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PERFORMANCE EVALUATION OF LOW-COST MATERIALS IN REMOVING POLLUTANTS FROM WASTEWATER

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Abstract

The study was conducted to investigate the effectiveness of gravels, sandy soils and coal for treating household waste water in the laboratory. Electrical Conductivity (EC) and Total Dissolved Solids (TDS) of wastewater filtered through constructed filter columns were measured over time to evaluate the pollutant removal characteristics of these filter materials. During filtration, coarse gravel, fine gravel 1 (white), fine gravel 2 (brown), coarse sand, sandy clay and coal could reduce EC of wastewater by 269, 385, 429, 56, 167 and 32 µS cm^{-1} in 39, 39, 32, 170, 212 and 48 minutes, respectively. These materials reduced TDS by 143, 171, 218, 57, 79 and 18 ppm, respectively during the same period required for reduction of EC. Coal showed very poor performance in reducing EC and TDS from wastewater. Since the ability of the filter columns in reducing EC and TDS was decreased with time, washing was accomplished by using tap water. During washing, coarse gravel, fine gravel 1 (white), fine gravel 2 (brown), coarse sand, sandy clay and coal required 400, 400, 400, 700, 200 and 600 ml of tap water, respectively. The corresponding times for washing were 108, 126, 108, 275, 81 and 194 minutes, respectively. Among these six materials, sandy clay was washed very efficiently whereas coal was observed the poorest filter material in respect of washing.

Key words: Wastewater, low cost material, filtering, washing

Introduction

All over the world, the demand of fresh water is increasing day by day, especially in arid and semi-arid regions (Azad, 2003). Agriculture is the greatest user of water accounting for 80% of total consumption (FAO, 1996). It takes, roughly 1000 tons of water to grow 1 ton of grain and 2000 tons to grow one ton of rice (Raghunath, 1987). To obtain higher production in agriculture, huge amount of water is needed to irrigate the land for high yielding crop varieties.

The quality of water resources is deteriorating rapidly due to contamination. Both point and non-point sources are polluting our water resources as a result of rapid population growth, modern industrialization, civilization, domestic and agricultural activities and other geological, environmental and global changes. Whenever good quality water is scarce, water of marginal quality should be considered for use in agriculture. Expansion of urban population and increased coverage of domestic water supply and sewerage give rise to greater quantity of municipal wastewater. This wastewater use in agriculture has become an important consideration all over the world. FAO (1992) reported that the use of wastewater in agriculture could be an important consideration when its disposal is being planned in arid and semiarid regions. Wastewater reuse, after low-cost treatment, may be an important dimension of water resources planning to solve the arising problem of water scarcity throughout the world. Wastewater use in irrigation not only conserves valuable water resources, but also takes advantage of the nutrients contained in sewerage to grow crops. The nitrogen and phosphorous content of sewage might reduce or eliminate the requirements for chemical fertilizers. If we can reuse the wastewater from household and sewerage (i.e. municipal wastewater), it is possible to preserve our scarce resource of fresh water. Many countries have included wastewater reuse as an important dimension of water resource planning (Shuval *et al*. 1986). Bartone (1986) reported on benefit-cost studies of an effluent irrigation schemes in Peru that it was economically viable though land, operation and maintenance costs for wastewater treatment were charged to farmers. Cifuentes *et al.* (1992) reported that Mexico is studying the cost-benefit of doubling irrigation with wastewater in the next decade. In Australia, China, Pakistan, New Zealand, Kuwait, Saudi Arab, UK, USA and many more countries, wastewater is being used in agriculture releasing high quality water supplies for potable use (WHO, 1989). Various methods for water purification and recycling have been developed and used. Important ones are reverse osmosis, ion exchange, electro dialysis, electrolysis, adsorption and

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infiltration through porous media (ash, sand, gravel, husk, etc.). Among these, reverse osmosis, ion exchange, electro dialysis and electrolysis are costly technologies. Adsorption is a fast, inexpensive and widely applicable technique. Moreover, it is universal in nature as it can be applied for the removal of soluble and insoluble contaminants and biological pollutants with removal efficiency of 90–99%. In the industries, pollutants are removed from water by using columns and contractors filled with suitable adsorbents. Adsorption can also be used for source reduction, reclamation for potable, industrial and other purposes. As a result, much work has been done on water treatment by adsorption. Pathogen removal has very rarely been considered an objective, but for reuse of effluent in agriculture, this must now be of primary concern and process should be selected and design accordingly (Hillman, 1988). In spite of many large scale researches for wastewater treatment over the world, there are a lot of works to be done to develop best reliable and economic procedure for treatment of wastewater and reuse of this water thus meeting the demand of irrigation in Bangladesh. This study investigated the feasibility of treatment of wastewater in laboratory by using locally available low-cost materials. The specific objectives of this study were: (i) to determining the filtering capacity of different locally available low-cost materials and compare their performance, and (ii) to evaluate the washing characteristics of different filter materials after being polluted during filtering wastewater.

Materials and Methods

The experiments were carried out in the Soil and Water Engineering Laboratory of the Department of Irrigation and Water Management, Bangladesh Agricultural University (BAU), Mymensingh. Additional methodology is mentioned in the following paragraphs.

Collection and preparation of filter materials

Six different locally available materials used in this study. There were: (i) Coarse Sand > 0.425 mm, (ii) Sandy Clay < 0.15 mm (iii) Coarse Gravel > 2.77 mm (iv) Fine Gravel 1 (white) <2.77 mm (v) Fine Gravel 2 (brown) <2.77 mm and (vi) Coal (0.45 mm – 2.77 mm) were used as filter materials. All filter materials were collected from the bank of Brahmaputra River around BAU campus and Mymensingh town. All the materials were washed several times by tap water and dried in the sun for several days. Sand and gravels were also sieved to prepare uniform graded fraction.

Construction and set up of the filter columns

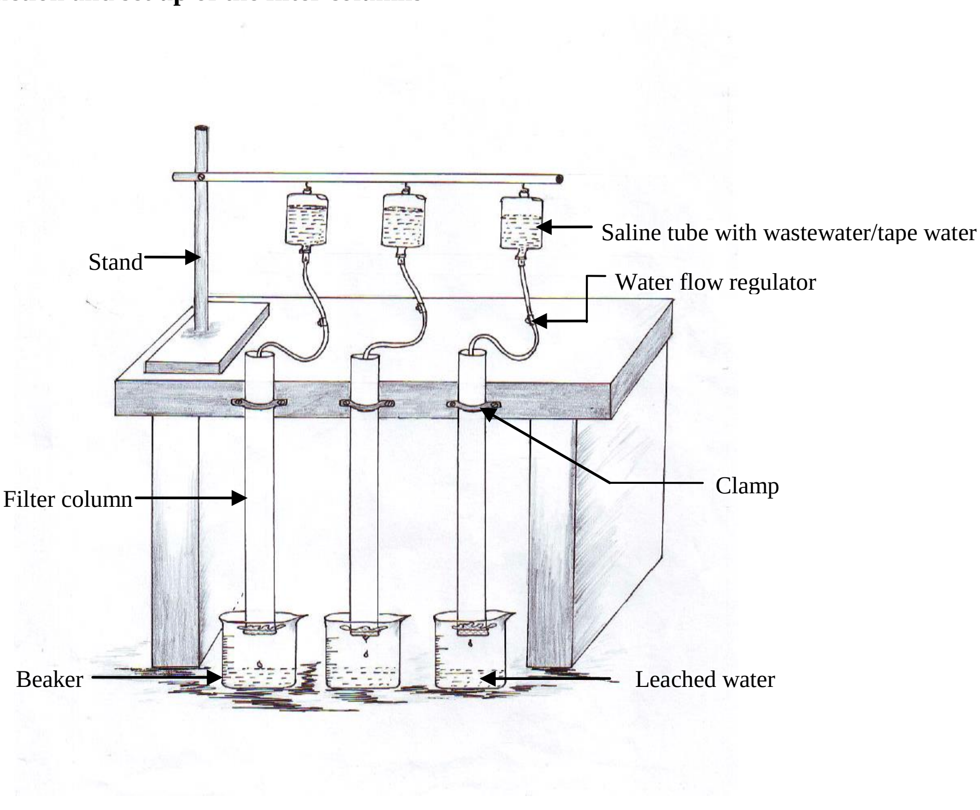

Fig. 1. Schematic diagram of the experimental setup for filtration and washing experiments

Three columns of polyvinyl chloride (PVC) pipes, each 91 cm long and 5.25 cm diameter, were cut for preparing filter columns. The bottoms of these columns were closed with nylon cloth that permits passing water but hold the filter materials in the pipe. Well dried filter materials were poured in each column layer by layer with adequate compaction up to 50 cm from the bottom. Two to three layers of filter paper were placed on the column's material for well distribution of inflow water through the whole upper surface of the filter materials. The schematic arrangement of the experimental equipments and the overall instrumentation are illustrated in Fig. 1. Three prepared columns of the filter materials were clamped with laboratory bench in such a way that the column alignments remained vertical. One beaker was placed just below each column to collect the filtrated water passing through the columns. Adequate arrangements were taken to prevent the evaporation from the beakers. Three saline tubes were hung with a stand above the filter columns as shown in Fig. 1. Water was applied drop wise in the column at a pre-selected rate in order to maintain unsaturated flow through the columns.

Filtration of waste water

At the start of experiment, household wastewater was collected in a jar from the residential area of the Bangladesh Agricultural University campus. The characteristics like total dissolved solids (TDS), electrical conductivity (EC), temperature of the wastewater were measured by an EC meter. Then the water was poured into each saline tube by using a funnel. Pre-determined rate was adjusted for a specific filter material with the help of saline tube regulator and stopwatch. The rates of water application in different filter materials are shown in Table 1. For applying wastewater in the filter columns, the saline tube outlets were placed in the center of the column pipe and the starting time was recorded. Wastewater was passed through the filter material and leached out at the column bottom. The leachates were collected in the beaker, placed at the bottom of each column. When 100 ml of filtered water was collected in a beaker, it was replaced by a new one. Simultaneously, the time to collect this water was recorded. The characteristics (TDS, EC and temperature) of the filtrated water were measured immediately after collection so that the characteristics of water did not change with time. The collection and measurement of leachate for specific filter material was continued until and the characteristics of the filtrated water showed constant values of TDS and EC. This experiment was conducted in the three columns of filter materials at a time. In a second set of similar experiment, the other three filter materials were used.

Table 1. Application rates of wastewater for different filter materials at the time of filtration

Type of filter materials	Rate of application (ml min^{-1})
Coarse sand	6.53
Coarse gravel	8.46
Fine gravel 1 (white)	8.46
Fine gravel 2 (brown)	8.46
Sandy clay	8.46
Coal	8.46

Washing of filter materials

Table 2. Application rates of tap water for washing different filter materials

Type of filter material	Rate of application (ml min^{-1})
Coarse sand	11.0
Fine gravel 1 (white)	8.33
Fine gravel 2 (brown)	11.0
Coarse gravel	8.33
Sandy clay	8.33
Coal	11.0

Maintaining the same procedure as for the filtration experiment, filter columns for all six materials were prepared and experimental set up was done. First, the TDS and EC of wastewater were measured. Then 600 ml wastewater was applied and allowed to pass through the filter materials. The leachate was collected in a beaker placed at the bottom of the column. The characteristics of this collected water (TDS and EC) were measured. Another 600 ml wastewater was added when required to make the filter material in the column fully polluted. The material became fully polluted when it leached out water whose TDS and EC values are the same as that for the applied wastewater. The rate of tap water application for washing different filter materials is given in Table 2. Pollution of filter material was ensured by continuous measurement of the TDS and EC of the leachate. After that (clean) tap water was poured into the saline tube and the rater was adjusted for unsaturated flow. The water was applied in the polluted filter column. The same procedure was followed to collect the leachate water and measurement of TDS and EC, which was followed during filtration experiment. This experiment was continued until the TDS and EC of the leached water became same as that of the applied water or constant values. It then ensured that the filter material was fully washed. The volumes of the clean water required for washing were recorded.

Results and Discussion

Filtration characteristics of different materials

Course sand

The electrical conductivity (EC) of the applied wastewater was 840 µS cm^{-1}. It is observed from Fig. 2 that the first 100 ml water, collected within the first 122 minutes of filtration, had high EC value (818 µS cm^{-1}). The EC of wastewater gradually decreased to 784 µS cm^{-1} at 170 minutes. After that, the filter's ability of removing EC decreased and the EC of filtered water started increasing. Until 240 minutes, the filter material filtrated the wastewater of volume 600 ml and EC increased to 797 µS cm^{-1}. The EC of wastewater was reduced only by 56 µS cm^{-1} by the filter within first 170 minutes. Within this period, the amount of filtrated water was 300 ml. The variation of TDS in the filtrated water with time was similar to that of EC. This is illustrated in Fig. 3. The TDS of wastewater was reduced from an initial value of 421 ppm to 339 ppm in 170 minutes. The amount filtrated water was 300 ml during this period. The materials could reduce TDS up to 398 ppm at 260 minutes.

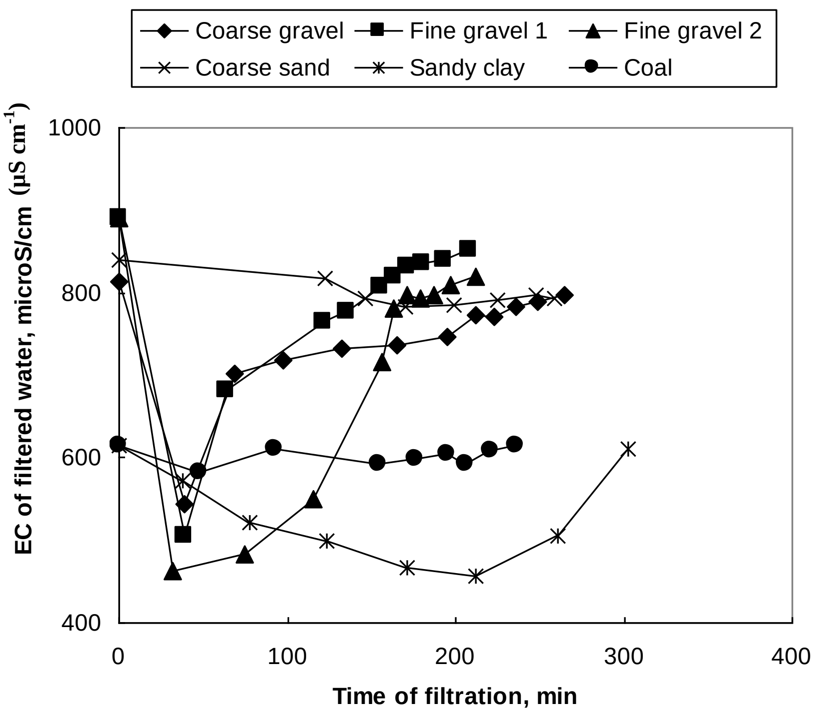

Fig. 2. Variation of electrical conductivity (EC) of filtered water with time for different materials

Coal

The EC and TDS of the applied wastewater were 614 µS cm^{-1} and 306 ppm, respectively. It is observed from Fig. 2 and 3 that the first 100 ml of water collected within the first 48 minutes of filtration had EC and TDS of 582 µS cm^{-1} and 288 ppm, respectively. The filter material thus reduced EC by 32 µS cm^{-1} and TDS by 188 ppm during this time. After collecting the second 100 ml sample of the filtered water, it was found that EC and TDS increased to 610 µS cm^{-1} and 304 ppm, respectively within 93 minutes. After that, the EC and TDS reduced to 593 µS cm^{-1} and 277 ppm, respectively in 154 minutes. Finally, the filter material could not reduce the EC and TDS of water after 236 minutes, and the EC and TDS were the same as that of the applied wastewater. This indicates the reducing capacity of filter material.

Coarse gravel

The EC of the applied wastewater was 813 µS cm^{-1}. This wastewater was passed through the filter column. It is observed from Fig. 2 that the first 100 ml water collected within first 39 minutes of filtration had low EC (544 µS cm^{-1}). After that, the filter's ability of removing EC decreased and the EC of filtered water started increasing. Until 265 minutes, the material filtered 1100 ml of the wastewater and EC increased to 797 µS cm^{-1}. The filtering capacity was rapid up to first 200 ml of water within 69 minutes and after that the capacity decreased slowly. The variation of TDS in the filtrated water with time was similar to that of EC. This is shown in Fig. 3. The TDS of the applied wastewater was 415 ppm and the TDS of first 100 ml filtrated water was reduced to 272 ppm from the initial value in 39 minutes. After that, the TDS of filtrated water started increasing up to 399 ppm in 265 minutes. The volume of filtrated water was 1100 ml during that period.

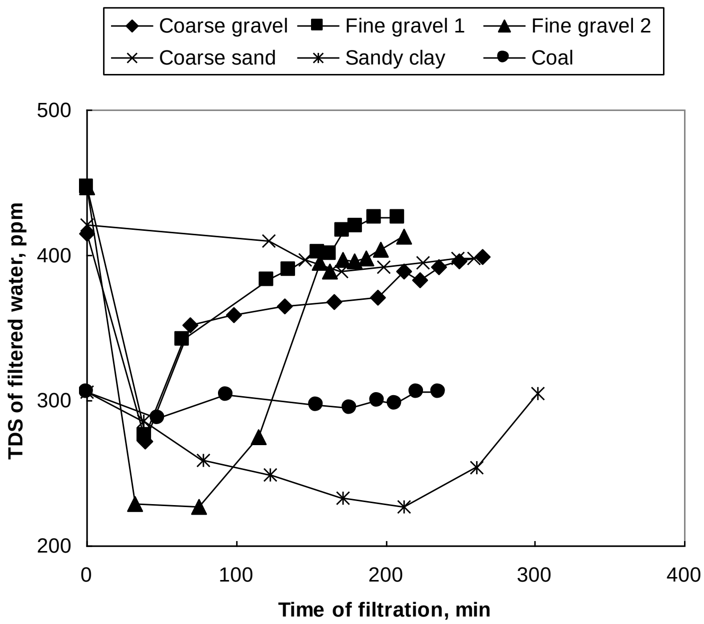

Fig. 3. Variation of total dissolved solids (TDS) of filtered water with time for different materials

Fine gravel 1 (white)

The variation of EC and TDS value of the filtrated water with time of filtration is shown in Figs. 2 and 3, respectively. The EC and TDS of the applied wastewater were 891 µS cm^{-1} and 447 ppm, respectively at 20.9^0C temperature. Fig. 2 shows that 100 ml water, collected within first 39 minutes of filtration, had low EC and TDS values of 506 µS cm^{-1} and 276 ppm, respectively. The filter reduced the EC and TDS of wastewater by an amount of 385 µS cm^{-1} and 171 ppm, respectively within 39 minutes. The material filtrated a small amount of water (400 ml) effectively after that the filter's ability of reducing pollutants decreased. Up to 208 minutes, the filter material filtrated 1000 ml water and the EC and TDS increased to 852 µS cm^{-1} and 426 ppm, respectively.

Fine gravel 2 (brown)

The EC of the applied wastewater was 891 µS cm^{-1} and TDS was 447 ppm at 20.4^0C temperature**.** It is observed from Figs. 2 and 3 that the first 100 ml water collected within the first 32 minutes of filtration had EC of 462 µS cm^{-1} and TDS of 229 ppm. The performance of this filter was relatively better than that of the other ones whose performances are shown in Figs. 2 and 3. The filter's capacity of removing pollutants gradually decreased with time. Up to 156 minutes, the filter material filtered the wastewater of volume 400 ml and EC increased to 716 µS cm^{-1} during this period. The filter material reduced the EC by an amount of 175 µS cm^{-1}. The TDS of wastewater decreased to 275 ppm within 115 minutes and the volume of filtrated water was 300 ml during this same period of time.

Sandy clay

The EC and TDS of the applied wastewater were 614 µS cm^{-1} and 306 ppm, respectively. It is observed from the

Figs. 2 and 3 that the first 100 ml water collected within the first 38 minutes of filtration had low EC and TDS, 573 µS cm^{-1} and 286 ppm, respectively. After that the filter's capacity of reducing EC and TDS decreased and the EC and TDS of filtrated water started increasing. Up to 212 minutes, the filter material filtered the wastewater of volume 700 ml. During this period, the EC and TDS increased to 611 µS cm^{-1} and 305 ppm, respectively.

Comparison of different filter materials in reducing EC and TDS

A summary of performance parameters of the six filter materials used in this study is given in Table 3. The performance parameters are: volume of effectively filtered water, time required for filtration, and reduction in EC and TDS. The performance of coal was found very poor whereas fine gravel performed the best.

Table 3. Reduction of electrical conductivity (EC) and total dissolved solids (TDS) of wastewater during filtration by different materials

Type of filter material	Volume of effectively filtered water (ml)	Time required (minute)	EC of applied wastewater (µS cm^{-1})	Range of reduction of EC (µS cm^{-1})	TDS of applied wastewater (ppm)	Range of reduction of TDS (ppm)
Coarse sand	700	259	840	784-818	421	421-398
Coal	300	174	614	582-610	306	288-304
Coarse gravel	600	195	813	544-797	415	272-399
Fine gravel 1 (white)	500	155	891	506-852	447	276-426
Fine gravel 2 (brown)	500	163	891	462-820	447	229-413
Sandy clay	500	261	614	457-611	306	227-305

Washing properties of filter materials used

Coarse sand

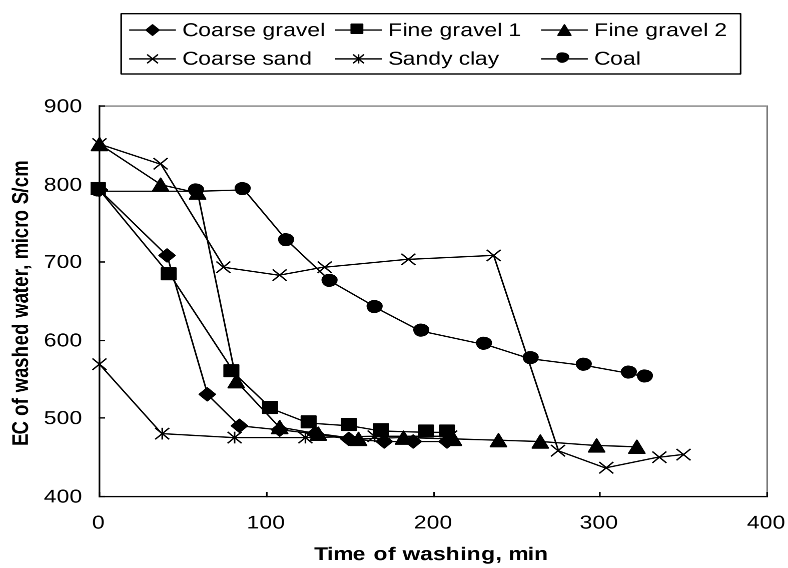

Fig. 4. Reduction of electrical conductivity (EC) of different filter materials with time of washing

The change of EC and TDS of leached water with time of washing is shown in Figs. 4 and 5, respectively. The coarse sand filter was fully polluted by wastewater of EC 851 µS cm^{-1} and TDS 426 ppm. The EC and TDS of tap water that was used for washing the filter were 461 µS cm^{-1} and 230 ppm, respectively. In order to wash the polluted filter, 800 ml tap water was needed. The time for washing was 304 minutes. Actually, the filter could not be fully washed out. The washing curve for this filter material shows quite different trend than that of the others. The filter was washed very quickly up to first 75 minutes after which the rate of washing decreased as can be revealed in Figs.

4 and 5.

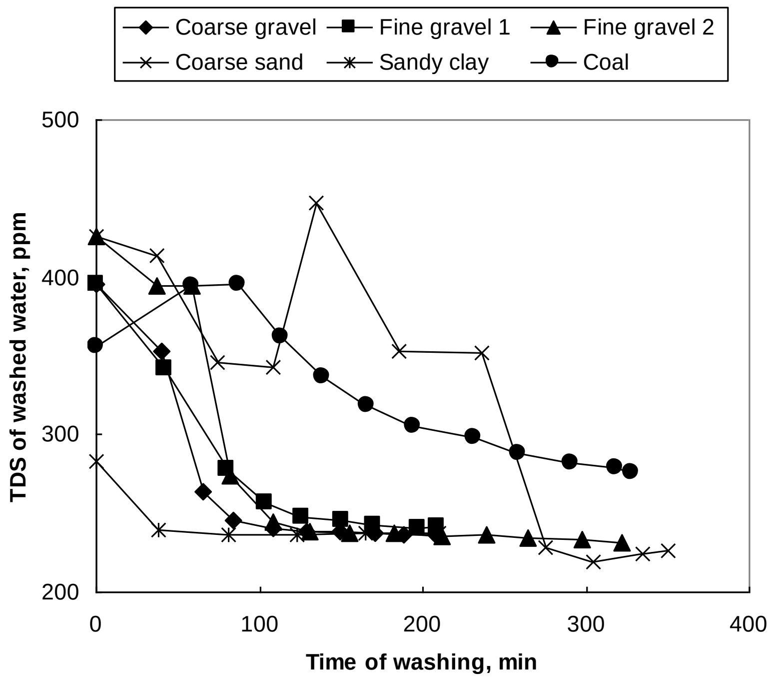

Fig. 5. Reduction of total dissolved solids (TDS) of different filter materials with time of washing

Coal

In this case, the EC and TDS of wastewater ware 79µS cm^{-1} and 356 ppm, respectively by which the filter was fully polluted. The EC and TDS of the last collected water from the polluted filter was the same as that of the wastewater applied during filtration. The EC and TDS of water passed through the filter column at 328 minutes were 552 µS cm^{-1} and 276 ppm, respectively. The total volume of water required for washing the filter was 1100 ml. During this time, it is observed from Figs. 4 and 5 that a large amount of water, in comparison to other filter materials, was required to wash the filter built with coal.

Coarse gravel

The variation of EC and TDS of filtered water with time of washing is presented in Figs. 4 and 5, respectively. The EC and TDS of water drained from the polluted filter were 793 µS cm^{-1} and 396 ppm, respectively for coarse gravel. These values were the same as that of wastewater applied during filtration. This is because the filter was fully polluted with wastewater having EC and TDS same as that of the applied wastewater during filtration. EC and TDS of tap water were 461 µS cm^{-1} and 230 ppm, respectively with which washing was accomplished. In order to wash the polluted filter, 900 ml of tap water was required. The total time for washing was 208 minutes. In practice, the filter could not be washed out completely. This is because some pollutants of wastewater might be strongly absorbed by the filter material. The filter was washed very rapidly up to first 84 minutes and after that the rate of washing decreased.

Fine gravel 1 (white)

The variation of EC and TDS of drained water with time of washing is shown in Figs. 4 and 5, respectively. The EC and TDS of water leached from the polluted filter at the early time were 793 µS cm^{-1} and 396 ppm, respectively, although the EC and TDS of the applied water was 461 µS cm^{-1} and 230 ppm, respectively. For washing the polluted filter, 800 ml of tap water was required. Washing was completed in 209 minutes. During the early time of washing (first 103 minutes), rate of washing was very rapid.

Fine gravel 2 (brown)

This filter was polluted during filtration with wastewater of EC and TDS of 851 µS cm^{-1} and 426 ppm, respectively. Major portion of washing was done by 300 ml of tap water within the first 82 minutes. The total volume of water required for washing the filter material was 1200 ml and total time required was 322 minutes, which shown in Figs. 4 and 5.

Sandy clay

The variation of EC and TDS of wastewater with time of washing are presented in Figs. 4 and 5, respectively. The EC and TDS of water leached through the polluted filter were 570 µS cm^{-1} and 283 ppm, respectively. Washing rate was very rapid within the first 38 minutes, and an amount of 100 ml of tap water was required during that time. This filter could not be fully washed by tap water. Because of some pollutants of wastewater might be strongly absorbed by the filter materials during filtration. The EC and TDS were reduced up to 477 µS cm^{-1} and 238 ppm, respectively by applying 500 ml of tap water.

Comparison of washing characteristics of different filter materials

A summary of performance of different filter materials during washing is given in Table 4. The sandy clay soil was found the best in terms of easy of washing while, coal was found the poorest one.

Table 4. Reduction of electrical conductivities (EC) and total dissolved solids (TDS) during washing the used filter of different materials

Type of filter material	Water required for washing (ml)	Time required for washing (minute)	EC of polluted filter (µS cm^{-1})	EC after washing (µS cm^{-1})	TDS of polluted filter (ppm)	TDS after washing (ppm)	Tap water EC (µS cm^{-1})	Tap water TDS (ppm)
Coarse sand	700	275	851	454	426	226	443	220
Coal	600	194	791	552	395	276	443	220
Coarse gravel	400	108	793	470	396	236	461	230
Fine gravel 1 (white)	400	126	793	482	396	242	461	230
Fine gravel 2 (brown)	400	108	851	484	426	231	443	220
Sandy clay	200	81	570	476	283	236	461	230

Six filter materials (coarse gravel, fine gravel 1, fine gravel 2, coarse sand, sandy clay and coal) were used for filtering wastewater. In terms of reducing electrical conductivity (EC) and total dissolved solids (TDS), fine gravel 1 (white) showed the best performance. For the other materials, the sequential of performance in respect of advantages is: fine gravel 2 > coarse gravel > sandy clay > coarse sand > coal. With respect to the requirement of amount of tap water and total time for washing, sandy clay was found the best in respect of performance. The sequential performance of other five materials in respect of advantages is: coarse gravel > fine gravel 2 (brown) > fine gravel 1 (white) > coal > coarse sand. In respect of both filtering and washing quality, fine gravel 1 (white) was found the best and coal was the worst performing filter material among all the filter materials.

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