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Potential use of waste rubber shreds in drainage layer of landfills - An experimental study

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Abstract. Laboratory tests were conducted to evaluate the performance of waste rubber shreds in leachate collection layer of engineered landfills. The study found that waste rubber shreds layer in combination with a gravel layer can be of potential use in landfill drainage system. To study the performance, conventional gravel along with waste rubber shreds were used in different combinations (with total layer thickness = 500 mm) as leachate collection media. For the laboratory study poly vinyl chloride (PVC) pipes were used. The size range of waste rubber shreds used were 25 mm to 75 mm in length and width = 10 to 20 mm. The gravel size used in the leachate collection media is 10 mm to 20 mm size. Performance study of 7 Test Cols. with different combinations of waste rubber shreds and gravel bed thickness were studied to find out the best combination. The study found that the Test Col.-3 having waste rubber shreds thickness = 200 mm and gravel layer thickness = 300 mm gave the best results in terms of percentage removal in various physico-chemical parameters present in the leachate. Further to find the best size rubber shreds three more Test Cols - 8, 9 and 10 were constructed having the rubber shreds and gravel layer ratio same as that of Test Col.-3 but having rubber shreds width = 10 mm, 15 mm and 20 mm respectively. Based on the results obtained using Test Cols. 8, 9 and 10 the study found that smaller size rubber shreds gave bests results in terms of improvement in various leachate parameters.

Keywords: landfill; leachate collection medium; gravel; rubber shreds; physico-chemical parameters

1. Introduction

Large amounts of rubbers are used in the manufacture of various products for example vehicle tires (largest consumption of rubber, greater than 65% in automobile industry alone). But after a long run these tires are either discarded or the reuse is very minimal. As a result, huge quantity of rubber wastes is being generated every year. Due to special properties of certain types of synthetic rubber, and there are now more than hundred thousand types of articles in which rubber is used as a raw material. This poses two major problems: wastage of valuable rubber and disposal of waste tires leading to environmental pollution (Adhikari *et al*. 2000). The reuse or disposal of rubber wastes has become a major issue throughout the world especially in industrialized nations. In the

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United States alone the market demand for scrap tires in 2007 corresponded to 89% of the annual generated quantities. The total volume of scrap tires consumed in end use markets in the U.S. reached approximately 4105.8 thousand tons of tires (Rubber Manufacturers Association, 2009). The principal use of scrap tires in US are in the energy sector (54%), Ground rubber applications (17%) which include manufacturing of new rubber products, and other sports surfacing and rubber-modified asphalt and for civil engineering applications about 12%. Agricultural use and final landfilling amounts to about 17%. India is the fourth largest producer of natural rubber (NR) by accounting for 8.1% of the global supply (Indian Rubber Statistics 2013). The country produced 913,700 tons of NR during the year 2013. In terms of consumption of NR during the year 2012, India stood the second among all NR consuming countries by accounting for 9% of the global demand. From the above statististics it is clear that huge quantity of rubber being utilized for the manufacture of various products and throughout the world efficient management of rubber waste is a technological challenge (Bhalla *et al*. 2010).

Due to disposal problems or environmental concerns the prominence is more on the reuse of rubber waste products (e.g., vehicular scrap tires etc.). Today, used vehicular tiers are used in many of the civil engineering applications. Shredded tire obtained from scrap tires have been used an alternative fill material for road, embankment and backfill construction etc. (Reddy *et al*. 2010). Whole waste tires have found demand, suitability and economic advantages in fields such as erosion control, highway crash barriers, breakwaters, dams, artificial reefs, playground equipment, etc. Tire shreds have also been used in the in the leachate collection medium as an alternative material to the conventional gravel (McIsaac and Rowe 2005, Plameira and Silva 2007, McIsaac and Rowe 2007). Normally, locally available soil is used as a daily cover in engineered landfills. An innovative waste-derived paste of waste tire chips and paper sludge was proposed for daily cover applications in municipal solid waste landfills (Kelvin and Irene 2010). According to the Mississipi Department of Environmental Quality (2002) the recommended nominal size of the tire shred to be used in leachate collection medium is 50 mm with an acceptable range of 25-100 mm. Further, the leachate collection drainage layer must be 300-500 mm thick and should have a permeability greater than 0.01 cm/sec (MOE 1998, CPHEEO 2000).The effect of insulation on prolonging the service-life of a secondary geomembrane and, consequently, on contaminant transport through a liner system is examined for the case of a volatile organic compound (dichloromethane) found in landfill leachate. The study suggests that the use of tire chips warrants consideration, however there are other practical issues that require consideration in the detailed design and construction of landfill liners (Hoor and Rowe 2012). Bhalla *et al*. (2010) studied the potential use of scrap tire shreds in drainage medium of engineered landfills.

The main objective of the present study is to investigate the potential use of waste rubber shreds in the drainage layer of landfills. The procedure recommended by Bhalla *et al*. (2010) has been used in the present investigation by studying the performance of PVC Test Cols. constructed in the laboratory consisting of gravel and rubber shreds beds as leachate collection medium. Best combination of waste rubber shreds and gravel bed has been identified based on the size of the rubber shreds and percentage reduction in various physico-chemical parameters after the leachate is passed through the experimental Test Cols.

2. Materials and methods

2.1 MSW leachate

Mangalore is an key city in Karnataka Prefecture (India) and is situated on the west coast (12°-52′N latitude and 74°49′E longitude). Mangalore city with a population of about 450,000 produces an average municipal solid waste (MSW) of 220 TPD. All the MSW generated from the city is being landfill at an landfill site, Vamanjoor. At the time of study local landfill leachate was not available and it was therefore prepared in the laboratory synthetically. The selection of leachate for the present study was based primarily on the observed similarities of tropical leachates reported in the literature (Sunil *et al*. 2008, Azeez *et al*. 2013, Dasgupta *et al*. 2013). Table 1 shows concentration of each component of the leachate selected for this study. Chemicals were used in the preparation of leachate, and demineralized water was used in its dissolution and dilution. The mass of each chemical product was obtained on a balance with a sensitivity of ± 0.001 g. The quality of the demineralized water was periodically controlled during each preparation of the synthetic leachate (about 8-10 litres).

2.2 Experimental setup

During this investigation, the performance of leachate collection media with different combinations of gravel and waste rubber shreds have been studied using poly vinyl chloride (PVC) pipes (Test Cols.) The procedure recommended by Bhalla *et al*. (2010) is used in the construction of Test Cols. Ten laboratory Test Cols. were constructed each of height 1200 mm and diameter 160 mm. Details of the Test Cols. are presented in Table 2. Fig. 1 shows close up of gravel and rubber shreds used in the present work. In Test Cols. 1 to 7 waste rubber shreds (size range 25 mm to 75 mm) and gravel layer (size range 10 mm to 20 mm) were compacted either singly or in combination with a total bed thickness of 500 mm (MOE 1998, CPHEEO 2000). Three more Test Cols. 8, 9 and 10 were constructed having gravel and waste rubber shreds layer ratio same as that of the Test Col. that gave best results out of the columns. 1 to 7 (i.e., Test Col.-3 having waste rubber shred layer=200 mm and gravel layer=300 mm). To identify the most suitable rubber shred width, rubber shreds of 10 mm, 15 mm and 20 mm were used in Test Col. 8, 9 and 10 respectively. The illustration of the experimental setup, Test Cols. 1-10 are shown in Fig. 2.

2.3 Methodology

To attain the study objectives 10 Test Cols. were constructed in the laboratory each having height 1200 mm and diameter 160 mm. Synthetic leachate required for the study was prepared by using laboratory grade chemicals. The physico-chemical parameters of leachate before passing through the Test Cols. are shown in Table 1. Details of the Test Cols. are summarized in Table 2.

Table1 Chemical composition of synthetic leachate

Parameter	pH	EC	TDS	Tur.	$CaCO_3$	BOD	COD	Cl^-	NH_4	Ca	Fe	Mg	Cr(VI)
Concentration	7.42	8.1	5022	184	11730	3250	17280	1818	864	456.7	31.5	2541	473.6

*All units are in mg/L except for pH, conductance (mS/cm), turbidity (NTU), and chromium hexa. (μg/L)
**EC-electrical conductance; Tur.-turbidity; $CaCO_3$-hardness; Cl^- chloride; NH_4-Ammonia nitrogen; Fe-iron; Mg-magnesium; Cr(VI)-chromium hexavalent

Table 2 Details of test cols

Test Col.	Test Col. Dimension mm	Rubber shred		Gravel size mm	Drainage layer thickness mm	
		Length (l) mm	Width (w) mm		Rubber shred (t_s)	Gravel (t_g)
1					-	500
2					100	400
3					200	300
4			10-25		250	250
5	Height = 1200 Diameter = 160	25-75		10-20	300	200
6					400	100
7					500	-
8			10		200	300
9			15		200	300
10			20		200	300

(a) Gravel (b) Rubber shreds (c) Leachate

Fig. 1 Materials used for the study

3. Results and discussion

The parameters of synthetic leachate presented in Table 1were beyond USEPA permissible limits. During the study, the leachate was passed through all the Test Cols. separately. The effluent from all Test Cols. after 24 hours was analyzed for various physico-chemical parameters. The performance results of Test Cols. (i.e., 1-7) are presented in Table 3. Percentage reduction in various leachate parameters were calculated using Eq. (1)

$$\% \text{ reduction} = \left(\frac{l_p - l_t}{l_p}\right) \times 100 \tag{1}$$

where l_p=physico-chemical parameters of raw leachate; l_t=physico-chemical parameters of leachate after treatment.

The experimental results of various physico-chemical parameters after passing the leachate sample through the Test Cols. are shown in Fig. 3. From the Fig. 3 it is observed that

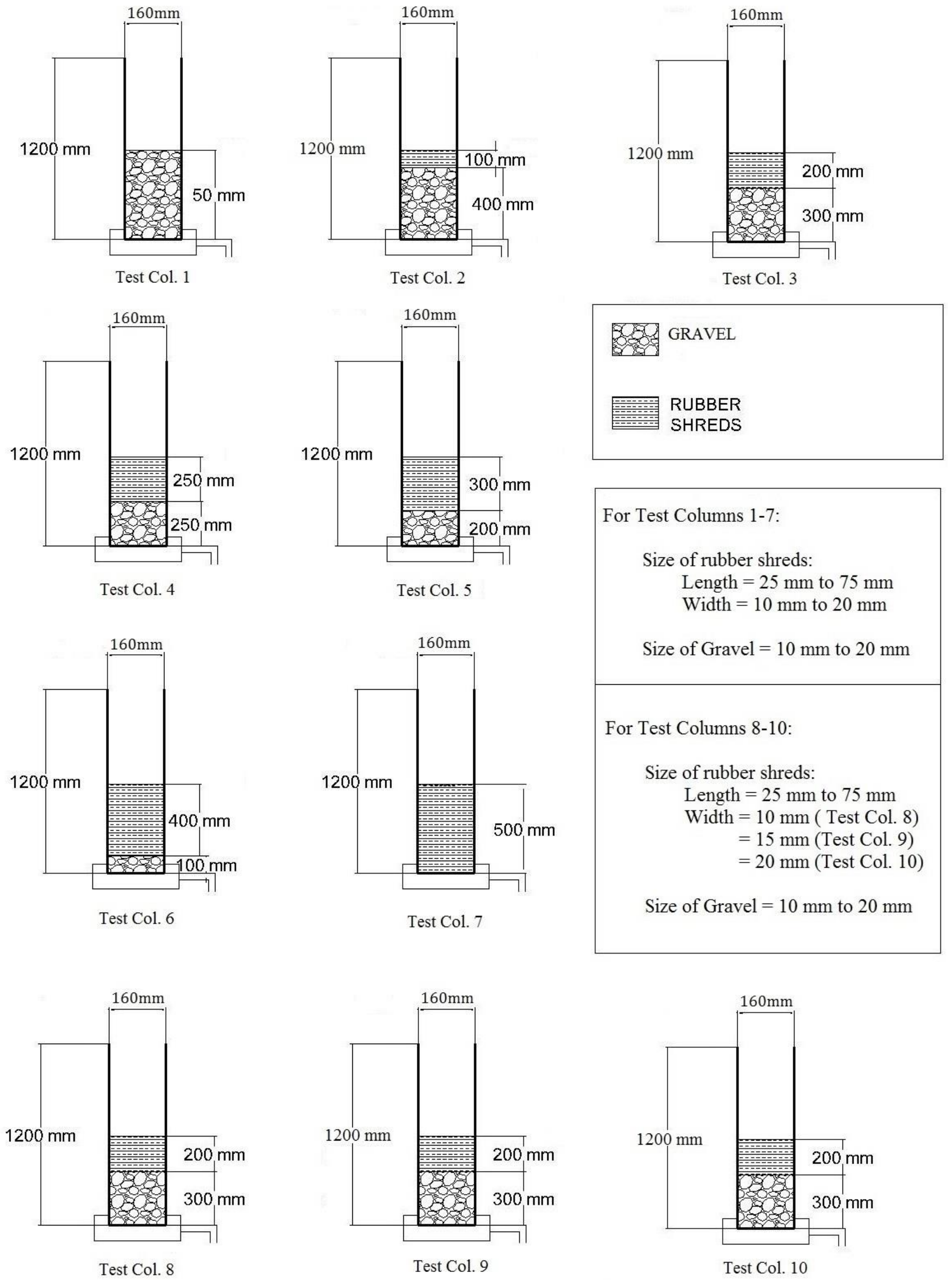


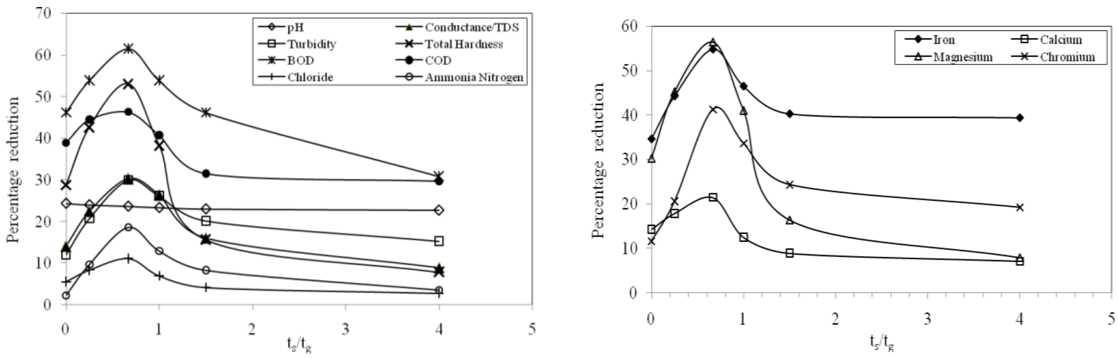
Fig. 2 Schematic representation of experimental test cols. 1-10

improvement in various physico-chemical parameters of the effluent leachate is significant in the range of t_s/t_g=0.25-1.5 (where t_s=thickness of waste rubber shreds layer; t_g=thickness of gravel layer). For t_s/t_g ratio beyond 1.5 the removal efficiency was insignificant. In this research work on the use of waste rubber shreds in the leachate collection system the t_s/t_g ratio for the initial seven Test Cols. were kept as recommended by Bhalla *et al*. (2010): Test Col.-1 (t_s=0 mm, t_g=500 mm,

Table 3 Performance results of test cols. 1 to 7 (*l*=25 to 75 mm; width *w*=10 to 25 mm) after 24 hours

Parameters	Leachate sample	Test Col. 1	Test Col. 2	Test Col. 3	Test Col. 4	Test Col. 5	Test Col. 6	Test Col. 7
pH	7.40	9.20	9.20	9.20	9.20	9.10	9.10	9.00
Conductance	8.10	6.96	6.28	5.64	5.96	6.80	7.38	7.93
TDS	5022.00	4315.20	3893.60	3496.80	3695.20	4216.00	4575.60	4916.60
Turbidity	184.00	162.00	146.00	129.00	136.00	147.00	156.00	169.00
Hardness (as $CaCO_3$)	11730.00	8364.00	6732.00	5508.00	7242.00	9894.00	10812.00	11322.00
BOD (5 days at 27°C)	3250.00	1750.00	1500.00	1250.00	1500.00	1750.00	2250.00	2500.00
COD	17280.00	10560.00	9600.00	9280.00	10240.00	11840.00	12160.00	12800.00
Chloride	1818.14	1717.14	1666.63	1616.10	1691.80	1742.30	1767.60	1792.80
Ammonia Nitrogen	864.00	844.00	780.00	703.00	752.00	792.00	833.00	851.00
Calcium	456.96	391.68	375.36	359.04	399.84	416.16	424.32	440.64
Iron	31.50	20.62	17.58	14.26	16.88	18.84	19.12	20.98
Magnesium	2541.00	1772.30	1390.40	1106.49	1498.10	2124.80	2340.20	2452.80
Chromium Hexavalent	473.60	418.80	376.20	278.20	314.40	358.40	382.60	464.80

*All units are in mg/L except for pH, conductance (mS/cm), turbidity (NTU), and chromium hexa (µg/L)



(a) (b)

Fig. 3 Percentage reduction versus (t_r/t_g) ratio

t_s/t_g=0); Test Col.-2 (t_s=100 mm, t_g=400 mm and t_s/t_g=0.25 mm); Test Col.-3 (t_s=200 mm, t_g=300 mm and t_s/t_g=0.67); Test Col.-4 (t_s=250 mm, t_g=250 mm and t_s/t_g=1); Test Col.-5 (t_s=300 mm, t_g=200 mm and t_s/t_g=1.5); Test Col.-6 (t_s=400 mm, t_g=100 mm and t_s/t_g=4); Test Col.-7 (t_s=500 mm, t_g=0 mm and t_s/t_g=∞);

From Table 4 it is observed that the percentage improvement in terms of reduction in various physico-chemical parameters of leachate samples was maximum with Test Col.-3 having waste rubber shreds to gravel layer ratio, t_s/t_g=0.67. This performance is mainly attributed to the presence of waste rubber layer in the leachate collection system. Laboratory studies conducted by Bhalla *et al*. (2010) to show the effectiveness of scrap tires in leachate collection media concluded that improvement in various physico-chemical parameters was maximum at t_s/t_g=0.67. According to Bhalla *et al*. (2010), scrap-tire-shreds have high porosity, high rubber content and the compressibility is several orders of magnitude greater than conventional gravel layer. Due to high rate of compressibility scrap-tire-shreds bed work as better filter media.

Thus the improvement in the effluent characteristics after passing into the leachate collection layer containing the mixture of rubber shreds and gravel is attributed largely due to the sorption of chemicals and probable filterability characteristics of rubber shreds. For the present study best combination of drainage layer corresponds to Test Col.-3.

The size effect of waste rubber shreds in Test Col.-3 was further investigated using Test Cols.-8, 9 and 10. The width of the rubber shreds in the above Test Cols. was varied in the following manner: Test Col.-3 (t_r/t_g=0.67 and waste rubber shreds width=10 to 20 mm). Test Col.-8 (t_r/t_g=0.67 and waste rubber shreds width (w)=10 mm, w/t_g=0.033); Test Col.-9 (t_r/t_g=0.67 and w=15 mm, w/t_g=0.05); Test Cell-10 (t_r/t_g=0.67 and w=20 mm, w/t_g=0.066). The comparative performance of the Test Cols.-8, 9 and 10 are presented in Table 5. Fig. 3 shows the percentage reduction in various physico-chemical parameters of leachate passed through Test Cell-3, 8, 9 and 10. It is assumed that the smaller sized rubber shreds provide larger surface area and hence better sorption of leachate constituents. The results obtained are comparable with other studies. According to Bhalla *et al*. (2010) when the leachate collection media have only gravel layer of specified thickness it possess less surface area, fewer interconnecting voids for fluid movements; leachate flow is limited to only a few flow channels in comparison to rubber tire shreds, when included in the drainage layer.

Table 4 Percentage improvement in physico-chemical parameters (after 24 hours)

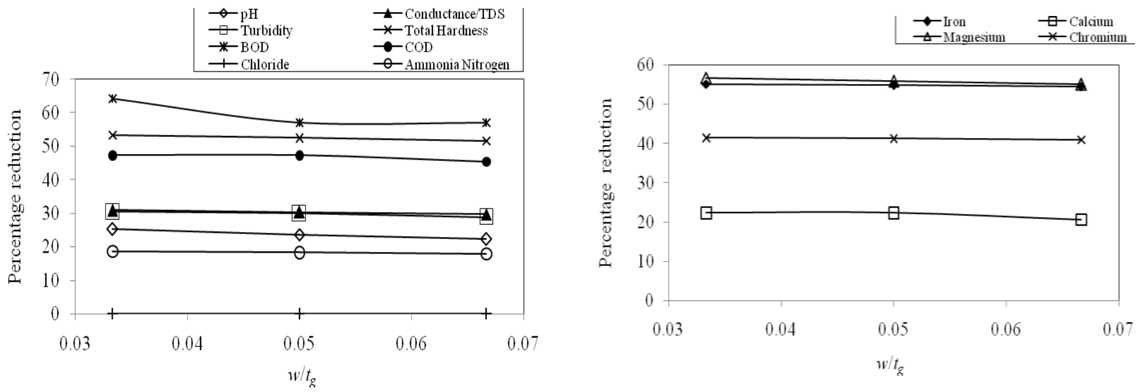
Parameter	Test Col.1	Test Col. 2	Test Col. 3	Test Col. 4	Test Col. 5	Test Col. 6	Test Col. 7
Gravel bed thickness (t_g)	500.00	400.00	300.00	250.00	200.00	100.00	-
Rubber shred thickness (t_s)	0.00	100.00	200.00	250.00	300.00	400.00	500.00
t_s/t_g	-	0.25	0.67	1.00	1.50	4.00	∞
Conductance and TDS	14.07	22.47	<u>30.37</u>	26.42	16.05	8.89	2.10
Turbidity	11.96	20.65	<u>29.89</u>	26.09	20.11	15.22	8.15
Total hardness	28.70	42.61	<u>53.04</u>	38.26	15.65	7.83	3.48
BOD (5 days at 27°C)	46.15	53.85	<u>61.54</u>	53.85	46.15	30.77	23.08
COD	38.89	44.44	<u>46.30</u>	40.74	31.48	29.63	25.93
Chloride	5.56	8.33	<u>11.11</u>	6.94	4.17	2.78	1.39
NH_4-N	2.31	9.72	<u>18.63</u>	12.96	8.33	3.59	1.50
Iron	34.66	44.30	<u>54.82</u>	46.51	40.30	39.42	33.52
Calcium	14.29	17.86	<u>21.43</u>	12.50	8.93	7.14	3.57
Magnesium	30.25	45.28	<u>56.45</u>	41.04	16.38	7.90	3.47
Chromium Hexavalent	11.57	20.57	<u>41.26</u>	33.61	24.32	19.21	1.86

*All units are in mg/L except for pH, conductance (mS/cm), turbidity (NTU), and chromium hexa (μg/L), t_g - Gravel layer thickness, t_s- rubber shred layer thickness

Table 5 Results of Test Cols. - 3, 8, 9 and 10 having waste rubber shreds l=25 mm-75 mm and with different widths Test Col - 3 (w=10-20 mm), Test Col.-8 (w=10 mm), Test Col.-9 (w=15 mm) and Test Col.-10 (w=20 mm)

Parameter	Test Col. 3	Test Col. 8	Test Col. 9	Test Col. 10
pH	9.20	9.50	9.40	9.40
Conductance	5.64	5.26	5.31	5.38
TDS	3496.80	3261.20	3292.20	3335.60
Turbidity	129.00	123.00	125.00	126.00
Hardness (as $CaCO_3$)	5508.00	5406.00	5508.00	5610.00
BOD (5 days at 27°C)	1250.00	1000.00	1000.00	1250.00
COD	9280.00	8640.00	8960.00	8960.00
Cl^-	1616.10	1464.62	1489.87	1489.87
Ammonical Nitrogen	703.00	654.00	658.00	661.00
Calcium	359.04	350.88	359.04	359.04
Iron	14.26	14.02	14.14	14.22
Magnesium	1106.49	1086.91	1106.50	1130.98
Chromium hexavalent	278.20	262.50	266.40	267.90
t_g (mm)	300.00			
t_s (mm)	200.00			
t_s/t_g ratio	0.67			

*All units are in mg/L except for pH, conductance (mS/cm), turbidity (NTU), and chromium hexa. (µg/L), t_g - Gravel layer thickness, t_s- rubber shred layer thickness



(a) (b)

Fig. 4 Percentage reduction versus (w/t_g) ratio

From the study it is found that the leachate sample passed through the combined drainage layer (beds of waste rubber shreds and gravel) resulted in improvement of various leachate parameters compared to the Test Col. containing gravel bed or waste rubber shreds bed alone. The study also imply that waste rubber shreds can be a potential alternative material for the construction of leachate collection system of engineered landfills. When appropriate thickness of waste rubber

Table 6 Percentage improvement of test Cols. 3, 8, 9, and 10

Parameter	Test Col. 3	Test Col. 8	Test Col. 9	Test Col. 10
t_g (mm)	300	300	300	300
t_s (mm)	200	200	200	200
w (mm)	10-20	10	15	20
w/tg	-	0.03	0.05	0.07
Conductance/TDS	30.37	30.90	30.38	29.74
Turbidity	29.89	30.41	29.90	28.87
Total Hardness	53.04	53.39	52.54	51.69
BOD	61.54	64.29	57.14	57.14
COD	46.30	47.27	47.27	45.45
Chloride	11.11	11.59	11.59	10.15
Ammonia Nitrogen	18.63	18.72	18.36	17.89
Iron	54.82	55.08	54.82	54.51
Calcium	21.43	22.41	22.41	20.69
Magnesium	56.45	56.77	55.83	55.08
Chromium Hexavalent	41.26	41.44	41.24	40.92

shred bed is used in drainage layer it will improve upon the reduction in various leachate parameters of environmental concern. The percentage improvement in terms of reduction in various physico-chemical parameters of original leachate are shown in Table 5. In the case of BOD and COD values percentage reduction was as high as 64.29 and 47.27 respectively.

4. Conclusions

Following are the important conclusions drawn from the present study.

• The study found that leachate parameters of environmental concern are significantly reduced after passing the leachate through combined drainage layer, consisting of waste rubber shreds bed and gravel bed as compared to using a conventional gravel or waste rubber shreds bed singly.

• Reduction in various physico-chemical parameters of synthetic leachate was observed after passing through the combination of waste rubber shreds and gravel layer. The removal efficiency was significant in the range of t_r/t_g=0.25-1.5. Further, for t_r/t_g>1.5 improvement was almost negligible. The of range of t_r/t_g ratio is same as those reported for waste tire shreds in the literature.

• The study also found that the smaller size rubber shreds have greater removal efficiency. The percentage improvement was maximum corresponding to Test Col.-3 (with t_r/t_g=0.67, w=10-20 mm), followed by Test Col.-8 (t_r/t_g=0.67, w=10 mm), Test Col.-9 (t_r/t_g=0.67, w=15 mm) and Test Col.-10 (t_r/t_g=0.67, w=20 mm) respectively

• The use of rubber shreds in the drainage layer of landfill helps to treat the leachate to some extent and at the same time solve the disposal problems of rubber waste by converting it to a beneficial material. Therefore the study emphasizes the use of rubber waste in leachate collection media.

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