Pondicherry Engineering College
Department of Civil Engineering

Final Project Report on

Characterization and Monitoring of solid waste dumping sites in Puducherry Region

Sanctioned under DSTE Grant – in-aid Research project proposal support (2007- 08)
(Ref: Lr. 10/DSTE/GIA/RP/JSA-I/2008/2419,dated 12-11-2008)

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1. INTROUCTION

Hazardous Waste generated by the industries can cause environmental pollution and adverse health effects if not handled and managed properly. In order to manage hazardous waste (HW) mainly solids, semi-solids, solvents and other industrial wastes not covered by the Water (Prevention and Control of Pollution) Act, 1974 and the Air (Prevention and Control of Pollution) Act, 1981, and to enable the authorities to control handling, transport, treatment and disposal of hazardous waste (HW) in an environmentally sound manner, Ministry of Environment & Forests (MoEF) promulgated Hazardous Waste (Management & Handling) Rules on 28 July 1989 under the provisions of the Environment (Protection) Act, 1986. In September 2008, the said rules were repealed and new rules entitled "Hazardous Waste (Management, Handling and Transboundary Movement) Rules, 2008" (here after referred as HW (M, H & TM) Rules) were notified. These rules were further amended in the year 2009.

According to the HW (M, H & TM) Rules, any waste, which by virtue of any of its physical, chemical, reactive, toxic, flammable, explosive or corrosive characteristics causes danger or is likely to cause danger to health or environment, whether alone or when in contact with other wastes or substances has been defined as „hazardous wastes" and includes wastes generated mainly from the 36 industrial processes referred under Schedule - I of the said Rules. In addition, some wastes become hazardous by virtue of concentration limits as well as hazardous characteristics listed under Schedule - II of the said Rules.

Based on the above Hazardous Management and Handling rules, Pondicherry Pollution Control Board (PPCB) involves in segregating Hazardous wastes from various wastes in 5 municipalities and proper disposal. Hazardous waste collection, transport and disposal in UT and their challenges is discussed below.

2.0 Types of Waste generation in Puducherry

Waste generation is a natural outcome of many of the human activities. Generation of wastes is inevitable. The management of wastes assumes importance in view of the environmental hazards they pose. The different types of wastes are dealt in detail below:

2.1 Municipal solid waste:

Municipal Solid Wastes are all those wastes arising from human and animal activities that are normally solid and which are discarded as useless or unwanted. The Municipal bodies are responsible for the collection and proper disposal of municipal solid waste as per the Municipal Solid Waste Management Rules, 2000 notified under Environment Protection Act, 1986. The PPCC is the nodal body overseeing the implementation of the Rules.

There are 5 Municipalities (2 in Pondicherry, 1 each in Karaikal, Mahe and Yanam regions) in the U.T. Apart from these as a French legacy the U.T. has 10 communes (5 each in Pondicherry and Karaikal regions), which are agglomerations of villages. These civic bodies are entrusted with municipal solid waste management i.e., collection, transport and disposal.

2.2 Industrial solid & hazardous wastes:

Hazardous wastes are characterized mainly by their properties like ignitability, corrosivity, reactivity, toxicity and persistence. These wastes pose a substantial danger to our health and environment. Due to their distinct properties and by way of ingestion, inhalation, contact etc. they affect human beings adversely. The Hazardous Wastes (Management and Handling) Rules, 1989 (as amended in 2003) envisage a proper mechanism for handling, treatment and disposal of the Hazardous Wastes.

Under the Rules it is the responsibility of the individual industries to collect, store, transport & dispose of the industrial solid & hazardous wastes. PPCC is the regulatory body. The hazardous wastes can be categorized under three broad categories-Recyclable, Incinerable and Landfillable.

Used oil is recyclable. Waste oils etc. are incinerable. ETP Sludge etc. Are landfillable.

Biomedical waste:

Wastes being generated by the hospitals/nursing homes can broadly be grouped into three categories i.e. (1) domestic wastes (2) hazardous wastes and (3) infectious wastes.

Domestic wastes generated are similar to the municipal (domestic) solid waste and if properly segregated (without being contaminated) these can be collected, transported and disposed of along with the municipal solid wastes. Hazardous wastes generated in hospitals primarily comprise of discarded and off - specification chemicals and consumables, the packaging of the medicines, radioactive materials and other such materials which are hazardous.

Infectious wastes being generated in hospitals and nursing homes are a matter of concern as there is a danger of spread of diseases. Under the Biomedical Wastes (Management & Handling) Rules, 1998 it is the responsibility of the individual generator to safely dispose of the biomedical waste. PPCC is the regulatory agency overseeing the implementation of the Rules.

3.0 Pressures:

3.1. Municipal solid wastes

Rapid increase in population and urbanization and the consequent increase in the volume of Municipal solid waste making it difficult to manage with the existing infrastructure facilities.

Changing lifestyles and consumption patterns with ‘use and throw’ products result in increase in the per capita generation of waste. It is estimated that on an average there is generation of 400 gms of waste (garbage) per person per day. Increasing income levels and consumerism has lead to generation of more wastes. Obviously the proportion of non-biodegradable wastes such as plastics is on the rise.

3.2 Industrial hazardous wastes:

With the increase in number of industries and the consequent rise in the industrial output the industrial waste generation also has increased. The main industrial sectors that are generating hazardous wastes in the U.T. are those manufacturing chemicals, pharmaceuticals, Paints/ Pigments, Electronics, Engineering, Textiles, Tiles, Distilleries and Waste re-processing units. Certain processes like electroplating generate more hazardous wastes.

3.3 Biomedical waste:

Increase in population and the consequent need for more health facilities, incidence of disease, occupational health disorders, etc., are the main pressures. Lack of adequate health facilities in the surrounding areas of the neighbouring states also creates pressure in the sense that people from those areas come to the U.T. for treatment. Changing lifestyles and consumption patterns coupled with sedentary lifestyle is also an important pressure.

Increased awareness regarding health, hygiene and the fear of spread of infectious diseases has lead to the use of disposable syringes in place of reusable glass syringes. This has significantly increased the waste generation.

4.0 State:

4.1. Status of municipal solid waste:

The approximate quantity of waste generated town-wise is as below:

Table 4.0: Waste generated town wise

S.No.	**Name of the Town (Municipality)**	**Population (2001 Census) (in thousands)**	**Estimated Quantity of waste (Tons per day)**
1.	Pondicherry - (Pondicherry Municipality)	221	175
2.	Pondicherry - (Oulgaret Municipality)	217	125
3.	Karaikal - (Karaikal Municipality)	74.33	15
4.	Yanam – (Yanam Municipality)	31.3	05
5.	Mahe –(Mahe Municipality)	36.8	15
	Total	190.43	335

4.2 Collection & Disposal:

The local authorities are collecting the waste in most of the urban areas on a day to day basis. The collection and transport has been privatized in some areas and in some areas the 'Hyderabad model' involving collection of segregated municipal solid waste at doorsteps is being tried. The waste is disposed of in the disposal yards. In view of the inadequate space Pondicherry municipality has acquired a new site for the disposal. The major constraints in this regard are lack of adequate space, objection from the nearby residents for dumping of waste, inefficient or no segregation of biodegradable waste from non-biodegradable waste, at point of collection.

Part of the waste is being composted. The major deficiencies found in the management of municipal wastes are:

- Littering of garbage due to unorganized collection
- Establishment of storage facilities like dustbins or other facilities and their operation is not satisfactory. Insufficient number of dustbins and their small size makes frequent lifting necessary, otherwise there will be spillage.
- Processing of garbage is not practiced. No segregation of waste at source level or at the community level.
- Lack of co-operation from the public.
- No scientific management is seen.

4.3 Status of industrial hazardous and solid wastes.

In accordance with the Hazardous Waste (Management and Handling) Rules, 1998 notified under the EP Act, 1986 the PPCC is regulating issues relating generation, transportation and disposal of hazardous wastes. At present there are 88 units which are under the purview of the Rules. PPCC has granted authorization under the Rules to nearly 85 units.

Most of the hazardous waste generating industries in the U.T. are located mainly in Pondicherry region. Few are located in Yanam and Karaikal regions. No such units are there in Mahe region.

Table 4.1: Hazardous waste generation details.

Total No. of units issued authorization (1)	#Recyclable (TPA) (2)	$Handling as Raw material (TPA) (3)	*Land fillable (TPA) (4)	@Incinerable (TPA) (5)	Total (TPA) (2)+(3)+(4)+(5)
85	10631.7	16946.3	92.3	6.8	27667.1

Note:

1. Out of the total Hazardous waste of 27667 TPA, 92.3 TPA is landfillable and 305.423 tones of accumulated landfillable waste has been stored on land (cumulative). It is required to be shifted to TSDF of adjacent State.

2. 4 No. of units which got authorization have wound up their operation.

– Hazardous waste to be reprocessed by other units (eg. Waste oil, dichromate waste, zinc ashes etc.)

$ - Hazardous waste handling as raw material by other units (eg. Dichromate waste)

* - Hazardous waste cannot be reused or reprocessed (eg. ETP sludge)

@ - Hazardous waste cannot be reused or reprocessed; can be incinerated
(eg. Cotton soaked with waste oil)

The total quantity of hazardous waste generated in the U.T. is about 27667.1 tons per annum. Pondicherry region accounts for 87.88 % of the total waste followed by Yanam region accounting for 11.85 % and Karaikal region accounting for 0.25 %. Out of the total quantity of hazardous wastes, 16946.3 TPA is being re-used as raw material for further production. About 10,631.7 TPA is of recyclable & reusable quality and about 92.3 TPA is landfillable. There is no Treatment, Storage & Disposal facility (TSDF) in the U.T. The High Powered Committee constituted by the Supreme Court on the issue of hazardous wastes as advised that states generating less than 20,000 TPA of hazardous wastes might tie up with the neighbouring states for disposal.

In view of the limited land resources and in view of the comparatively less quantity of waste generated, PPCC is planning to tie up with the neighbouring state of Tamilnadu for disposal of hazardous wastes. Tamilnadu is in the process of setting up a TSDF. Presently, the

Hazardous Waste Generators are given authorizations to store the wastes within their premises. After getting approval from the neighbouring states for using TSDFs established in their States the accumulated wastes will be sent to the concerned TSDFs.
As far as the non-hazardous wastes are concerned some of the recyclable wastes like wastes from plastic units are used as raw materials by small-scale units. In some other cases there is no proper disposal (e.g. slag from M.S. Ingots is often dumped in low-lying areas).

4.4 Bio medical waste:-

Under the Biomedical Waste Management Rules, 1998 notified under the EP Act, 1986, it is the responsibility of the generator to dispose of the biomedical waste in a safe manner. In the U.T., Pondicherry region is the main center for medical services. There are 6 medical Colleges and around 90 hospitals and Clinics.

Bio-medical Wastes have to be treated in accordance with Schedule - 1 of the Rules. They need to conform to the standards prescribed in Schedule V. Wastes have to be segregated at the source and collected in colour coded bags/containers as per Schedule II of the Rules and labelled as per Schedule III of the Rules and transported with labelling as per Schedule IV of the Rules.

To comply with the above, the primary option for treatment/ disposal of the wastes is incineration/landfilling (excluding chlorinated plastics). Other major options for treatment/ disposal of the wastes are Autoclaving / Microwaving of the wastes. The residue, ash and chemical wastes used in disinfecting processes can be disposed of in secured landfills. In the U.T. PPPC has been declared as the Prescribed Authority for issuing authorizations for hospitals for treatment/storage/disposal of the wastes.

Most of the hospitals have primary treatment facilities like microwaving /autoclaving. Some hospitals have their own incinerators. There are eight medical institutions / hospitals are having incinerators in the U.T. of Pondicherry . Most of the incinerators are pyrolytic incinerator with dual chamber with light diesel oil, 100 feet chimney and venturi scrubber as air pollution control system. As per Bureau of Indian Standards, (BIS), the quantity of solid waste generated can be between 1 and 2 kg per bed per day. (The waste generated per head in U.S hospitals is as high as 4 or 5 kg/bed).

Table 4.3: Details of Hospitals

S.No.	Category	Total No. of Hospitals	Time limit to get Authorization	Authorization issue status
1.	Above 500 Beds	3 (2-G, 1-P)	June 2000	Authorization Issued
2.	200 to 500 Beds	7 (2-G, 5-P)	Dec. 2000	Authorization Issued
3.	50 to 200 Beds	7 (5-G, 2-P)	Dec. 2001	Authorization Issued
4.	Less than 50 Beds	73 (46-G, 27-P)	Dec. 2002	Authorization issued –26
5.	All other not covered in above	Animal Dispensary - 8 Vet. College – 1	Dec. 2002	Yet to issue

At present the municipal authorities are collecting and disposing of the biomedical waste. Some hospitals like (1) Government General Hospital, (2) Jawaharlal Institute of Post Graduate Medical Education and Research (JIPMER), (3) Pondicherry Institute of Medical Sciences (PIMS), (4) Mahatma Gandhi Medical College and Research Institute (MGMCRI), (5) Arupadai Veedu Medical College and Hospital (all in Pondicherry region), (6) Vinayaga Missions Medical College and Hospital, Karaikal 8) Government General Hospital, Mahe have their own incinerators for disposing of the biomedical wastes.

5.0 Impact:

The possible impact are detailed below:

5.1. Municipal solid waste:

Unscientific disposal of collected municipal solid waste poses the following problems:

- The food and other organic wastes attract insects such as flies, which in turn cause a menace to the nearby residents. This also results in emission of bad odour. The main reason for vehement opposition of the nearby residents for the disposal of municipal solid waste is the problem of bad odour and flies.(In the U.T. land is a scarce resource)

- Improper disposal of plastics often leads to blockage of sewer pipes etc. leading to unhygienic conditions.
- Inadvertent consumption of plastics among the solid waste by animals, thereby affecting themImproper disposal attracts pigs, which may lead to incidence of diseases like brain fever etc.
- Leachate from the disposal site may contaminate ground water.

5.2 Industrial waste:

The major problem with the industrial waste is that its improper disposal may result in the contamination of ground water. In a study carried out by PPCC on the impact of Acid Slurry Units on ground water it is noted that improper handling of raw materials and indiscriminate disposal of effluents in some of the Acid Slurry manufacturing units has resulted in contamination of ground water (pH and Conductivity are affected).

5.3. Biomedical waste:

If incinerators are not operated properly to maintain sufficient residence time, residence temperature and turbulence, there is more harm caused in the form of emission of toxic gases including dioxins (in case of chlorinated plastics). Improper disposal of disposable syringes etc. results in illegal recycling. Similarly disposal of sharps without shredding often causes injuries to the persons handling the same. If the biomedical waste is not disinfected there is possibility of spread of infections.

6.0. Response:

6.1 Proper Management of municipal solid waste: Initiatives:

COMPOSTING:

PASIC (Pondicherry Agro Services & Industries Corporation Ltd.), a Pondicherry State Unit, is manufacturing compost from biodegradable municipal solid waste generated in the Pondicherry city. Compost is also produced from the press mud generated in the Co-operative Sugar Mills located in Lingareddipalayam, near Pondicherry.

The compost is also enriched by adding additional nutrients. PASIC has 3 units (2 in Pondicherry and 1 in Karaikal) for producing compost of 7000 M.T. per annum

New dump site:

PASIC is developing new facility near Pondicherry for proper disposal of municipal solid waste. PASIC also has plans to generate fuel from waste plastics (particularly Polypropylene and Polyethylene).

The Table below gives details of concerned Departments and their specific initiatives to tackle the problems associated with different kinds of wastes.

Table 6.0: Response Matrix

Dept / Agency	Policy	Institution	Programmes / Functions
PPCC	Regulatory agency for issuing authorizations under various Rules dealing with different kinds of wastes such as municipal, hazardous, bio medical wastes etc.	Coordinates with Local administration Department regarding proper disposal of municipal and biomedical waste.	• Conducts regular inspection. • Issue of directions to industrial units not complying with the Rules. Remarks: - Need to increase awareness and disseminate the data collected
Local Admn. Dept.	Implementation of Municipal Solid Waste Management Rules.	Municipalities in Urban areas and Commune Panchayats in Rural areas are the implementing agencies.	Has initiated collection of segregated municipal wastes in some locations based on 'Hyderabad Model'. Acquisition of land for disposal of municipal wastes generated in Pondicherry city.

6.2 DIFFERENT PHASES OF WASTE STABILIZATION

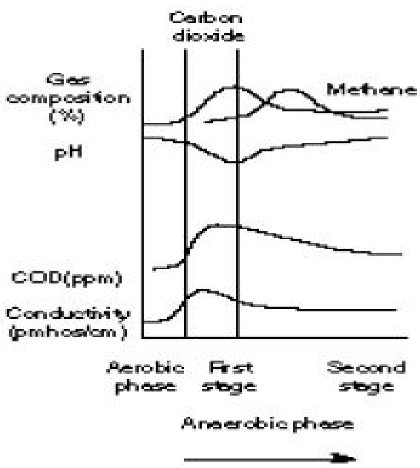


Figure 2.1 Phases of Solid Waste Decomposition (Farquhar and Rovers 1973)

Leachate composition is primarily a function of the age of the landfill and the degree of waste stabilization. Numerous landfill investigation studies (Pohland and Harper, 1985) have suggested that the stabilization of waste proceeds in five sequential and distinct phases. The rate and characteristics of waste produced and biogas generated from a landfill vary from one phase to another and reflect the microbial mediated processes taking place inside the landfill. The rate of progress through these stages is dependent on the physical, chemical, and microbiological conditions developed within the landfill with time (Pohland et al., 1985). The phases experienced by degrading wastes are described below. Figure 2.1 illustrates the five sequential phases of landfill stabilization. Since landfills have various sections or cells, a landfill is not experiencing a single phase of waste stabilization but rather many phases of stabilization are occurring simultaneously.

6.2.1 Phase 1 - Initial Adjustment Phase

This phase is associated with initial placement of solid waste and accumulation of moisture within landfills. An acclimation period (or initial lag time) is observed until sufficient moisture develops and supports an active microbial community. Preliminary changes in environmental components occur in order to create favorable conditions for biochemical decomposition. During this first stage of decomposition, aerobic microorganisms degrade the organic materials to CO2, H2O, and partially degraded residual organics; producing considerable heat . Since only a finite quantity of oxygen is buried within the waste, and there are limitations on air transport into the landfill, aerobic decomposition is responsible for only a small portion of biodegradation within the landfill. Any leachate produced during this initial phase is most likely a result of moisture squeezed out of the waste during compaction and cell construction. Leachate formed during this phase is characterized by the entrainment of particulate matter, dissolution of highly soluble salts initially present in the landfill, and the presence of relatively small amounts of organic species from aerobic degradation (Lu et al., 1985; McBean et al., 1995).

2.2.2 Phase II - Transition Phase

In the transition phase, the field capacity is often exceeded, and a transformation from an aerobic to an anaerobic environment occurs, as evidenced by the depletion of oxygen trapped within the landfill media. A trend toward reducing conditions is established in accordance with shifting of electron acceptors from oxygen to nitrates and sulfates, and the displacement of oxygen by carbon dioxide. By the end of this phase, measurable concentrations of COD (480 to 18000 mg/L) and volatile organic acids (VOA) (100 to 3000 mg/L) can be detected in the leachate.

6.2.3 Phase III - Acid Formation Phase

The continuous hydrolysis (solubilization) of solid waste, followed by (or concomitant with) the microbial conversion of biodegradable organic matter results in the production of intermediate VOAs, ammonia, hydrogen, and CO2 at high concentrations throughout this phase. Acid phase anaerobic biodegradation processes are carried out by a mixed anaerobic population, composed of strict and facultative anaerobes (Lu et al., 1985). Facultative anaerobes aid in the breakdown of materials and reduce the redox potential so that methanogenic bacteria can grow. A decrease in pH values is often observed, and is accompanied by metal species mobilization resulting in a chemically aggressive leachate. Also, a decrease in the sorptive capacity of the refuse is seen during this phase (Lu et al., 1985). The highest concentrations of BOD (1000 to 57700 mg/L), COD (1500 to 71100 mg/L), and specific conductance (1600 to 17100 mhos/cm) occur during the acid formation phase. Viable biomass growth associated with the acid formers (acidogenic bacteria), and rapid consumption of substrate and nutrients are the predominant features of this phase (McBean et al., 1995).

6.2.4 Phase IV - Methane Fermentation Phase

Transition from the acid formation phase to the methane fermentation phase occurs in the range of 4 to 10 years after waste placement and may continue over a period of several years (Krug and Ham, 1995). During Phase IV, intermediate acids are consumed by methane-forming consortia (methanogenic bacteria) and converted into methane and carbon dioxide. Reducing conditions corresponding to this phase will influence the solubility of inorganics, resulting in precipitation or dissolution of these constituents. For example, sulfate and nitrate are reduced to sulfides and ammonia, respectively. COD and BOD concentrations decline since much of these materials are converted to gas (McBean et al., 1995). A small portion of the original refuse organic content (e.g. lignin-type aromatic compounds) is not degraded to any extent anaerobically and remains in the landfill material. These lignin-type compounds are important factors in adsorption and complexation mechanisms (Lu et al., 1985). The pH level is elevated, being controlled by the bicarbonate buffering system, and consequently supports the growth of methanogenic bacteria. Heavy metals are removed by complexation and precipitation. Methanogens work relatively slowly but efficiently over many years decomposing any remaining degradable organics.

6.2.5 Phase V - Maturation Phase

During the final stage of landfill stabilization, nutrients and available substrate become limiting and the biological activity shifts to relative dormancy. Gas production dramatically drops and leachate strength remains steady at much lower concentrations. Oxygen and oxidized species may slowly reappear. However, the slow degradation of resistant organic fractions may continue with the production of humic-like substances.

7.0 LEACHATE GENERATION FROM A LANDFILL

Leachate is produced when moisture enters the refuse in a landfill, extracts contaminants into the liquid phase, and produces moisture content sufficiently high to initiate liquid flow. Generally, as more water through the solid waste, more pollutants are leached. It is therefore important to review the methods that can be used to estimate the amount of leachate generated at a Municipal Solidwaste Landfill site (Tchobanoglous et al. (1993).

7.1 MECHANISMS OF LEACHATE FORMATION

A generalized pattern of leachate formation is presented in Fig. 2.2. The components shown include the following steps:

1. Precipitation (P) falls on the landfill and some of it becomes runoff (RO).
2. Some of P infiltrates (I) the surface (uncovered refuse, intermediate cover, or final cover).
3. Some of I evaporates (E) from the surface and (or) transpires (T) through the vegetative cover if it exists.
4. Some of I may make up a deficiency in soil moisture storage (S) (the difference between field capacity (FC) and the existing moisture content (MC)).
5. The remainder of I, after E, T, and S have been satisfied, moves downward forming percolate (PERC) arid eventually leachate (L) as it reaches the base of the landfill.
6. PERC may be augmented by infiltration of groundwater (G). The procedure used to analyze these processes is referred to as a water balance (WB), various forms of

which are commonly used for the simulation of surface water hydrology. The algebraic statement of this form of water balance is

$$PERC = P - RO - ET - AS + G$$

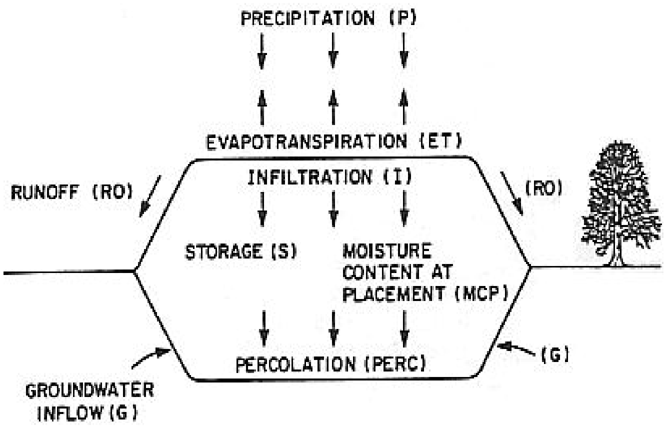


Figure 2.2 Generalized pattern of leachate formation

While the above equation is conceptually correct and comprehensive, accurate predictions of leachate flow are difficult to achieve because of the uncertainties associated with estimating the various terms. Most formulae and methods in use are empirical. Some of the data base required is stochastic in nature (temperature, heat index, precipitation, wind, vegetative growth). Other data are poorly defined (runoff coefficients, refuse arid cover density and compaction, moisture storage capacities).

7.1.1 Precipitation

It includes all water that falls from the atmosphere to the area under consideration. It may occur in a variety of forms including rainfall, snow, hail and sleet. Precipitation varies geographically and seasonally. The amounts of precipitation some times vary considerably within a short distance. Therefore reliable precipitation data for the area under consideration must be developed.

7.1.2 Surface runoff an infiltration

A portion of incident precipitation runs off the site and is lost to the overland flow before it has a chance to infiltrate. The amount of surface runoff depends upon factors such as intensity and duration of the storm, the surface slope, the permeability of the soil cover, and the amount and the type of vegetation. The Runoff coefficients used in the rational method for estimation quantities of storm runoff are provided in table 2.1 (joint committee of WPCF and ASCE 1970). In most cases, it is expected that the surface runoff coefficients for sanitary landfill conditions may lie within the range of 0.07 to 0.2

Table 2.1 typical values of coefficient of Runoff

Surface and slope	Runoff in percent	Coefficient
Grassy/Sandy Soil		
Flat	2%	0.05-0.10
Average	2-7%	0.10-0.15
Steep	7%	0.15-0.20
Grassy/Heavy Soil		
Flat	2%	0.13-0.17
Average	2-7%	0.18-0.22
Steep	7%	0.25-0.35

7.1.3 Evapotranspiration

The amount of moisture available for evapotranspiration at a landfill site is affected by the type of soil and vegetation. Table 2.2 provides some example values of consumptive use from the literature (Lutton e t al 1982)

Table 2.2 Soil moisture storage

S.No	Crop	Consumptive use (m/year)
1	Affalfa	3.5
2	Pasture	3.5
3	Wild hay	2.6
4	Grass/weeds	1.8
5	Small grain	1.6
6	Oats	1.2
7	wheat	1.3

The moisture content in the soil is continually changing; increasing due to infiltration and decreasing due to evapotranspiration. The depletion of moisture due to evapotranspiration is limited to an upper soil zone defined by the effective root zone depth. Table 2.4.3 shows the water holding capacity of several soils.

7.2 LEACHATE GENERATION BASED ON RAINFALL PATTERN

The rainfall pattern of adjacent events decisively determines the water balance of a landfill. Being aware of this fact the available rainfall data have been evaluated and rainfall periods of 1-5 day's duration determined. For the fundamental step of determining the leachate generation or flow-rates to the treatment system the HELP model deems to be suitable.

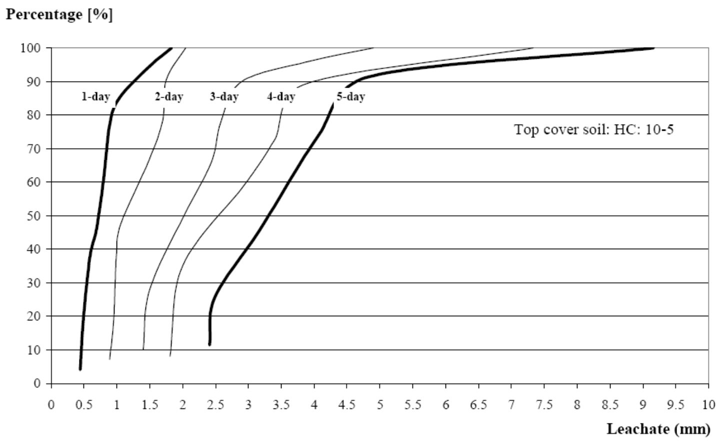


Figure 2.3 Leachate generation rates for covered system (IDF curves)

Rainfall events of 1-day, 2-days, and 5-days show the most frequent occurrence. The effect on the leachate generation is evident however; the double- and triple-fold increase shows only a moderate total amount (Figure.2.3). For an almost covered system the contribution over a long lasting rain event is of minor significance. In contrary to these findings an open system generates much more leachate even if the field capacity is high. An uncertainty lies in the permeability of the waste itself. Provided a common permeability of 10-3 is given the leachate generation will increase by a factor of 5 - 10 (Figure.2.4).

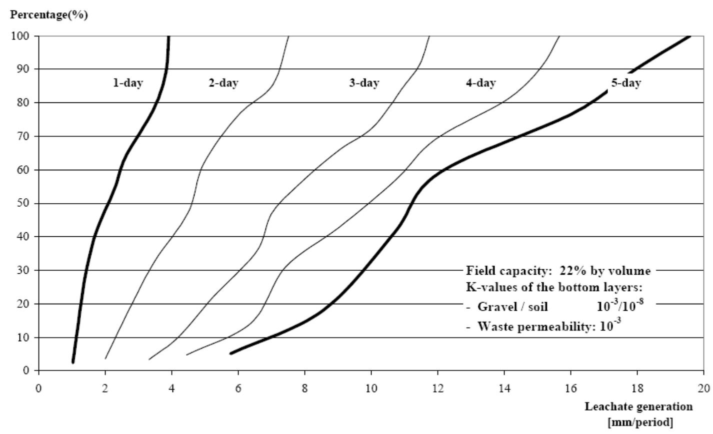


Figure 2.4 Leachate generation rates for open systems (IDF curves)

7.3 SEASONAL VARIATION IN LANDFILL LEACHATE

Rainfall acts as a medium of transportation for leaching and migration of contaminants from a landfill. Rainfall also provides the required moisture content for methane production and biological activity. It has been experienced that in hot and humid climates, leachate production is much higher and varies more than in hot and arid regions due to intensive microbial activity (Trankler, et al., 2001). During dry season, the leachate production is very low due to the evaporation whereas in raining season, the leachate production is related to amount of rainfall intensity. Landfill for disposal of municipal solid waste and developing a treatment scheme for leachate treatment, the quality and quantity of leachate must be determined which may be influenced by climate and microbial activity. On the other side, though high rainfall leads to increased leachate production, it reduces leachate strength due to the dilution. The quality of leachate produced may be regarded as proportional to the volume of water percolating through the landfill waste. Reduction of the quantity of water entering the tip is therefore of great importance in reducing the rate of leachate generation (Tatsi and Zouboulis, 2002). Few researchers have measured the temporal variation in leachate production as 2-45 L/s, depending largely on the precipitation over the landfill (Martin, et al., 1995). The influence of seasonal variation in the landfill leachate quality and quantity varies from place to place which is also influenced by other factors. It is necessary to consider the hydrological and leachate quality data while suggesting a treatment technique to avoid environmental deterioration problems caused by direct disposal.

Considering the quality of design and construction of landfills in developing countries, little information can be derived from randomly taken leachate samples. Leachate generation and composition under monsoon conditions have been studied using lab scale

Reactor to simulate MSW landfills and open cell settings. In this study, Reactors were filled with domestic waste. Results over two subsequent dry and rainy seasons indicate that the open cell Reactor simulation shows the highest leachate generation throughout the rainy season, with leachate flow in all Reactor coming to a halt during the dry periods. More than 60% of the precipitation was found in the form of leachate. The specific COD and TKN load discharged from the open cell was 20% and 180% more than that of the sanitary landfill lysimeters. Types of waste material and kind of pre-treatment prior to landfilling strongly influenced the pollutant load. Compared to the sanitary landfill lysimeter filled with domestic waste, the specific COD and TKN load discharged from the pre-treated waste lysimeter accounted for only 4% and 16%, respectively. Considering the local settings of tropical landfills, these results suggest that landfill design and operation has to be adjusted. Leachate can be collected and stored during the rainy season, and recirculation of leachate is recommended to maintain a steady and even accelerated degradation during the prolonged dry season. The open cell approach in combination with leachate recirculation is suggested as an option for interim landfill operations. (Tränkler et al 2005). There are significant short-term variations in concentration that appear to be related to rainfall, rather than fundamental changes to leachate composition. Inorganic parameters related to pH, such as alkalinity, calcium, and magnesium appear to be chemically buffered. Chromium, cobalt, vanadium, zinc, and the metalloid boron display significant short-term co-variance with a decreasing trend. Iron and manganese concentrations increased significantly after capping. Based on the predominance of ammonia, historic methane generation, and increasing trends for iron and manganese after closure, the landfill cell has an anaerobic (reducing) interior environment. (Statom et al 2004)

7.4 EFFECTS OF MONSOONING CONDITIONS IN TROPICAL COUNTRIES

The typical meteorological boundaries of the tropical region govern not only the leachate generation but also the composition. Due to a low compaction and in consequence rather aerobic/anoxic degradation a stable methanogenic phase deems not to be reached for a landfill 3 years under operation. Moreover dry-out phases followed by flooding affect the landfill performance more significantly. Provided the relative high ambient temperature the degradation seems to happen exceptionally fast. After breakdown phases methane formation can eventually be observed restarting rapidly**.** Accordingly the leachate composition shows peak concentrations that is significant lower than that known from landfills of the Northern Hemisphere. The forthcoming concentrations are lower of those reported from landfills in an acidogenic or an early stage of the methanogenic phase. The intensity of dry and wet phases shows a particular reduction during the dry season and certain spill-out effects with emerging heavy rainfalls of the rainy season. Prevailing hardly degradable matter characterized by high COD and low BOD concentrations is discharged during this initial phase.

The local weather are of paramount concern and are best described as an alternation of an arid season (no rain up to 5 months) and a humid season with extreme rainfall events. Figure 2.5 shows an evaluation of rainfall events corresponding to intensity-duration and frequency relations. The temperature in the tropical regions ranges between 25^{o} C to 40 ^{o} C over a year and high solar radiation throughout the year has an enormous effect upon the evaporation. These conditions and the related design govern the elements of a landfill's water balance namely runoff, evapotranspiration, retention and leachate generation.

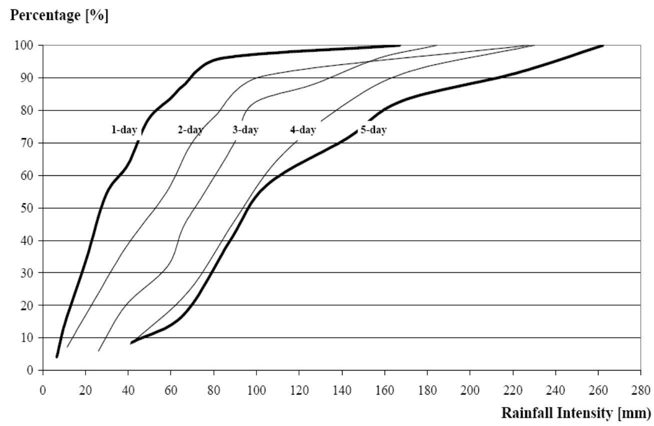


Figure 2.5 Intensity – duration – frequency curves

7.5 MODELLING OF LANDFILL WATER BALANCE

The variation of leachate generation and leachate composition were analysed and compared based on the findings of modelling the water balance of the sanitary landfill Analytical and numerical models are commonly used to simulate the water balance and to predict discharge from landfills. Several models like MOBYDEC (Guyonnet et al., 1998), PREFLOW (Zeiss and Uguccioni 1997), FILL (Khanbilvardi et al., 1995), HELP (Schroeder, 1994) have been published and some of them widely used. MOBYDEC model avoids the use of a waste hydraulic conductivity, as the applicability of this medium property is questionable for MSW due to its non-Darcian nature. The model assumes that the waste behaves as a "double porosity system" (Proceedings Sardinia 2001).Time with rainfall events can be reproduced by allowing a certain proportion of net infiltration into the waste to percolate rapidly through preferential pathways. PREFLOW is a more physically sound dual-domain flow model for a fractured porous medium that takes channelling into account and has been calibrated to MSW. The flow through the matrix is calculated by Richard's equation with sink terms for water removal, addition of water from channels, and removal or addition of water from boundaries (Zeiss and Uguccioni 1997). Despite the physical superiority, the specification of parameters such as channel diameter, length etc required by PREFLOW is hard to define at field scale (Marques, 2000). The HELP, Hydrological Evaluation of Landfill Performances (Schroeder, 1994) model takes into account accumulation of water up to field capacity (FC) and the time lag in the precipitation leachate discharge relation. It does not take into consideration the computation for the vertical and lateral components of flow in each layer of the landfill profile (Khanvilbardi, 1995). HELP predicts leachate flow according to 1-D uniform Darcian flow through a homogeneous solid matrix layer.

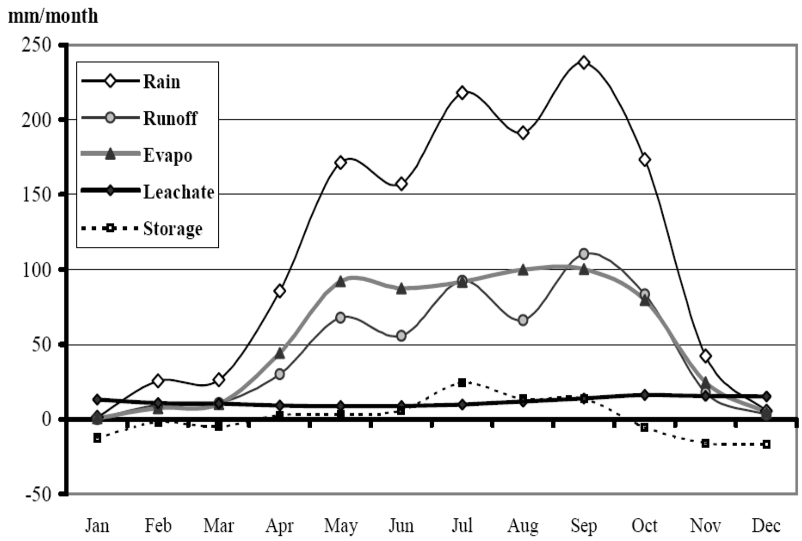


Figure 2.6 Monthly mean values of water balance elements (basis 20 years)

The HELP shall be applied despite some critical features (Fleenor, 1995: Berger, 2000). Main purpose of applying the HELP model is a better understanding of the movement of water through the landfill body. This comprehension should serve for a better prediction of the amount of leachate generated to provide systems for its collection and treatment. Applicability and features for the design of a leachate treatment system shall be discussed based upon the study made at Phitsanulok landfill. Input data and parameters for the

modelling of the water balance are collected at place to the extent possible. The use of default values was intended to be very limited. Figure 2.6 shows one of the water balance components that are mostly influencing the outcome is evapotranspiration. The application of the US based model in the tropical climate like
Thailand has raised some issues like the effect on water balance by variations of short-term intensive rainfall, which might have greater input into evaporation and run-off than infiltration.

7.6 LEACHATE MODELING METHODOLOGY

Leachate migration assessment typically involves two steps. First, leachate generation and infiltration through the landfill liner is quantified, then the migration of contaminants is modeled or measured in the porous subsurface until the point of compliance (the point where pollution level is to be assessed). The theory and governing equations of flow and transport in porous media has been the subject of extensive work, particularly in the past two decades, in response to problems arising from subsurface contamination. Numerous analytical or numerical models have been developed to simulate leachate flow and transport in the subsurface. All these models solve mass, momentum and heat transport equations; however, model capabilities and solution schemes may differ widely. (El-Fadel et al., 1997, and US EPA, 1993)

7.7 MODELING TEMPORAL VARIATIONS IN LEACHATE QUANTITY

Kahrizak landfill has been in operation for several decades with no record of the quantity of the generated leachate. An attempt was made to develop water balance models, which despite the current rough estimates of annual leachate quantity at this site, takes into account the precipitation and evaporation patterns as well as the concept of field capacity. Changes in field capacity and water consumed in gas generation were formulated based on empirical relationships of the nearest applicability to this site found in the literature. Monthly meteorological data were employed with an option provided to convert them into daily average values to match the daily time step if required. Relatively high moisture content of MSW disposed of at Kahrizak landfill site was considered the key leachate generating component. The method of modelling leachate generation presented in this paper was constructed based on a conceptual approach to the problem. This model, despite those introduced in the literature, takes into accounts the changes in the field capacity of the waste and the water loss due to biochemical reactions. The approach seems applicable to Kahrizak landfill site and similar landfills in other arid and semi-arid regions of Iran. The results obtained through execution of model for Kahrizak landfill site seem to be in good agreement with the estimation made by OWRC, although a number of key parameters mainly the field capacity remain to be determined through extensive field measurements and monitoring. The proposed model, which is constructed on a conceptual basis, can be considered a first attempt to determine leachate production rate in Iran. With no data available, the results cannot be considered reliable. Further research is required especially to determine model parameters, based on which the model can then be validate (Safari and Baronian 1999)

7.8 BREAKTHROUGH TIMES

Practical waste and flow parameter values were determined to predict accurate leachate breakthrough times and flow rates for landfill leachate. The experimental design, measurement and analytical procedures of a 2^2 factorial experiment with a total of eight cells are developed to validate channeled flow and characterize flow patterns, measure key waste and flow parameters, and determine the effects of infiltration rate and waste density on the flow parameters and leachate discharge. The measured waste and flow parameter values consist of a practical field capacity of 0.12, a pore size distribution index λ of 0.67, an ultimate moisture content of 1.5 times the practical field capacity, and apparent hydraulic conductivities of $\leq 7.3\ 10^{-3}$ cm/s. These values differ from the HELP water balance model default values. The leachate generation results from the eight pilot waste cells are compared with the HELP predictions. The leachate breakthrough times and discharge volumes compare closely with the measured values if the modified parameters are used in the HELP model. Further research is suggested to construct an appropriate model to predict the channeled and matrix flows. In the mean time, the results in this article provide more accurate waste and flow parameter values for leachate discharge predictions. (Zeiss, et al, 1997)

7.9 THE UNSATURATED ZONE

The flow and attenuation in the unsaturated zone are complex due to the heterogeneity of the topsoil and unsaturated rock zone beneath the landfill. Hence, this region was modeled as a control volume with a constant leachate breakthrough time. Flow was assumed to be one-dimensional. The rock beneath the site contains extensive fracturing and faulting, and the connectivity and influence of these networks on infiltration time is difficult to establish with a reasonable degree of scientific certainty. If the rock beneath the site features a network of connected fractures, the breakthrough time may be reduced to just a few days. To account for this possibility and to present a worst case scenario, chemical attenuation in the un-saturated zone was neglected. Therefore, all leachate and contaminants infiltrating to the subsurface are assumed to reach the groundwater table after the break- through time. (El-Fadel et al,2004)

8.0 METHADOLOGY AND MONITORING SCHEMES

8.1 STUDY AREA

The site used for this study is located in east central part of Puducherry. Puducherry is situated on the southeastern part of India with an altitude of 12°00′47.74″N, 79°51′13.78″E / 12.0132611, 79.8538278. The climate in puducherry is generally humid as it is located in the coastal areas of South India. Winter Runs from December through February. Daily temperature around 30° C and nights are pleasant, even cool. Summer runs from March through July has hot and humid climate. Temperature is normally around 35° C - 38° C. Average annual rainfall of Puducherry region is around is 1338 mm/year. The major source of drinking water is groundwater. The groundwater table is located from 15m to 35m below ground surface (BGS) in most areas. About 190 tons per day of Municipal Solid Waste (MSW) is generated in Puducherry and about 120 tons per day in Oulgaret municipality. Wastes are currently dumped in low-lying areas. The Details of Solid waste Composition for Puducherry is depicted in table 3.2.

Table 3.1 Physical composition of solid waste in Pondicherry

S.No	Physical Components	Value%
1	Organic Matter	39.03
2	Soil Matter	39.40
3	Paper	5.50
4	Textiles	5.20
5	Plastic and Recyclables	4.63
6	Stones	3.20
7	Wood and Coconut	1.53
8	Metal Scraps	0.78
9	Rubber	0.73

The major component of the solid waste in Puducherry is organic matter that constitutes around 40%. The other components present in the waste stream include soil matter, metals, plastics, papers etc. The rag pickers collect most of the valuable recyclables to be sold to the junk dealers. The major non-compostable or non-recyclable residues in the waste stream are plastic carry bags and disposable teacups that have less or almost no value for recycling.

Table 3.2 Chemical composition of solid waste in Pondicherry

S.No	Chemical Components	Value
1	Moisture Content, % mass	37.30
2	Organic carbon, % mass	38.49
3	Calorific value, kJ/ kg	2415.80
4	Nitrogen content, % mass	0.78
5	Phosphorous, mg/ kg	128.00
6	Potassium, mg/ kg	54.00
7	Copper, mg/ Kg	2.00
8	Zinc, mg/ kg	75.00
9	C / N ratio	37.2 to 49.3

The major chemical component of the solid waste in Pondicherry is the organic carbon that constitutes around 38.49%. The other components present in the waste stream include Nitrogen, Phosphorus, Potassium, Copper, Zinc, etc.

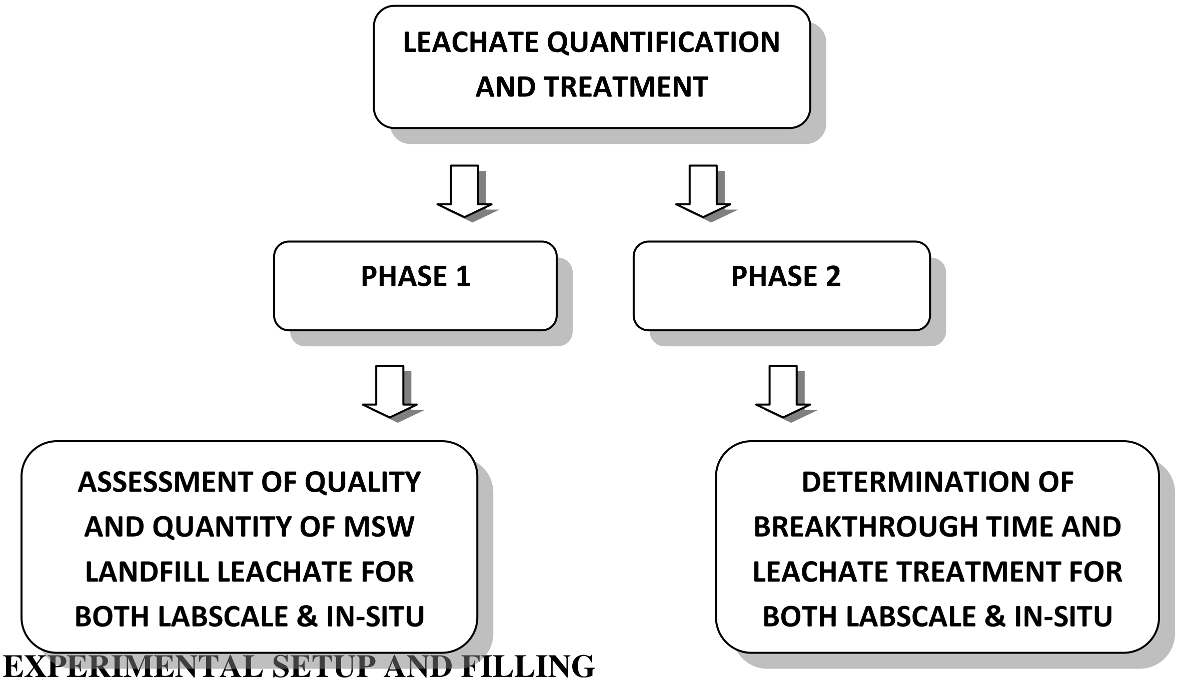
8.2 PARAMETERS USED FOR THE STUDY

The conventional parameters that were analyzed in this study were as follows:

- Chemical Oxygen Demand (COD),
- Biological Oxygen Demand (BOD_5),
- Sulphate (SO_4),
- Chlorides (Cl),
- Total Solids (TS),
- Total Suspended solids (TSS),
- Total Dissolved solids (TDS),
- Total Volatile solids(TVS)
- pH
- Electrical conductivity

These parameters were chosen because sufficient data were available for each one at a majority of the landfill sites. The levels of chloride show no difference between degradation phases. Like the toxic and organic parameters.

8.4 METHODOLOGY



8.5 EXPERIMENTAL SETUP AND FILLING

The experimental setup for lab scale as shown in figure.3.1 comprised of 80cm height and 8.5cm diameter PVC pipe column filled with 40cm deep MSW layer obtained from the disposal site of Puducherry. A 12cm thick layer of locally available red soil is provided both at the top and bottom of MSW column. The bottom soil layer was supported with 4cm thick layer of pebbles with 12-20mm sizes. The schematic of the reactor is shown in figure 3.1 of which one is control and the other one is active. Initially the moisture content was very less when the Solid waste was loaded. Therefore, external addition of water was required to produce leachate in active reactor. Initially water is added 100% by volume of solid waste and the Leachate is collected and analyzed for characteristics. After which subsequent addition of water is entailed increasing by 10% until complete saturation is obtained. Experiment is continued till the quantity

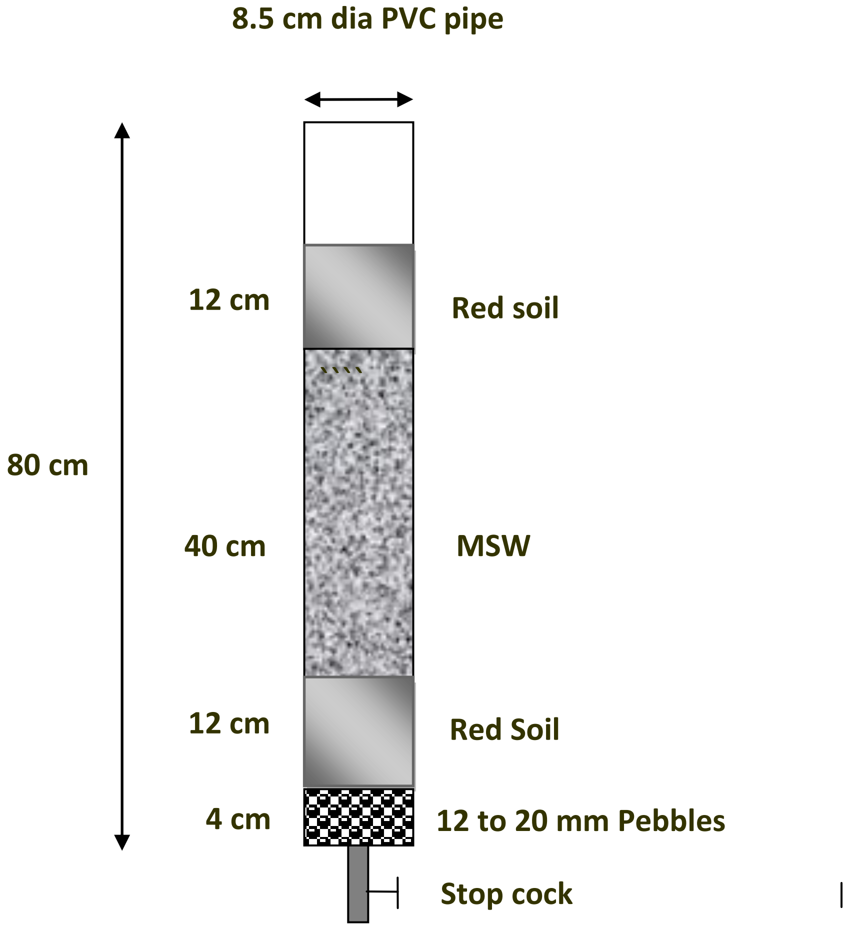


Figure 3.1 Schematic of Solid waste Reactor

of leachate produced at certain percentage coincides with the theoretical value obtained using rainfall intensity. Characterization is done for each % dilution of Solidwaste of leachate produced. In order to determine the quality variation during heavy rains, duration of leaching is monitored for different percentage dilution of Solid waste. Then the leachate is collected and stored at $4^{o}C$ for further analysis. The leachate was analyzed for parameters such as pH, EC, COD, BOD, Solids (total, dissolved, and volatile), metals etc as per ASTM Methods and then subjected to treatments.

Figure 3.2 Reactors used for the experimental study

8.6 CONSTRUCTION OF IN-SITU LEACHATE POND

Two pits shown in figure 3.4 were dug each in the size of 6 feet long, 6 feet wide and 3 feet deep in which the one is control. And a concrete tapering was provided at the depth of the pit. Slope provided for the landfill was 2%.

Figure 3.3 GI mesh for the drain of leachate from solid waste

A GI wire mesh of required dimension was placed on the top of the concrete tapering. Soil collected from the site was spread over the mesh over which the Solid waste was filled.

Volume of solid waste dumped in the pit was 54 cu.ft. Then the solid waste was covered by the soil layer. Type of soil collected from the site was silty loam. Different percentage dilution of Solidwaste added at the top and allowed to leach. The time and quantity of leachate collected is noted to know the seasonal variation.

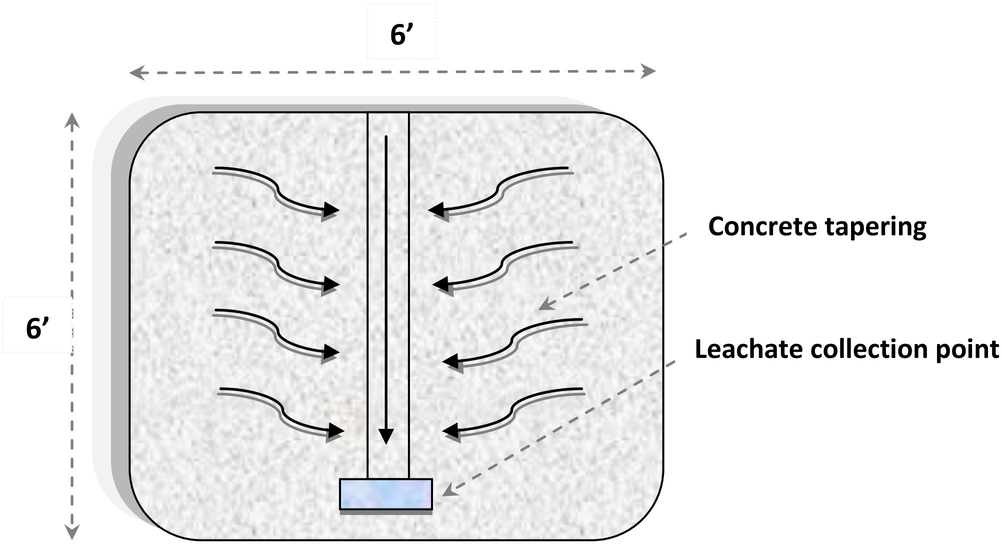


Figure 3.4 Construction of In-Situ Leachate pit

The leachate would then be characterized for different parameters such as pH, EC, COD, BOD, Solids (total, dissolved, and volatile). Similar to laboratory reactor he value from the experimental data is compared with the theoretical value obtained using rainfall intensity of Puducherry region.

8.7 LEACHATE FLOW MODEL IN SANITARY LANDFILL

Simulation of Subsurface and Rock Flow Unsteady flow through a sanitary landfill is modeled numerically. The overland flow over the surface layer is represented by Saint Venant equation and the Izzard's data were used for its verification. The non saturated flow through the surface covering layer and the solid waste layer is described by Richard's equation and its numerical results show good agreement with Strack Otto's theoretical solution. The model can be used to predict the maximum saturated depth in the drainage layer for given rainfall data and for proposed landfill structure, which must be less than the thickness of the drainage layer. The maximum saturated depth enables to calculate the maximum drain discharge which in turn makes possible to design the porous drain pipe of the landfill. Since the hydraulic conductivity of the waste layer is greater than that of the cover soil, all the moistures infiltrated the cover soil percolate downward into a saturated zone of the drainage layer through the waste layer (Tae Hoon Yoon, Tae Sun Park., 1998)

Table 2.3 Hydraulic properties of typical soils

	K_o	φ_o	n	m	c	d
	(cm/s)	(cm)				
Clay	3.4 10^{-5}	90	0.45	0.44	7.5	4.3
Silty loam	3.4 10^{-4}	40	0.35	1.2	4.7	2.9
Sandy loam	3.4 10^{-4}	25	0.25	3.3	3.6	2.3
sand	8.6 10^{-3}	15	0.20	5.4	3.4	2.2

By employing Darcy's law and the mass conservation principle in a differential control volume of leachate mound, the saturated leachate flow can be described by

$$K_d \frac{\partial}{\partial x}\left[y\left(\frac{\partial y}{\partial x} + \tan\alpha\right)\right] + N_l - q_l = n_e \frac{\partial y}{\partial t}$$

Where, K_d is the hydraulic conductivity of drainage layer,

y is the leachate depth over the liner,

x is the liner slope in angle,

n_e is the effective porosity of the drainage layer,

q_l is the leakage rate through the liner.

$$q_l = K_L\left(1 + \frac{y}{d}\cos\alpha\right)$$

Where, K_L is the saturated vertical hydraulic conductivity of the liner, and d is the liner thickness. Table 2.4 gives maximum inflow rate through different cover soils.

Table 2.4 Maximum inflow rate through different cover soils

	clay	silt	sandy loam	sand
Rainfall intensity(mm/day)	26.0	37.0	49.0	42.0
Maximum inflow rate(mm/day)	25.1	36.6	48.0	41.8

8.8 MAXIMUM SATURATED DEPTH

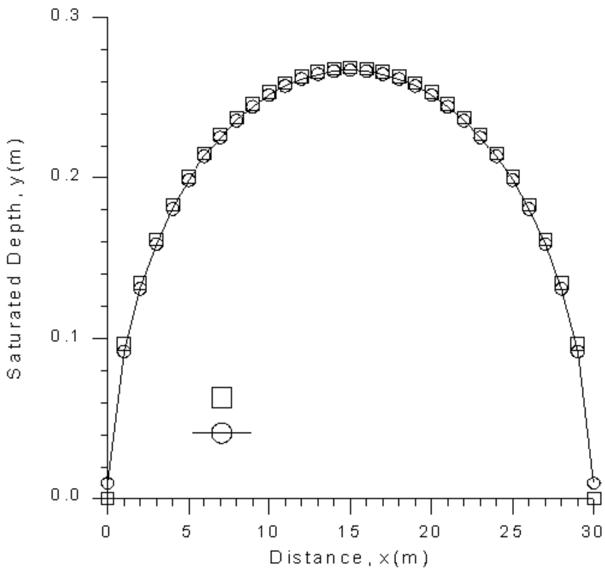


Figure 2.7 Saturated depths over horizontal liner

The maximum saturated depth over the liner should not exceed the thickens of the drainage layer, so that saturated conditions do not extend into the overlying soil cover. L=30m, Kd=8.64m/day, Nl=0.00274m/day Analytical Solution - Numerical Solution Figure 2.7 shows Saturated depth over horizontal liner. Regarding this condition U.S. EPA recommends a minimum hydraulic conductivity of 10-2 cm/s for the drainage layer and a maximum hydraulic conductivity of 10-7 cm/s for the clay liner. The EPA also recommends a minimum thickness of 90cm for clay liners, a drainage length of 15-60m, and a maximum leachate input of 100 cm/yr into a covered landfill. The EPA formula for the maximum saturated depth presented by (Moore 1983) reads as

$$y_{\max} = \frac{L}{2}\left(\frac{N_l}{K_d}\right)^{1/2}\left[\frac{K_d(\tan\alpha)^2}{N_l} + \frac{K_d\tan\alpha}{N_l}(\tan\alpha)^2 + \frac{N_l}{K_d}\right]$$

in which y_{max} is the steady state maximum saturated depth over the liner, Kd is the hydraulic conductivity of the drainage layer. McEnroe(1993) derived the steady state maximum saturated depth based on the principles of confined seepage as.

$$Y_{\max} = \left(R - R_S + R^2S^2\right)^{1/2}\left[\frac{(1-A-2R)(1+A-2RS)}{(1+A-2R)(1-A-2RS)}\right]^{1/2A}$$

Where

$$Y_{max} = {y_{max}}/{L} \tan\alpha, A = (1-4R)^{1/2}, B = (4R-1)^{1/2}$$ and

$S = \tan\alpha$.

Using the present model, one can predict the maximum saturated depth on the liner. It is found that for steady state the EPA formula overestimates the maximum saturated depths than the McEnroe's formula and the present model, meanwhile for unsteady state the EPA formula underestimates it than the present model. It was demonstrated that the model enables the determination of the size of drains.

Major conclusions drawn from the research study are,

1. The systematic monitoring of the physico-chemical characteristics of leachate from lab scale reactor and field in simulated controlled dumps has revealed that the rainfall and the age of the waste has a significant effect on leachate generation and the characteristics.
2. During monsoon, rainwater percolated through the refuse beds and solubilized the constituents, producing a larger volume of dilute leachate, while during the dry summer the concentration of certain pollutants (Sulphate, Total solids and Chloride) were higher.
3. However, the characteristics of leachate are also affected by many site specific factors such as waste composition, moisture availability, and climate.
4. It takes almost 61 days for the landfill to become completely saturated.
5. The effects of major parameters on the Fenton process were evaluated using a batch reactor. It was proved that organic materials in leachate could be successfully removed by Fenton’s reagent. Favorable operation conditions were thoroughly investigated. The oxidation of organic materials by Fenton’s reagent was so fast that it was complete in 30 min with batch experiments.
6. The oxidation of organic materials in the leachate showed a pH dependence and was most efficient in the pH range of 3. A favorable H_2O_2/Fe(II) molar ratio was 2, and organic removal increased as dosage increased at the favorable H_2O_2/Fe(II) molar ratio.
7. The efficiency of hydrogen peroxide obtained from the removed COD values by oxidation was observed to be about 65%.