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Evaluation of some low-cost materials in removing pollutants from wastewater

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ABSTRACT

This study investigated the feasibility of treatment of household wastewater in laboratory by using gravels, sandy soils and coal. In this study, the Electrical Conductivity (EC) and Total Dissolved Solids (TDS) of wastewater filtered through constructed filter columns were measured over time in order to evaluate the pollutant removal characteristics of the 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 in 39, 39, 32, 170, 212 and 48 minutes, respectively. These materials could reduce TDS by 143, 171, 218, 57, 79 and 18 ppm, respectively in the same time 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. At the time of 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 time for washing was 108, 126, 108, 275, 81 and 194 minutes. Among these six materials, sandy clay was washed very efficiently whereas coal was the poorest filter material in respect of washing.

INTRODUCTION

The world population is expanding at a high rate and the fresh water resources have to meet the demand of 6.0 billion people. At the same time, the demand for per capita consumption of water and the need for food production for population are apparent. So, water is the greatest need of any community. Although, some 700 m of water per person are provided by the annual rains in the continents (FAO, 1993), its unequal distribution in time and space allows only parts of this volume to be tapped economically. However, already 45% of this rainfall is being used by the existing demands. Agriculture is the single largest consumer of fresh water resources, using a global average of 70 % of all surface water supplies (FAO, 1996). As the world population is increasing, the need for the food production is also increasing. To get higher production in agriculture, huge amount of water is need to irrigate the land for high yielding variety crops.

Irrigated agriculture occupies approximately 17% of the world's total arable land but production from this land comprises about 34% of the world total. It is well recognized that our finite good quality water resources have been decreasing day by day for using in agriculture and household works. 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. Wastewater can be made usable by making sufficient storage and treatment facility, and developing proper reuse technique for domestic, agriculture, industrial and forest wood production

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system. United Nations predictions of global population increase for 2025 will require an expansion of food production of about 40-45%. As of 2000, 75% of irrigated land is located in the developing countries. It is estimated that, after certain period, this irrigated land will increase to 90% of total land.

Expansion of urban populations and increased coverage of domestic water supply and sewerage give rise to greater quantity of municipal wastewater. This amount of wastewater use in agriculture has become an important consideration all over the world. However, the quantity of wastewater available in most countries will account for only a small fraction of the total irrigation water requirements. Nevertheless, application of wastewater in agriculture will result in the conservation of scarce resource of fresh water and its use for other purposes than irrigation.

Wastewater reuse, after low-cost treatment, may be an important dimension of water resources planning to solve the arising problems of water scarcity throughout the world. Wastewater treatments, today in its various types of treatment processes, utilize microorganisms to convert the organic substance in the sewage into harmless materials. Wastewater treatment duplicates the naturally occurring activities of soil and water microorganisms that use the organics in the sewage as its food source. Adopting as low a level of treatment as possible is especially desirable in developing countries, not only from the point of view of cost but also in acknowledgement of the difficulty of operating complex systems reliably In many locations, it will be better to design the reuse system to accept a low grade of effluent. Pathogen removal has very rarely been considered an objective but, for reuse of effluent in agriculture, this must now be of primary concern and processes should be selected and designed accordingly (Hillman, 1988).

In spite of many large scale researches for wastewater treatment over the entire world, there are lots of works to be done on this issue. Day by day, people are trying to develop best reliable procedure for treatment of wastewater and reuse of this water thus meeting demand of increasing population. People face various problems in developing such procedures and techniques some of which are -unavailability of proper instruments, unavailability of proper filter materials, inability of locally available materials to remove dissolved pollutants, economic problem, and unavailability of support system. With consideration of these problem, the present study was undertaken to investigate the feasibility of treatment of wastewater in laboratory by using locally available low-cost materials. The objectives of the study were to determine the filtering capacity of different locally available low-cost materials and to compare their performances, and to determine the washing characteristics of different filter materials after being polluted during filtering wastewater.

MATERIALS AND METHOD

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.

Collection and preparation of filter materials

The experiments were conducted with six different locally available filter materials. These materials were:

Coarse Sand > 0.425 mm
Sandy Clay < 0.15 mm
Coarse Gravel > 2.77 mm
Fine Gravel 1 (white) <2.77 mm
Fine Gravel 2 (brown) <2.77 mm
Coal (0.45 mm - 2.77 mm)

Sands (coarse and fine) were collected from the bank of the river Brahmaputra. These were washed several times by tap water and dried in the sun for several days. Gravel (coarse and fine) were collected from road construction site within the Bangladesh Agricultural University campus, washed and dried following the same procedure used for the sand. Coal was collected from coal processing and storage place at the Mymensingh town. They were broken by wooden hammer and sieved by a square mesh sieve. All the materials were kept separately in different trays in the laboratory. Sand and gravel were also sieved to prepare uniform graded fraction.

Construction of filter columns

Three columns of polyvinyl chloride (PVC) pipes, each 91 cm long and 5.25 cm diameter, were cut for preparing filter columns. The bottom of these columns was closed with nylon cloth that permits passing water but holds 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 papers were placed on the column's material for well distribution of inflow water through the whole upper surface of the filter materials.

Set up of filtration experiment

The schematic arrangement of the experimental equipments and the overall instrumentation is illustrated in Figure 1. Three prepared columns of filter materials were clamped with laboratory bench in such a way that the column alignments remain 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 illustrated in Figure 1. Water was applied drop wise in the column at a pre-selected rate in order to maintain unsaturated flow through the columns.

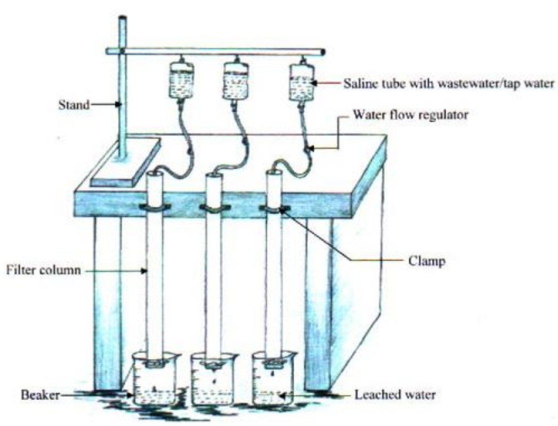

Figure 1: Schematic diagram of the experimental setup for filtration and washing experiments

Conduction of filtration experiments

At the start of the experiment, household wastewater was collected in a jar from the residential area of the Bangladesh Agricultural University campus. The characteristics (Total Dissolved Solids, Electrical Conductivity, temperature, etc.) of the wastewater were measured by an EC meter. Then this 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 given in Table 1.

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

Type of filter materials	Rate of application (ml/min)
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

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 passed through the filter material and leached out at the column bottoms. The leachates were collected in the beaker, which was placed at the bottom of each column. When 100 ml of filtered water was collected in a beaker then 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 soon after their 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.

Conduction of washing experiments

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 3.2.

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

Type of filter materials	Rate of applicatio (ml/min)
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

The 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

Coarse sand

The electrical conductivity (EC) of the applied wastewater was 840 µS/cm. It is observed from Figure 2 that the first 100 ml water, collected within the first 122 minutes of filtration, had high EC, 818 µS/cm. The EC of wastewater gradually reduced to 784 µS/cm at 170 minutes. After 170 minutes, the filter's ability to remove EC decreased and the EC of filtered water started increasing. Up to 240 minutes, the filter material filtrated the wastewater of volume 600 ml and EC increased to 797µS/cm. The EC of wastewater was reduced only by 56 µS/cm by the filter within the first 170 minutes. Within this period, the amount of filtrated water was 300 ml.

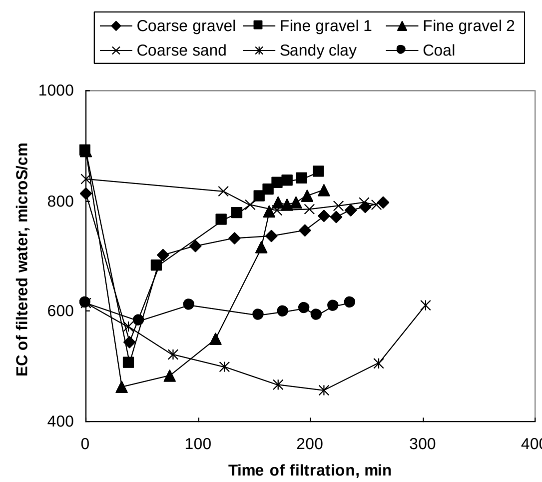

Figure 2: Variation of Electrical Conductivity (EC) of filtered water with time for different materials

The variation of TDS in the filtrated water with time was similar to that of EC. This is illustrated in Figure 3. The TDS of wastewater was reduced from an initial value of 421 ppm to 339 ppm at 170 minutes. The filtrated water was 300 ml during this period. The material could reduce TDS up to 398 ppm at 260 minutes.

Coal

The EC and TDS of the applied wastewater were 614 µS/cm and 306 ppm, respectively. It is observed from Figures 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 and 288 ppm, respectively. The filter material thus reduced EC by 32 µS/cm and TDS by 188 ppm during this time. In the second 100 ml collected water, EC and

TDS increased to 610 µS/cm and 304 ppm, respectively within 93 minutes. After that, the EC and TDS reduced to µS/cm and 277 ppm, respectively up to 154 minutes. Finally, the filter material could not reduce the EC and TDS of water after 236 minutes, and the EC and TDS was the same as that of the applied wastewater. This indicates the reduction capacity of filter material. The volume of filtrated was 600 ml.

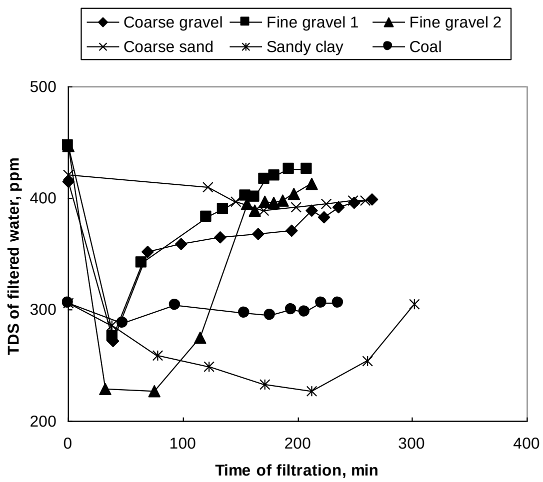

Figure 3: Variation of Total Dissolved Solids (TDS) of filtered water with time for different materials

Coarse gravel

The electrical conductivity of the applied wastewater was 813 µS/cm. This wastewater was passed through the filter column. It is observed from Figure 3 that the first 100 ml water collected within the first 39 minutes of filtration had low EC, 544 µS/cm. After that, the filter's ability to remove EC decreased and the EC of filtered water started increasing. Up to 265 minutes, the material filtered the wastewater of volume 1100 ml and EC increased to 797µS/cm. The filtering capacity was rapid up to first 200 ml of water within 69 minutes after that the capacity decreased slowly.

The variation of TDS in the filtrated water with time was similar to that of the EC. This is shown in Figure 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 at 39 minutes. After that, the TDS of filtrated water started increasing up to 399 ppm at 265 minutes. The volume of filtrated water was 1100 ml during this period.

Fine gravel 1 (white)

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

Fine gravel 2 (brown)

The electrical conductivity of the applied wastewater was 891 µS/cm and total dissolved solids was 447 ppm at temperature 20.4 °C. It is observed from Figure 2 and 3 that the first 100 ml water collected within the first 32 minutes of filtration had EC of 462 µS/cm and TDS of 229 ppm. The performance of this filter was relatively better than that of the other filters whose performances are shown in Figures 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 during this time. The filter material reduced the EC by an amount of 175 µS/cm. 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 electrical conductivity and the total dissolved solids of the applied wastewater were 614 µS/cm and 306 ppm, respectively. It is observed from Figures 2 and 3 that the first 100 ml water collected within the first 38 minutes of filtration had low EC and TDS, µS/cm and 286 ppm, respectively. After that the filter's capacity to reduce 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 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 very poor while that of fine gravel is the best.

Table 3: Reduction of electrical conductivity and total dissolved solids of wastewater during filtration by different materials**.**

Type of filter materials	Volume of effectively filtered water ml)	Time required (minute)	EC of applied wastewater (µS/cm)	Range of reduction of EC (µS/cm)	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	8131	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 used filter materials

Coarse sand

The change of EC and TDS of leached water with time of washing is shown in Figures 3 and 4, respectively. The coarse sand filter was fully polluted by wastewater of EC 851 µS/cm and TDS 426 ppm. The EC and TDS of tap water that was used for washing the filter were 461 µS/cm 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 Figures 4 and 5.

Coal

In this case the electrical conductivity and total dissolved solids of wastewater ware 791 µS/cm and 356 ppm, respectively with 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 and 276 ppm, respectively. The total volume of water required for washing the filter was 1100 ml. During this time, it is observed from Figures 4 and 5 that a large amount of water, in comparison to other filter materials, was required to wash the filter built with coal.

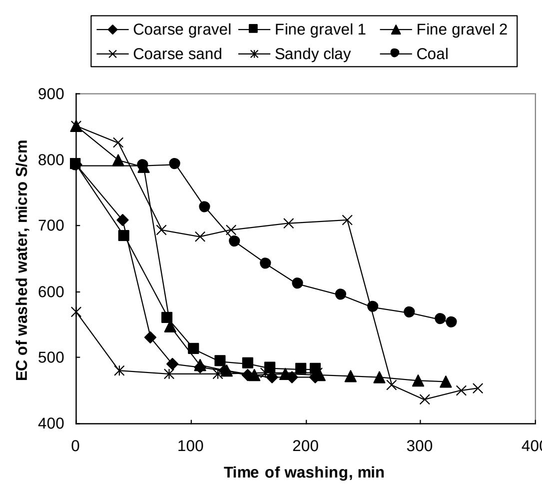

Figure 4: Reduction of Electrical Conductivity (EC) of different filter materials with time of washing.

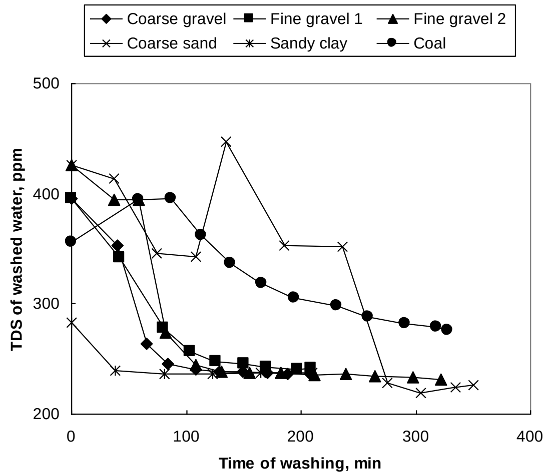

Figure 5: Reduction of Total Dissolved Solids (TDS) of different filter materials with time of washing.

Coarse gravel

The variation of EC and TDS of filtered water with time of washing is illustrated in Figures 4 and 5, respectively. The EC and TDS of water drained from the polluted filter were 793 µS/cm 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 µS/cm 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 after which the rate of washing decreased.

Fine gravel 1 (white)

The variation of EC and TDS of drained water with time of washing is displayed in Figures 4 and 5, respectively. The EC and TDS of water leached from the polluted filter at the early time were 793 µS/cm and 396 ppm, respectively, although the EC and TDS of the applied water was 461 µS/cm and 230 ppm, respectively. For washing the polluted filter, 800 ml of tap water was required. Washing was accomplished 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 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 Figures 4 and 5.

Sandy clay

The variation of EC and TDS of wastewater with time of washing is illustrated in Figures 4 and 5, respectively. The EC and TDS of water leached through the polluted filter were 570 µS/cm 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 this time. This filter could not be fully washed by tap water. This is because some pollutants of wastewater might be strongly absorbed by the filter material. The EC and TDS could be reduced up to 477 µS/cm and 238 ppm, respectively by applying 500 ml of tap water.

Comparison of washing characteristics of different filter materials

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

Table 4: Reduction of electrical conductivities, EC (μS/cm), and total dissolved solids, TDS (ppm), during washing the used filter of different materials. Also included in this table is the quantity of water required to wash the used filter.

Type of filter materials	Water required for washing (ml)	Time required for washing (minute)	EC of polluted filter (μS/cm)	EC after washing (μS/cm)	TDS of polluted filter (ppm)	TDS after washing (ppm)	Tap water EC (US/cm)	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

CONCLUSIONS

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 and total dissolved solids, fine gravel 1 (white) showed the best performance. For the other materials the sequence of performance is in order of advantages is: fine gravel 2 >coarse gravel >sandy clay >coarse sand >coal. Again, with respect to the requirement of amount of tap water and total time for washing, sandy clay showed the best performance. The sequence of performance of the other five materials in order of advantages is: coarse gravel >fine gravel 2 (brown) >fine gravel 1 (white) >coal >coarse sand. Considering both filtering and washing performance, fine gravel 1 (white) is the best and coal is the least performing filter materials among these filter materials.

RECOMMENDATIONS

Further detailed studies are needed before recommending any filter material(s) for practical use. Some other locally available materials, such as rice husks, dust, ash, stones, bricks, etc. need to be evaluated to test their filtration capacity of wastewater. Additionally, different combinations of all these materials may also be used for further in-depth study. All constituents of wastewater need to be measured for identifying filter performance.

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