultrafiltration one. Accordingly, regardless from physico-chemical interactions between contaminants, iron and corrosion products, contaminant removal by pure size exclusion (or adsorptive size exclusion) will inevitably occur with increasing service life. The next important feature of concern is the dynamic nature of iron oxide formation within the filter. The contaminants are fundamentally entrapped within the film of corrosion products in the vicinity of the Fe⁰ surface [8]. The filter has showed quality deterioration after passing a bed volume of 86. All the filter run was stopped when quality deterioration was observed.

A comparison of the long term efficiency of all the three filter media's are presented in table IV.

Parameter	Sand	Sand+ Crushed Brick	Sand + Metallic Iron and Pumice Stone Mixture
Quantity of	64BV	102BV	86BV
water treated	Effluen t Concen tration *	Effluent Concentratio n [*]	Effluent Concentration *
Turbidity (NTU)	2.86	1.28	2.97
Fluoride (mg/L)	1.83	0.91	1.41
Fecal coliform (MPN/100 mL)	467	46	49

TABLE IV COMPARISON OF THE LONG TERM FILTER PERFORMANCE

*Mean of 18 values

From the above results it is observed that filter containing sand with an extra layer of crushed brick has better performancein short term as well as long term studies. It showed significant fluoride (>70%) and turbidity (>85%) removal studies.

IV. CONCLUSIONS

In this study the chemical contaminants and microorganism's removal efficiency of four different media sand, sand with an extra layer of crushed brick, sand with an extra layer of metallic iron and pumice stone mixture were studied and compared. The following may be concluded from this work:

Sand with an additional layer of crushed brick showed higher degree of contaminant removal than other media. Sand with an additional layer of crushed brick showed a fluoride, turbidity and faecal coliform removal efficiency of 80.80%, 94.03% and 99.97% respectively. Whereas in the case of sand with an extra layer of metallic iron and pumice stone, the average removal efficiency of fluoride, turbidity and fecal coliform was 71.80%, 85.44% and 99.00% respectively.Studieswere conducted at an optimum treatment time of 6 hours. Sand with an extra layer of crushed brick showed excellent fluoride removal (80.80%) and therefore it can be suggested as a best remedy for treating water with high fluoride contamination.Long duration column studies conducted in filter containing sand and crushed brick showed breakthrough at the end of 101 bed volume, whereas that containing iron & pumice stone showed breakthrough



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at 86bed volumes. These results prove that sand with an additional layer of crushed brick have better life thanthat with iron and pumice stone mixture.

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