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Assessment of Sewage Sludge and Coir Pith as Alternative Cover Materials to Red Soil in Bioreactor Landfills

Latha P, Jaya V, Mohammed Iqbal Thayyil

Abstract*: *This study assessed the performance of sewage sludge and coir pith as a potential alternative to virgin red soil as cover material in bioreactor landfills. Three field scale models of anaerobic bioreactor landfills were set up so as to study the performance of the cover materials on leachate generation time, quality and quantity. In one reactor (R1), red soil was used as the cover and was kept as control. In the other two reactors (R2 and R3), modified sewage sludge and coir pith were used as the cover materials, respectively. The leachate produced from each were analyzed based on its quality (Total Solids, pH, BOD, COD, Nitrate and Iron), quantity and generation time. Red soil provided respectively 41.08% and 25.5% reduction in BOD than modified sewage sludge and coir pith. However, coir pith showed better performance in reduction of leachate quantity, total solids, nitrate and iron, thus making it suitable for use as an alternate cover material.

Index Terms*: *Red Soil, Bioreactor Landfills, Sewage Sludge, Coir Pith.

I. INTRODUCTION

In the recent decades, rapid urbanization, population growth and advancements in industrial processes have led to a dramatic growth in the quantum of solid and liquid waste generated (Han et al., 2020). It is expected that by 2050, the municipal solid waste generation will increase up to 3.4 billion tones, of which over 70% will reach landfills (World Bank, 2020). A variety of options are currently adopted for disposal of solid waste, including engineered and non-engineered landfills, incineration, gasification, pyrolysis, composting etc. Landfilling is the oldest and most popular method adopted for ultimate disposal of solid waste. Even though it is considered as the least desirable option in the hierarchy of waste management, it is still practiced in many countries as it is more economical and can generate energy from landfill gas and leachate (Han et al., 2020).

A Municipal Solid Waste Landfill (MSWLF) is a discrete area of land or excavation that receives household waste, non-hazardous wastes like commercial solid waste, non-hazardous sludge and industrial non-hazardous solid waste (M.Swathy et al., 2007). A bioreactor landfill is a MSWLF which rapidly transforms and degrades organic waste. The working principle of a bioreactor landfill is that it accelerates the biological degradation of the organic fraction of the waste by maintaining optimum moisture content inside the cells where it is stored (Nanda and Berruti, 2020). Leachate recirculation controls the moisture content and the microbes stabilize the organic waste resulting in improved quality of leachate (Kumar et al., 2011). Once waste is placed inside a bioreactor landfill, stabilization occurs in five successive phases, namely initial adjustment phase, transition phase, acid formation phase, methane fermentation phase and maturation phase, resulting in the production of leachate and landfill gas composed mostly of methane and carbon dioxide (Bikash et al., 2014). Landfill leachate is a major threat due to its toxicity, heavy metals and higher organic matter (Pasalari et al. 2018).

A comprehensive design of a bioreactor landfill inevitably involves liner systems, cover materials, facilities for collection, storage and conveyance of leachate, landfill gas recovery systems, surface and subsurface water monitors etc. However, the most widely adopted operation is limited to depositing waste into the ground and concealing it with soil (Nanda and Berruti, 2020). Cover materials in landfills prevent the waste from deterrence of pests and acts as a sealant between waste and air. The quantity of cover in a typical landfill is about 20-25% of the fill capacity (Afshin and Mamadou, 2016). Traditionally, soil is used as the daily cover. Due to high cost and scarcity of virgin soil, there is a need to exploit the usability of locally available waste materials as alternate cover materials in bioreactor landfills.

Many studies have been done using biochar (Ding et al., 2019), compost (Hurst et al., 2005), construction and demolition waste (Solan et al., 2010), fly ash (Shaikh et al., 2021), dredged marine materials (Çevikbilen et al., 2020) and peat based materials (Afshin and Mamadou., 2016). By virtue of its hydraulic performance and capability of leaching toxicity, sewage sludge can be used as temporary cover material Jun et al (2015) proposed the use of sewage sludge as a cover material in landfills. But due to its high permeability and low strength, sludge cannot be directly used as a cover material. Permeability required for daily cover is of the order of 1.0 x 10^{-4} cm/s.

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Sludge is usually modified with lime, cement, slag, construction waste and mineralized refuse when used as landfill cover material. Sewage sludge mixed with red gypsum was used by Rosli et al (2020) and an optimum composition was obtained as 1:1. Vinitha et al., (2017) modified dry sewage sludge by mixing with 30% coir pith so as to bring the permeability to the acceptable limit for daily cover. Coir pith, a spongy material that binds the coir fibre in the husk, is a by-product of the coir fibre processing industry. The potential of coir pith has not been fully utilized in spite of its advantages and large availability (Coir Board Report, 2016). It is being accumulated near coir processing units, causing disposal problems, groundwater contamination by the release of phenolic compounds and fire hazards. Neethi and Subramanian (2006) investigated various physical properties of coir pith with regard to its moisture content and particle size. From the survey of previous literatures, it can be observed that significant field scale research has not been done in assessing the properties of the leachate while interacting with different cover materials. Most of the studies focused on mitigation of methane emissions and odour from landfills. The influence of cover materials on the quality and quantity of leachate was not fully understood. This study evaluates the performance of modified sewage sludge and coir pith as cover materials and proposes their use as alternative to red soil. This can also provide a sustainable solution to the management of these waste materials as a landfill cover, which would otherwise have posed serious environmental problems when dumped openly.

II. MATERIALS AND METHODS

A. Design of Field Scale Bioreactor Landfill

Three bioreactors namely R1, R2 and R3 of dimensions 1.5m x 1m x 1m were used for the field study (Fig. 1). In R1, Red soil was used as the cover material and was kept as the control. In R2, modified sewage sludge and red soil was used as the cover material in 1:1 ratio. Dry sewage sludge was modified by mixing with 30% coir pith so as to bring the permeability to the acceptable limit for daily cover (Vinitha et al., 2017). In R3, coir pith and red soil was mixed in 1:1 ratio and was used as the cover material.

Fig. 1 Bioreactors R1, R2 and R3 on field

At the bottom of each reactor, 12mm aggregates were placed over 20mm aggregates for a total depth of 20 cm. Over this, perforated PVC pipes (3/4” dia) were placed at a slope of 2% towards the drainage outlet (Fig. 2). Valves were attached to the outlet pipe to regulate the flow of leachate. Over this, a geotextile liner is placed as the transition layer and vertical pipes were also inserted for leachate recirculation (Fig. 3).

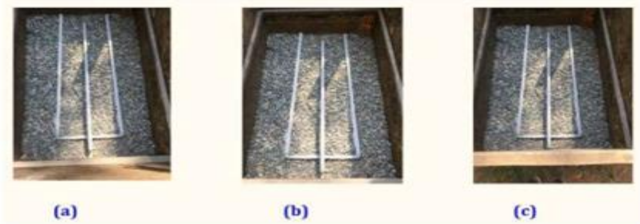

Fig. 2 Under drainage piping to collect leachate for (a) R1, (b) R2, (c) R3

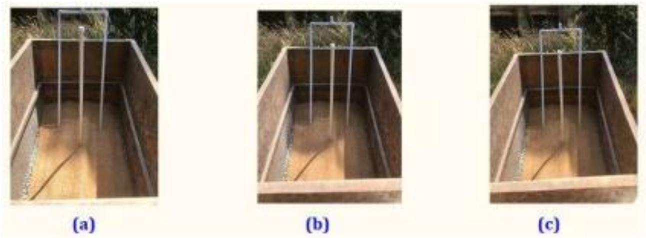

Fig 3. Geotextile liner and leachate recirculation pipes for (a) R1, (b) R2, (c) R3

B. Characterization and Quantification of MSW

Synthetic solid waste was prepared as per the composition given in MSW Manual 2016 (Table. I). This waste was filled in a vessel of size 15cm x 15cm x 15 cm with mild compaction. Density was determined by dividing the mass of waste filled with the volume of the waste in the vessel. Moisture content of solid waste was determined using wet-mass method of measurement (Eq. 1).

$$Moisture\ content\ (\%) = \frac{a-b}{a} * 100 \qquad (1)$$

Where a = initial mass of the sample

b = final mass of the sample after drying

After calculating the density of the solid waste and the total volume to be filled, the total weight of waste required to be collected was obtained.

Table I Composition of MSW

Components	Percentage
Biodegradables	47.43
Paper	8.13
Plastic / Rubber	9.22
Metal	0.5
Glass	1.01
Rags	4.49
Other	4.02
Inerts	25.2

C. Characterization and Quantification of Cover Materials

Water content, density, particle size distribution and permeability of red soil, modified sewage sludge and modified coir pith were determined using standard soil laboratory test methods (IS: 2720) at Geotechnical Engineering Lab of College of Engineering Trivandrum. Sewage sludge was modified using 30% coir pith and was mixed with soil in 1:1 proportion. Coir pith was modified by mixing with red soil in 1:1 proportion.

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Oven dry method (IS: 2720 Part II, 1973) was used to determine the water content of the sample (Eq. 2). The sample was dried at 105oC (80oC for modified sewage sludge to prevent charring of organic matter) for 24 hrs.

$$Water\ content\ (\%) = \frac{Ww}{Wd} * 100 \quad (2)$$

Where W_w = weight of water (g)
Wd = weight of dry solids (g)
For calculating the density, the sample was filled in a vessel of size 15cm x 15cm x 15 cm with mild compaction. Density was determined by dividing the mass of filled waste by the volume of the sample in the vessel. Dry sieve analysis was carried out as per IS: 2070,1965 to determine the particle size distribution of cover materials. The result of the sieve analysis is reported graphically on a semi log graph, taking sieve size on log scale and % finer in arithmetic scale. Falling head permeability test was carried out to find the coefficient of permeability as per IS 2720-Part 17 (1986). Water was flown through a relatively short sample connected to a standpipe which provides the water head and also allows measuring the volume of water passing through the sample. Coefficient of permeability was found out using the following Eq. 3.

$$k = 2.303 * a * L * \frac{\log(h1/h2)}{A*t} \quad (3)$$

Where
k = coefficient of permeability (cm/s)
a = area of stand pipe (cm2)
L = Length of pipe (cm)
h1 = Initial reading of stand pipe (cm)
h2 = Final reading of stand pipe (cm)
A = Cross sectional area of sample (cm2)
t = Time (s)
After calculating the density of the cover materials and the total volume of daily cover to be filled, the total weight of cover required in each of the reactor R1, R2 and R3 was obtained. Red soil was collected from inside College of Engineering Trivandrum. Dry sludge was collected from the Sewage Treatment Plant at Muttathara, Thiruvananthapuram. Coir pith was collected from a coir fibre processing industry near Attingal, Thiruvananthapuram. The schematic diagram of the operational bioreactor is shown in Fig. 4.

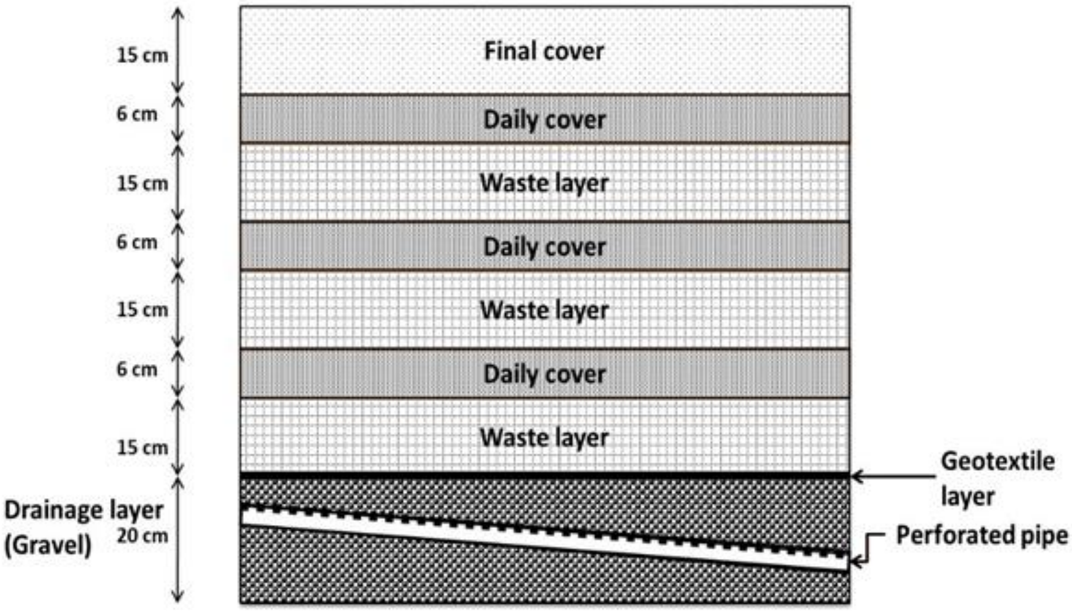

Fig. 4 Schematic section of bioreactor landfill

D. Placement of Waste and Digestion in Bioreactors

Different components of MSW were collected in composition as shown in Table I. These were mixed together on a tarpaulin platform. The mixed waste was then filled in each reactor in three layers, each of depth 15 cm. The first layer of waste was placed, followed by the first daily cover. In a similar manner, second and third layers of waste and daily covers were filled. Daily cover in R1 was red soil and it was the control reactor. In R2 and R3, the daily covers were modified sewage sludge and coir pith respectively. The depth of one layer of daily cover was 6 cm in each of the reactors, fixed in accordance with the dimensions and working conditions of the bioreactors. After filling, the bioreactors were secured by tarpaulin sheets to prevent the entry of rain and pests.

E. Collection and Analysis of Leachate

Leachate generation was first observed after 4 weeks from filling the bioreactors. Leachate was collected and analysed in a 7 days interval. The average temperature (in oC) and average relative humidity (in %) of each week was also noted. The quantity of leachate and the parameters like pH, BOD, COD, Total Solids, Nitrate and Iron were tested. pH was analysed using pH meter. All other tests were carried out as per APHA Standard methods for the examination of water and wastewater.

III. RESULTS AND DISCUSSION

A. Characterization and Quantification of MSW

Properties of synthetic MSW are given in Table II and component wise quantification in one bioreactor is shown in Table III. The density of the synthetic solid waste was obtained to be 300 kg/m^3.

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Table II. Properties of municipal solid waste

Parameter	Value
Density (kg/ m^3)	300
Moisture content (%)	54
Volatile matter (%)	49.3
Ash Content (%)	2.89

Table III. Component-wise quantification in one bioreactor

Item	Percentage	Quantity in one bioreactor (kg)
Biodegradables	47.43	96.05
Paper	8.13	16.46
Plastic/ Rubber	9.22	18.67
Metal	0.5	1.01
Glass	1.01	2.05
Rags	4.49	9.09
Other	4.02	8.14
Inerts	25.2	51.03
Total	100	202.5

B. Characterization and Quantification of Cover Materials

Water content, density, particle size distribution and permeability of red soil, modified sewage sludge and modified coir pith were determined and is shown on Table IV. Particle size distribution curve of the cover materials is shown in Fig. 5. The density of soil was found to be higher than modified sewage sludge and coir pith. Lowest density was for coir pith and soil mixed in 1:1 proportion. Maximum moisture content was observed for coir pith and soil mixture, which is used as the cover material in R3. This is due to the initial wetness of the coir pith during the time of collection and its higher moisture retention property. From Fig. 5. It is evident that soil was well graded than coir pith and modified sewage sludge. Highest effective size was observed for modified coir pith and soil mixed in 1:1 ratio. This is due to the bigger size of the coir pith. Permeability required for daily cover is of the order of 1.0 x 10^{-4} cm/s (Jun et al., 2015). Soil showed higher permeability, making it less suitable than modified sewage sludge and coir pith.

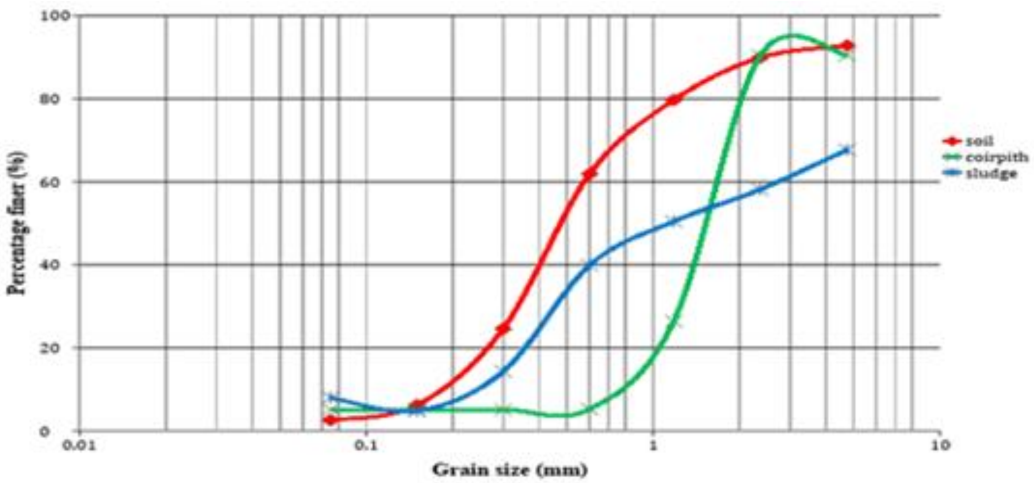

Fig. 5 Particle size distribution curve

Table IV. Properties of cover materials

Cover material	Density (kg/m^3)	Moisture content (%)	Effective size (mm)	Permeability (cm/s)
Soil	1496.3	3.09	0.18	7.24 x 10^{-3}
Soil+Sludge+ Coir pith	888.88	6.91	0.23	1.32 x 10^{-4}
Soil+Coir pith	622.22	33.29	0.73	5.33 x 10^{-4}

C. Quantity of Leachate Produced

Leachate generation was observed after 4 weeks of filling the bioreactors. Leachate was collected and analysed in a 7 days interval. Initially, the quantity of leachate increased with time (Fig 6).

The leachate produced during this time is mostly arising from the moisture content of the waste and from decomposition. The quantity of leachate from R1 was higher. This may be due to the higher permeability of soil. After the ninth week, there was a decline in the quantity of leachate. This may be due to the exhaustion of moisture content in the waste mass.

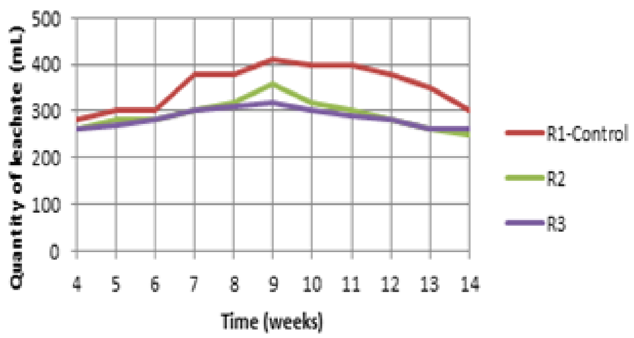

Fig. 6 Variation in quantity of leachate from R1, R2 and R3

D. Total Solids in Leachate

Total solid concentration is increasing with time in all the three reactors (Fig. 7). The maximum value of total solids was found in leachate from R1 with red soil as cover.

This may be due to its finer particle size. TS is lowest in leachate from R3. This may be due to the adsorption by coir pith, which is the cover material used in R3.

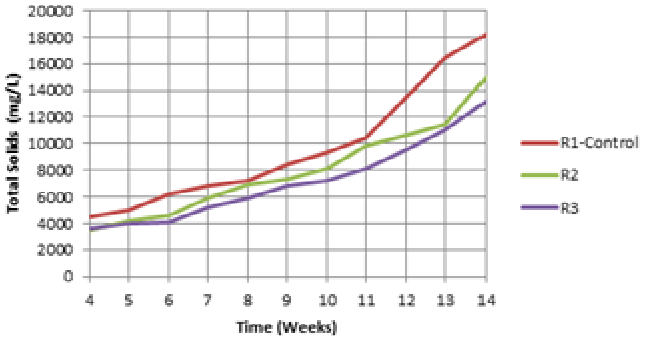

Fig. 7 Total solids in leachate from R1, R2 and R3

E. pH of Leachate

Leachate produced during the initial adjustment phase is as a result of release of moisture during compaction and short circuiting of precipitation through the landfill. pH is found to be within the acidic range for all reactors (Fig. 8). This may be due to the production of volatile fatty acids by microbial conversion of solid waste.

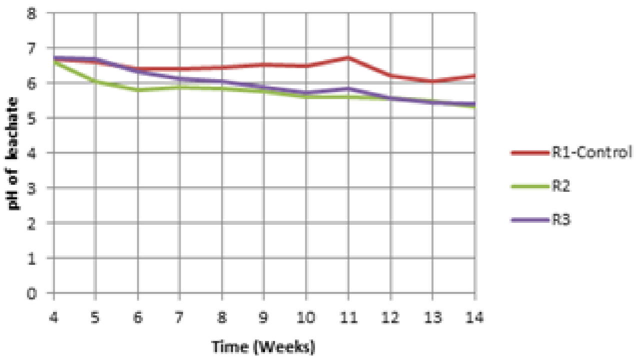

Fig. 8 Variation in pH of leachate from R1, R2 and R3

F. BOD of Leachate

A gradual increase in BOD is observed in all reactors (Fig. 9). Initially the BOD is relatively low. BOD increased with time due to the degradation of organic waste by microbes. R2 shows higher value of BOD. This may be due to the organic load from the sewage sludge which was used in the daily cover.

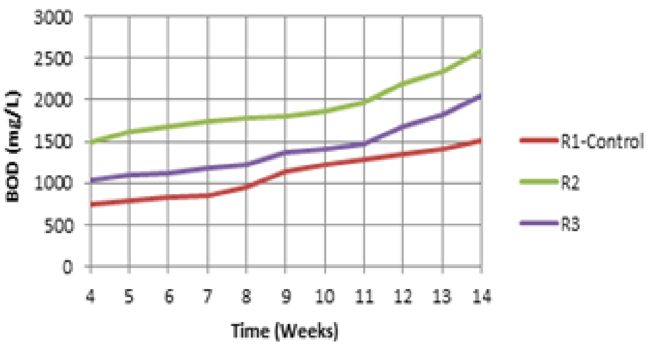

Fig. 9 Variation in BOD of leachate from R1, R2 and R3

G. COD of Leachate

The COD values ranged from 2900 to 14400 mg/L (Fig. 10). The gradual increase in COD may be due to continuous solubilization of solid waste and microbial conversion of biodegradable organic waste. R2 shows a higher value of COD. This may be due to the organic load from the sewage sludge which was used in the daily cover.

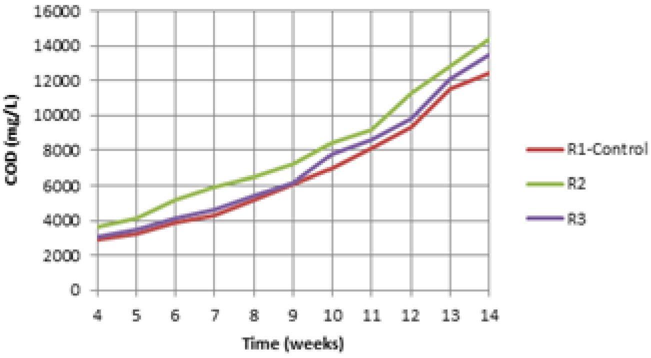

Fig. 10 Variation in COD of leachate from R1, R2 and R3

H. Nitrate in Leachate

In the initial weeks, nitrate concentration is increasing gradually. This is followed by a rapid increase which may be due to increase in biodegradation of solid waste (Fig. 11).

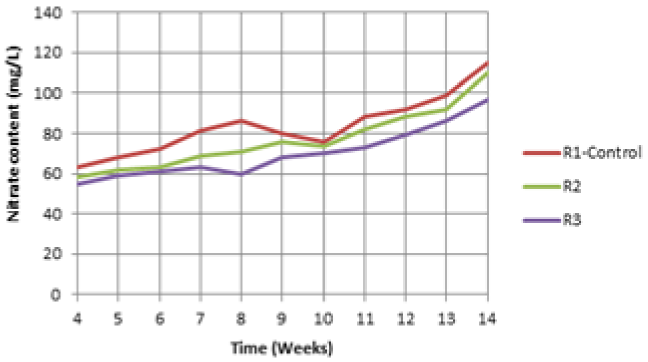

Fig. 11 Variation of nitrate in leachate from R1, R2 and R3

I. Iron in Leachate

Iron concentration was found to be lowest in R3 with coir pith as the cover (Fig. 12). This may be due to its highly porous nature promoting immobilization of metals like Iron. High value of iron obtained after 14 weeks in all the three reactors. This may be due to the leaching of the metal powder (mostly iron), added as a component of MSW in the waste mass prepared.

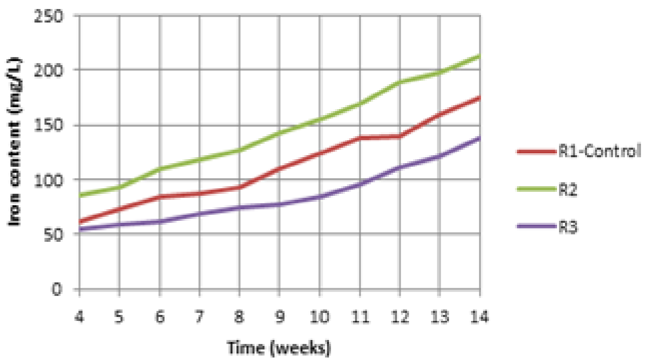

Fig. 12 Variation of iron in leachate from R1, R2 and R3

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IV. CONCLUSIONS

Table V summarizes the properties of leachate after 14 weeks and the EPA emission standards.

Table V. Summary of leachate properties after 14 weeks

Parameter	Cover materials			Emission Standard
	Red soil	Modified sewage sludge	Coirpith	
Peak quantity (mL)	410	360	320	-
Total solids (mg/L)	18200	15000	13200	2000
pH	6.2	5.32	5.4	5.5 – 9
BOD (mg/L)	1520	2580	2040	30
COD (mg/L)	12400	14400	13500	250
Nitrate(mg/L)	115	110	97	10
Iron (mg/L)	175	213	138	3

It is evident that all parameters of leachate except pH are much above the permissible effluent standards, emphasizing the need for further treatment before discharging into public sewers. Red soil, when used as a cover material, provided 41.08% and 25.5% reduction in BOD than modified sewage sludge and coir pith respectively. It was 13.9% and 8.14% more effective to remove COD than modified sewage sludge and coir pith respectively. Coir pith, when used as a cover material, provided 21.9% and 11.1% reduction in the peak leachate quantity, as compared to red soil and modified sewage sludge respectively. It was 27.5% and 12 % more effective to remove Total Solids than red soil and modified sewage sludge, respectively. In addition, it proved to be 21.14% and 35.21% more effective to remove Iron content, and 15.65% and 11.82% more effective to remove nitrate than red soil and modified sewage sludge, respectively. Hence, coir pith can be chosen as a better alternative to red soil and can effectively provide 50% savings in virgin red soil when used as a cover material in bioreactor landfills. Subsequent study will focus on the influence of various geotechnical parameters of coir pith on the quantity and quality of leachate.

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