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Evaluation of Domestic Wastewater Treatment Using Various Natural Filter Media

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Abstract: The performance of combined anaerobic and aerobic treatment system with different filter medias and their efficiencies were examined for domestic wastewater. The gravitational flow rate to the system includes Anaerobic Baffled Reactor (ABR), Anaerobic Filter (AnF) and Aerobic Filter (AF) and was kept constantly giving hydraulic retention time of 7.6 h, 7.2 h and 11.4 h respectively. The consecutive treatment efficiencies achieved were 43%, 79% and 94% on ABR, AnF and AF during the observation period. In anaerobic filter, gravel media show higher efficiency than slag media and PO_4 removal is proven to fail in the slag media. Gravel (2-4 mm) and pebble (8-10 mm) gives better performance than sand media (0.5 mm) in aerobic filter. Gravel (2-4 mm) with reed show higher efficiency (94%) than all other medias. Combination of these three-system gives excellent alternative (89 to 94.5% efficiency) to conventional treatment system, which proves and reduces the operational cost.

Key words: Wastewater, anaerobic baffled reactor, anaerobic filter, reed bed.

Introduction

Almost all the organic rich wastewater, both industrial and domestic, are treated using conventional biological treatment systems, such as the activated sludge process. While the high dependency on power where the power supply is highly irregular and high operating cost make these systems inoperational, very little efforts have been made to implement an alternative system, which is less complicated in operation, has low operating cost and less dependent on power. Most small and medium sized communities cannot afford the use of highly sophisticated wastewater treatment systems. This significant increase in demand for wastewater treatment systems, calls for a need to plan, design and construct effective, reliable, cost efficient and custom-made decentralized wastewater treatment systems (DEWATS) which includes Anaerobic Baffled Reactor (ABR), Anaerobic Filter (AnF) and Aerobic Filter (AF) (Sasse, 1998). Anaerobic treatment is a biological process in which microorganisms convert organic compounds to methane, carbon dioxide, cellular materials and other organic compounds. First the complex organics are broken down to a mixture of volatile fatty acids, mostly, acetic, propionic and butyric acids. This is achieved by "acidogens", a consortium of hydrolytic and acidogenic bacteria. The volatile fatty acids are in turn converted to carbon dioxide and methane by acetogenic (acetogens) and methanogenic (methanogens) bacteria respectively. Thus the processes can overcome the inherent disadvantages associated with chemical treatment methods, because anaerobic treatment require minimum place due to compact design, easy adaptation to change loading rates, less energy and nutrient consumption, 1/10 less sludge production than conventional treatment, odour and noise free operation, non aerosol features due to closed structure, lower

Figure 1: A view of collection tank, anaerobic baffled reactor, anaerobic filter and aerobic filters.

maintenance and rapid start up, suitable for seasonable operation, settler self-cleaning system and easy pre-treatment applications (Subrahamanyam and Sastry, 1988; Akunna et al., 1994; Kansal et al., 2002)). Hence this high rate anaerobic treatment is becoming more and more applied for the treatment of domestic sewage, especially for developing countries and tropical areas where the temperature ranges between 20 and 35°C, the anaerobic process holds prospects for the treatment (Elmitwalli et al., 2002). Consequently the present study focuses on the domestic wastewater treatment by combination of anaerobic and aerobic system such as ABR, AnF and AF using various natural filter media to achieve better efficiencies.

Study Area

Many works conducted in domestic wastewaters in the lab and pilot scale show a high efficiency in the low strength wastewater. In the present study the objectives were to: (i) study and compare various natural filter media to be used in anaerobic and aerobic filters (ii) to standardize design of unit/combination of units which can effectively produce similar results as that of activated sludge units. To achieve the above mentioned objectives, a detailed study was conducted on ABR, AnF and AF and the details of design and size etc. were given in Table 1 and Figure 1.

Table 1: Specifications of the Individual Treatment Unit and their Capacity

Sl. No.	*Characteristic of the units*	*Unit*	*ABR*	*AnF*	*AF*
1.	Length of each compartment	Metre	0.6	0.4	1.5
2.	Width of each compartment	Metre	2.3	0.5	1.0
3.	Depth of each compartment	Metre	1.63	1.2	0.5
4.	Volume in each compartment	Cubic metre	2.25	0.24	0.75
5.	Number of compartments	—	7	6	5
6.	Hydraulic retention time	Hour	7.9	7.2	11.4
7.	Flow rate in each section	Litre per hour	2000	200	66
8.	Number of sampling points	—	6	12	5
9.	Size of the filter media	Millimetre	—	80-90	0.5-10
10.	Uniformity coefficient of the media	%	—	8-10	20-30
Collection cum settling tank					
1.	Length	Metre	3.4		
2.	Width	Metre	1.35		
3.	Depth	Metre	1.35		

Anaerobic Baffled Reactor

The ABR has a series of baffles to force the wastewater containing organic pollutants to flow under and over the baffles as it passes from the inlet to the outlet. Bacteria within the reactor gently rise and settle due to flow characteristics and gas production, but move down the reactor at a slow rate. The main driving force behind reactor design has been to enhance the solids retention capacity. Equal distribution of inflow and widespread contact between the new and the old substrate are important process features. The fresh influent is mixed as soon as possible with the active sludge present in the reactor in order to get quickly inoculated for digestion. The wastewater flows from bottom to top with the effect that sludge particles settle against the upstream of the liquid. This provides the possibility of intensive contact between resident sludge and newly incoming liquid. It always starts with a settling chamber for larger solids and impurities followed by a series of upflow chambers. The water stream between the chambers is directed by baffle walls that form a downshaft or down-pipes that are placed on partition walls.

Anaerobic Filter

The anaerobic filter process is emerging as an efficient and economic method for the treatment of wastewater. Inexpensive organic stabilization coupled with efficient pathogen control makes the anaerobic filter process viable and hence broadens its applications. This process is a column filled with various types of solid media used for the treatment of the carbonaceous organic matter in wastewater. It is packed with material on which micro organisms can attach and which facilitates the development of a dense biofilm and the filter material should have a large surface area per unit of volume, provide rough texture for bacterial adhesion, have high durability, and not easily clog (Bodik et al., 2002). In the present system, the biofilm is retained within the reactor on filters made from materials such as gravel and slag. The filter material occupying 65% of the reactor volume and the reactor was operated in upflow mode. Also the system was monitored with upward wastewater flows through the column by contacting the media without being washed off in the effluent to attain mean cell-residence times to the order of 100 days.

Methodology

An aerial view of the anaerobic baffled reactor is given in Figure 1. The unit has been covered with mass concreting with small cover slabs of width 20 cm to facilitate sampling from each compartment separately. A ruttner sampler was used to collect the samples from the bottom of the chamber.

The anaerobic filter was divided into two sections in order to evaluate two different types of filter media simultaneously. Each section was designed to treat domestic wastewater at a flow rate of about 200 L/h. Each section consisted of six compartments and the flow into the filter was upflow mode. Both sections were fed with the help of inlet pipes. The wastewater enters each compartment by flowing beneath a baffle wall and then passed upwards through the media, during which time it got treated. This overflow then passes onto the next compartment via holes in the partition wall. The same flow pattern was followed in all compartments. There were sampling ports in each compartment; the sampling ports were situated in between the partition wall of one compartment and the baffle wall of the next. The filter media selected for the anaerobic filter was gravel and slag both of 80-90 mm in diameter. The basis for selection of the two media was to compare one natural and one synthetic medium for better treatment performance. The advantage of slag as compared to other synthetic media is that it is a waste product from the iron making process and hence is extremely inexpensive. The slag media was subjected to Toxicity Characteristic Leachate Procedure test, TCLP (APHA–1311). The leachate thus obtained was analysed for pH, TDS, TSS, sulphates, chlorides and total iron.

The aerobic filter was divided into five compartments to evaluate five types of filter media. The flow into the filter was in the horizontal mode. The wastewater enters each compartment by entering an inlet chamber and thereafter overflowing to surface of the media. The effluent then flows down and travels horizontally reaching the other end and gets collected and transported out by a pipe installed at the bottom of the compartment. The outflow is collected in an outlet chamber and then mixes together to form the treated effluent.

Initially the ABR was seeded with sludge from the anaerobically digested sewage. Regular feeding from the ABR into each section of the anaerobic filter was maintained at 200 L/h for 20 h per day and that to each compartment of the aerobic filter was maintained at 66 L/h for 20 h/d for three months. Samples of the raw sewage admitted into the collection-cum-settling tank were sampled regularly. The duplicate effluent from six compartments of the anaerobic baffled reactor, twelve compartments from the anaerobic filter and five outlets of the aerobic filters were collected at twice a month intervals. For all the samples, one litre of the same was collected and preserved in the refrigerator at 4°C. Quality control tools such as *x* and *s* control chart were executed during the time of analysis to confirm the accuracy. The individual parameters and detailed method of analysis were given in Table 2.

Table 2: Summarizes the Analytical Methods (APHA 1998)

Sl. No.	Parameters	Methodology/Instrument
1.	pH	pH meter-Model pH 197, WTW, Germany
2.	Electrical Conductivity	Conductivity meter – Model Conductivity 197, WTW, Germany
3.	Total Suspended Solids	Gravimetric method
4.	BOD	Winkler's method
5.	COD	Open Reflux (COD analyser)
6.	Sulphates	Turbidimetric method
7.	Phosphates	Stannous Chloride method
8.	Volatile Fatty Acids	Distillation method
9.	Total Alkalinity	Titration method
10.	Total Iron	Phenanthroline method
11.	Chlorides	Argentometric method

Results and Discussion

Leaching Studies of the Slag Media

As mentioned, the slag media (Figure 2) was subjected to leaching studies to determine its potential for leaching out the pollutants, if any, present in it. Characteristics of the leachate obtained from the slag media through TCLP test is presented in Table 3.

Table 3: Characteristics of TCLP Leachate from Slag Media

Sl. No.	Parameters	Slag A	Slag B	Average
1.	pH	5.92	5.77	—
2.	Electrical Conductivity (mS/cm)	6.47	6.55	6.51
3.	TSS (mg/L)	3.64	6.16	4.90
4.	Sulphates (mg/L)	24	15	20
5.	Chlorides (mg/L)	119	119	119
6.	Carbonates (mg/L)	71	57	64
7.	Total Iron (mg/L)	266	248	257

The pH was found to be in the acidic range due to the addition of acids in the TCLP test methodology. The electrical conductivity was in the range of 6.47 to 6.55 mS/cm with an average of 6.51 mS/cm. This indicates that the slag media may add a certain amount of total dissolved solids (TDS) into the wastewater being treated. The total suspended solids were found to be negligible with an average concentration of 4.9 mg/L, suggesting that there was no deterioration of the media even after being subjected to TCLP test conditions. The average sulphate concentration in the leachate was found to be 20 mg/L. The average chloride content of 119 mg/L indicates a potential for the leaching out of salts from the slag media. The alkalinity measured in the form of carbonates had an average concentration of 64 mg/L. This is the residual alkalinity obtained after neutralizing the highly acidic nature of the leachate, contributed by the addition of acids in the TCLP test.

As the slag media is a residue material of the steel making industry, the leaching out of iron was considered a possibility. The leachate was analyzed for total iron, which was found to be 257 mg/L on an average. This indicated the potential for iron leaching out of the slag media, though the higher quantity obtained during TCLP may be due to the acidic testing conditions and the same may not happen during the normal operation. Similarly, Chernicharo and Machado (1998), experimenting with blast furnace slag in a pilot scale anaerobic filter receiving anaerobically pre-treated wastewaters, observed no problems with deterioration of the slag media or clogging of the unit. The media samples analysed also demonstrated material integrity and good capacity to support the anaerobic biofilm.

Characteristics of Raw Sewage

The characteristic of the raw sewage after screening and grit removal is presented in Table 4. The results are the mean of the six samples collected by monthly basis from the V-notch flow meter at the inlet to the anaerobic baffled reactor during the period of study. The pH value in the influent varied from 6.7 to 7.4 and the pH at the outlet is close to neutral. The analysis showed that there was not much variation in final pH level.

In ABR, the present study shows, TSS reduces to 92% when compared with all other parameters. At the first chamber, the elevated concentration of 934 mg/L was observed and it reduces to 212 mg/L in the sixth compartment. The first compartment acts as a receiver of all suspended and settleable solids and by sequencing of reduction it reduces to 41 mg/L (74%) and 21 mg/L (92%) of AnF and AF respectively.

The chemical oxygen demand (COD) is the main indicator of wastewater treatment efficiency and capacity as it shows the degradation by oxidation of organic materials (Metcalf Eddy, 1969; Kobayashi et al., 1983;

Figure 2: View of media used in aerobic filter.

Table 4: Characteristics of Raw Sewage

Sl. No.	Parameters	Value Min.	Value Max.	Average
1.	pH	6.78	7.43	—
2.	Total Dissolved Solids (mg/L)	1112	1392	1244
3.	Total Suspended Solids (mg/L)	148	345	220
4.	Chemical Oxygen Demand (mg/L)	280	460	382
5.	Biochemical Oxygen Demand (mg/L)	140	290	210
6.	Chlorides (mg/L)	478	563	544
7.	Total Nitrogen (mg/L)	67	78	75
8.	Phosphates (mg/L)	10.5	28.3	18.9
9.	Sulphates (mg/L)	74	110	91

Sosnowski et al., 2003). The COD concentration ranges from 280 to 460 mg/L in the raw sewage and it got reduced to 160 mg/L in the ABR; 90 mg/L in AnF and 40 mg/L in planted gravel filter of AF. Figure 3 explains the gradual reducing trend in concentration of COD in the three consecutive observatory units. At AnF it achieves 77% of removal efficiency and it proves good performance of the system. Similarly several workers observed good performance for different types of wastewater in anaerobic filters (Kobayashi et al., 1983; Anderson et al., 1994; Bodik et al., 2000). The AF shows maximum reduction efficiency for various filter medias. Specific surface area, porosity, surface roughness and pore size were found to play an important role in the filter materials (Elmitwalli et al., 2000). The individual filter medias and their reduction rate are as follows: Pebbles (2-4 mm) 86% < pebbles (8-10 mm) and gravel (2-4 mm) 87% < sand (0.5 mm) 88% < gravel with reed 90%.

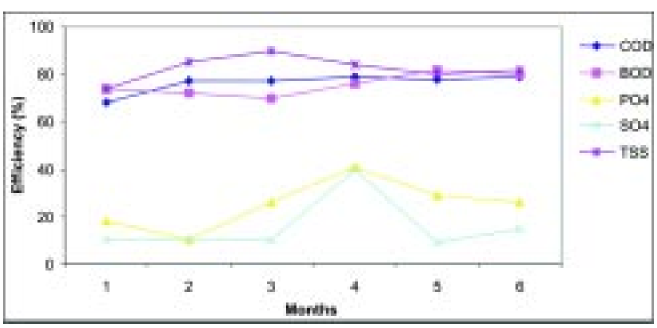
The average BOD load in the influent and the effluent of the ABR, AnF (with gravel and slag media) and AF are shown in Table 6. The BOD at the inlet varied from 140 to 290 mg/L and the outlet from 10 to 28 mg/L. At AnF, it attains 79% of reduction and then passes to the inlet of AF where maximum removal efficiencies were observed between 95 to 98% on pebble (2-4 mm) and planted gravel filter (PGF). The average removal efficiency of BOD in PGF was 94.5%, which shows a greater efficiency with maximum reduction capacity. The reason could be the roots of plant supply oxygen to the sub-surface and allow aerobic and facultative bacteria to oxidize the organic material. Additionally the character of substrate (pre-treated by AnF and suspended solids) and temperature of tropical conditions (Bodik et al., 2002) would be the main factor for better reduction.

The phosphate concentration varies from 11.3 mg/L (ABR) to 7.1 mg/L (PGF) in the present study. The maximum treatment efficiency of 23% was observed in the AnF followed by AF (20%) and ABR (11%). The phosphorus removal is mainly associated with the chemical precipitation and additional reaction with iron, calcium and aluminium ions present in the media (Stephen and Frederick, 1997).

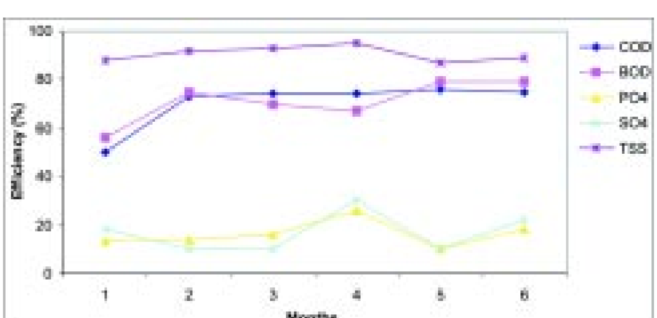
Among the system, first ABR treats the organics more or less 50% and it can be observed during the six months of study period. The inlet COD was observed as 350 mg/L in the first chamber and got reduced to 170 mg/L in sixth chamber. Similarly BOD is from 210 to 110 mg/L and TSS 930 to 240 mg/L. To optimise further treatment the effluents were passed to AnF inlet where two types of filter medias (slag and gravel) were neatly packed to enhance the bacterial growth. In the case of gravel media, it shows slightly better efficiency than slag media and can be seen in Figure 3 with gradual increase in trend towards time. In both cases, it is clearly evident that PO_4 is not removed considerably as it was expected especially in slag media since it has iron in it. Figure 4 shows aerobic filter with five different medias performance, which was pre-treated by ABR and AnF. Though the individual variation is not much among the filter medias, the optimised micro level difference was obtained by quality-controlled analysis. From this study the planted gravel filter and pebble (8-10 mm) got maximum treatment capacity and smooth operation. To conform the consecutive over all treatment efficiency for the combined system, individual inlet and outlet COD concentration was plotted in Figure 5 and shows steady performance during sixth months time and the reduction rates were observed by reduce in concentration curve by 90%.

Table 5: Comparison of Removal Efficiency in Anaerobic Filter with Various Type of Wastewater

Type of wastewater	*Loading rate*	*HRT (hr)*	*COD reduction (%)*	*BOD reduction (%)*	*Reference*
Domestic wastewater	0.25 g COD l^{-1} d^{-1}	7.2	77	79	Present study
Municipal wastewater	0.1-0.25g COD l^{-1} d^{-1}	6 – 20	46 – 92	41 – 96	Bodik et al. (2002)
Domestic wastewater	—	4 (13°C)	55	—	Elmitwalli et al. (2002)
Industrial dairy	8 kg COD $m^{-3}d^{-1}$	—	50 – 85	—	Garrido et al. (2001)
Synthetic wastewater	—	10 – 20	46 – 90	41 – 95	Bodik et al. (2000)
Dairy	21 kg COD m^{-3} d^{-1}	12	80	—	Ince et al. (2000)
Starch effluent	0.172 g COD l^{-1} d^{-1}	10 days	75 – 85	—	Desai and Nagori (1999)
Sewage wastewater	—	5.5	—	96 – 97	Kim et al. (1997)
Synthetic wastewater	4.4 g COD $l^{-1}d^{-1}$	23	77	—	Akunna et al. (1994)
Tuna fish processing	11-13 kg COD m^{-3} d^{-1}	1 – 4 days	90		Veiga et al. (1994)
Dairy (sintered glass media)	21 kg COD m^{-3} d^{-1}	12 – 24	82	—	Anderson et al. (1994)
Dairy (PVC media)	6 kg COD$m^{-3}d^{-1}$	0.9 – 2.8 days	80	—	Anderson et al. (1994)
Pharmaceutical	1.1 to 16.66 kg COD m^{-3} d^{-1}	1.25 – 5 days	82.5 – 84.2	—	Roy et al. (1993)
Distillery effluent	8.33-50 kg COD m^{-3} d^{-1}	1 – 6 days	71.5 – 93	—	Subramanyam and Sastry (1989)
Vegetable tanning	7.1 g CODl^{-1} d^{-1}	23.5	84.6	87.5	Routh and Dhaneswar (1988)
Distillery	2.05-3.46 kg COD m^{-3} d^{-1} (diluted)	15 – 30 days	62 – 77	—	Gadre and Godbole (1986)
	3.56-6.81 kg COD m^{-3} d^{-1} (undiluted)	15 – 30 days	55 – 72	—	
Domestic wastewater	0.02 lb CODft^{-3} d^{-1}	24	78	79	Kobayashi et al. (1983)



(a) Gravel media



(b) Slag media

Figure 3: Variations of removal efficiency in anaerobic filter.

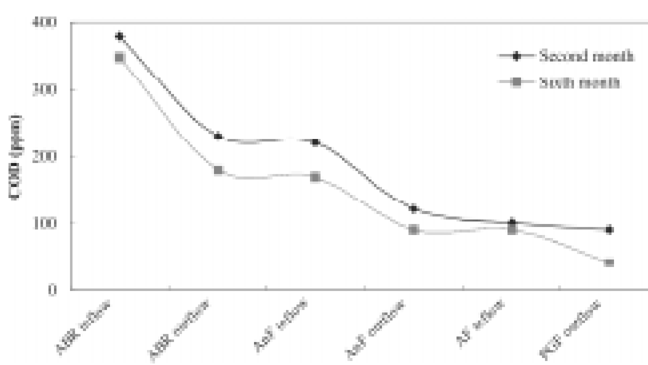


Figure 4: COD performance during the observation period.

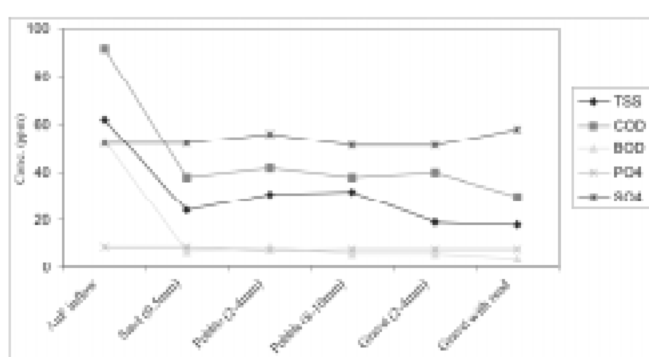


Figure 5: Effluent behaviour with various filter medias in aerobic filter.

Table 6: Average Wastewater Characteristics of the Combined Treatment System

System	*pH*	*Conductivity (mS/cm)*	*TSS (mg/L)*	*COD (mg/L)*	*BOD (mg/L)*	*PO_4 (mg/L)*	*SO_4 (mg/L)*
Anaerobic Baffled Reactor							
Raw influent	7.1	1.75	432	380	220	11.3	47.5
Chamber – 1	7.1	1.73	914	330	200	10.8	52.6
Chamber – 2	7.2	1.81	722	300	196	9.8	49.0
Chamber – 3	7.3	1.78	590	266	162	9.4	44.3
Chamber – 4	7.4	1.80	320	228	176	9.4	44.0
Chamber – 5	7.2	1.98	204	188	112	9.3	44.3
Chamber – 6	7.1	1.97	212	166	110	9.1	45.0
Anaerobic Filter (Gravel media)							
Chamber – 1	7.7	2.10	156	164	106	9.5	44.1
Chamber – 2	7.1	1.90	122	160	98	9.1	42.2
Chamber – 3	7.3	1.92	108	128	66	8.9	40.4
Chamber – 4	7.4	1.91	91	90	60	8.7	43.9
Chamber – 5	7.4	1.89	42	88	58	8.5	40.6
Chamber – 6	7.4	2.10	41	86	46	8.3	40.1
Anaerobic Filter (Slag media)							
Chamber – 1	7.2	1.91	85	170	108	9.2	46.2
Chamber – 2	7.2	1.85	92	162	100	8.9	48.7
Chamber – 3	7.7	1.96	87	150	88	8.1	42.7
Chamber – 4	7.8	1.91	45	128	70	10	38.7
Chamber – 5	7.7	1.89	37	120	70	10	40.4
Chamber – 6	7.8	1.99	32	98	66	9.5	38.3
Aerobic Filter (Different medias)							
AF influent	7.5	2.03	30	96	58	9.3	44.6
Sand 0.5 mm	7.3	2.10	24	42	22	9.1	48.0
Pebble 2-4 mm	7.2	1.95	32	40	22	7.8	47.2
Pebble 8-10 mm	7.2	1.99	30	40	18	7.1	49.0
Gravel 2-4 mm	7.1	2.04	19	44	20	7.6	50.2
Gravel planted	7.2	1.95	21	38	12	7.2	51.0

Conclusion

This study indicated a very good performance on combination of anaerobic baffled reactor followed by anaerobic filter and aerobic filter. The system could achieve very low BOD (around 8-10 mg/L) and COD (around 30-40 mg/L), which even conventional treatment units fail to achieve.

There is no appreciable reduction of phosphates even from the slag media in anaerobic filter, where good reduction was anticipated due to the presence of iron in it.

The planted gravel filter gives better results (COD 90%; BOD 98%) compared to its counter part without the plants.

Among the AF filter media, pebble (8-10 mm) gives better efficiency than other non-planted medias.

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