Draft Report

Guidelines on Odour Monitoring & Management in Urban Municipal Solid Waste (MSW) Landfill Site

CENTRAL POLLUTION CONTROL BOARD

(Ministry Of Environment, Forest & Climate Change)

Parivesh Bhawan, East Arjun Nagar, Delhi – 110032

Website: cpcb.nic.in; E-mail: cpcb@nic.in

February, 2017

Preface

Clean and natural air, is essential for sustainable civilization and treated as fundamental rights throughout the world. Presence of any air pollutants or odour affects the natural quality of air thereby affecting normal life of living beings. In India, regulatory frameworks have been implemented for prevention and control of air pollutants through the enforcement of Air (Prevention and Control of Pollution) Act 1981 and Environment (Protection) Act 1986. However, no regulation has been made for abatement and control of odour which is now becoming cause of major problem in urbanization and industrialization. In urban areas, odour related issues are mainly related with municipal waste disposal facilities.

Recognizing the urgent need for abatement of odour from municipal waste disposal facilities in urban sector, Central Pollution Control Board (CPCB) has taken initiation for Development of Guidelines. For this purpose, a Project on Development of Guidelines on Odour Monitoring and Management in Urban Municipal Solid Waste Landfill site was awarded by CPCB to JM EnviroNet (P) Ltd. (JMEPL) with specific and define Terms of Reference (ToR).

The scientific team of JMEPL carried out the required studies and monitoring for odour and odorous compound for two seasons, i.e. pre-monsoon and post-monsoon at municipal solid waste landfill site Ghazipur, Delhi in accordance with defined ToR of CPCB. Based upon the ToR of CPCB and studies such as preliminary site survey, monitoring, sampling, modeling conducted at Ghazipur landfill site, efforts have been made to develop guidelines on odour monitoring and management in urban municipal solid waste landfill site, incorporating protocol for sampling and analysis of odour and odorous compound and odour dispersion modeling.

We hope that this guideline will serve as useful tool for Regulatory Agencies for selection of MSW landfill site, bring improvement in present MSW sites, monitoring, abatement and management of odour from Urban Municipal Solid Waste Landfill site in future.

We are thankful to Officials of East Delhi Municipal Corporation for their kind support all through the project duration.

TABLE OF CONTENT

LIST OF FIGURES

List of Tables

****

LIST OF ABBREVIATIONS

APHA	:	American Public Health Association
ASTM	:	American Society for Testing and Materials
BDL	:	Below Detection Level
BOD	:	Biochemical Oxygen Demand
BAAQMD	:	Bay Area Air Quality Management District
BATEA	:	Best Available Technology Economically Achievable
BMP	:	Best Management Practices
C/N	:	Carbon/Nitrogen
C&D	:	Construction and demolition
C&I	:	Commercial and industrial
CEN	:	European Committee for Standardization
CERs	:	Certified Emission Reduction
COD	:	Chemical Oxygen Demand
CDM	:	Clean Development Mechanism
CH_4	:	Methane
CO_2	:	Carbon dioxide
COPCs	:	Contaminants of Potential Concern
cm	:	Centimeter
CPCB	:	Central Pollution Control Board
D/T	:	Dilution to Threshold
ECD	:	Electron Capture Detector
EPA	:	Environment Protection Act
EROM	:	European Reference Odour Mass
EU	:	European Union
FPD	:	Flame Photometric Detector
GC	:	Gas Chromatography
GAIL	:	Gas Authority of India Ltd.
GC-FID	:	Gas Chromatography -Flame Ionization Detector
GCV	:	Gross Calorific Value
GHG	:	Green House gases
GPS	:	Global Positioning System
GSI	:	Geological Survey of India
HRPM	:	Horizontal radial plume mapping
HDPE	:	High-density polyethylene
HFP	:	Hexa Fluro Propylene
HPLC	:	High Performance Liquid Chromatography
HS	:	Head Space technology
IARI	:	Indian Agricultural Research Institute
IMD	:	Indian Meteorological Department
IS	:	Indian standards
ISO	:	International Organization for Standardization
JMEPL	:	JM EnviroNet Pvt. Ltd.
kg	:	Kilograms
km	:	Kilometers
LFG	:	Landfill gas
LU / LC	:	Land use / Land Cover
M	:	Meters
mbgl	:	Meters Below Ground Level.
MCD	:	Municipal Corporation of Delhi
MOE	:	Ministry of the Environment
mm	:	Millimeter
MSW	:	Municipal Solid Waste

MSWM	:	Municipal solid waste management
MSME	:	Micro Small Medium Enterprise
MT	:	Million Tones
MTD	:	Million Tons per day
MW	:	Mega Watt
NAAQS	:	National Ambient Air Quality Standard
NABL	:	National Accreditation Board For Testing and Calibration Laboratories
NE	:	North East
NIOSH	:	National Institute for Occupational Safety and Health
NMAM	:	NIOSH manual of Analytical Methods
NGO	:	Non Government Organization
NMOCs	:	Non-Methane Organic Compounds
NSIC	:	National Small Industries Corporation
OU	:	Odour Unit
PAHs	:	Poly Aromatic Hydrocarbons
PFPD	:	Pulsed Flame Photometric Detector
POI	:	Point Of Implement
PCBs	:	polychlorinated biphenyls
ppb	:	Parts Per Billon
ppm	:	Parts Per Million
PTFE	:	Polly tetra Fluoro Ethylene
PET	:	Poly ethylene Terephtalate
RDF	:	Refused Derived Fuel
ROM	:	Reference Odour Mass
RSC		Reduced Sulfur Compounds
RSO		Reduced Sulphur Odourants
SE	:	South East
SH	:	Slaughter House
SOER	:	Specific Odour Emission Rate
SOP	:	Standard Operating Procedure
SPME	:	Solid Phase Micro Extraction
SWDS	:	Solid Waste Disposal Site
TD	:	Thermal Desorption
TDS	:	Total Dissolved Solids
TOC	:	Total Organic Carbon
TVOC	:	Total volatile organic compound
ToR	:	Terms of References
TKN	:	Total Kjeldahl Nitrogen
TPD	:	Tones per day
USA	:	United State of America
ULB	:	Urban Local Body
UV-DOAS	:	Ultra-violate Deferential Optical Absorption Spectroscopy
VRPM	:	Vertical Redial Plume Mapping
USEPA	:	United States Environmental Protection Agency
VOC	:	Volatile Organic Compound
XOCs	:	Xenobiotic organic compounds

CHAPTER-I
INTRODUCTION

1.0 INTRODUCTION

The odour is defined as the "perception of smell". In scientific terms, it is a stimulation or sensation resulting from the reception of the expression by the olfactory system. Odour sensation is induced by inhaling airborne volatile organics or inorganic, which may or may not have toxic effects. Partial putrefaction of the waste produces obnoxious odorous volatile organic and inorganic substances which spoils the aesthetic environment for human beings. The mismatch created between infrastructure available and increasing waste generation coupled with improper management of MSW and sanitation system, the odour problem is on the rise, which has attracted public complaints. The excess load of MSW restricts the usability of land earmarked for dumping. The people who reside nearby MSW disposal site to a major extent experience the odour problem.

1.1 CHARACTERISTIC OF ODOUR

There are some general characteristic of with reference, to perception of the people as given here under:

- Substance of similar or dissimilar chemical constitution may have similar odour, nature and strength of odour may change on dilution.
- Strong odourants mask the weak odourants irrespective of their concentration. Odour of same strength blends to produce a combination in which one or both may be unrecognizable.
- Constant intensity of odour causes as individual to quickly loose perception of the sensation and only noticed when it varies in intensity.
- Fatigue for one odour may not affect the perception of dissimilar odour but will interfere with the perception of similar odour.
- An unfamiliar odour is more likely to cause complaint than a familiar one.
- Two or more odorous substance may neutralize the smell of each other.
- Odour travels downwind.

1.2 ODOUR IMPACTS

Odour sensing olfactory cells are linked to areas of the brain that control emotions and memory processes. Offensive odours can therefore have impacts on the health and well-being of humans depending upon duration of exposure. At sufficiently high concentrations odorous compounds may have a direct effect on human health. Also, an individual's health may suffer indirectly due to stress associated with odour impact.

- Vomiting, Headaches, Nausea
- Stress, anxiety, frustration
- Social problem due to unwillingness to host guests due to embarrassment
- Restriction in outdoor activities
- Children unable to sleep due to odour in bedrooms,
- Discomfort for infirm elderly people.
- In addition to the above, the odourants responsible for odour may impact on health due to toxic nature.

  The study on the toxicity of odorous substances established that following odourants generated from MSW handling & management or dumping may impart health hazard by different physiological pathways.

  - **Mercaptans:** These are characterized by a particularly unpleasant odour even in very low concentration that provokes intolerable gastric effects even with low exposure times. With longer exposure times, these compounds can also interfere with blood haemoglobin and consequently with the oxygen transport process, causing temporary cyanosis.
  - **Hydrogen sulphide**: The effects of exposure range from irritation of the eyes and respiratory tract, for concentrations between 10 and 20 ppm, up to immediate loss of consciousness and death (1000–2000 ppm). The particular and hazardous nature of this compound resides in the fact that, at particularly dangerous concentrations (700 ppm), it loses its malodorous compound characteristics giving rise to an almost pleasant odour.
  - **Ammonia**: It is the cause of irritation of the bronchi and lungs, while prolonged exposure to low concentrations can provoke chronic bronchitis or emphysema.
  - **Amines:** Irritant effects have been encountered on the mucus of the primary respiratory tract, though possible irritation of the eyes with subsequent corneal damage cannot be ruled out.
  - **Organic acids:** Although these do not lead to any pathogenic effects at low concentrations, prolonged exposure can cause irritation of the respiratory tract.

1.3 ODOUR SENSITIVITY

Due to the complex nature of odour perception by the human olfactory system, levels of sensitivity to odour within a population will vary person to person.

Sensing of smell is the most complex and unique sense in human beings. Sense of smell is carried out by two main nerves:

- Olfactory nerve (first cranial nerve):- these nerves process the perception of chemical.
- Trigeminal nerve (Fifth cranial nerve):- process the irritation or pungency (sensation of chemical)

All the olfactory signals meet in the olfactory bulb where the information is distributed to two different parts of the brain. One of the major pathways of information is to the limbic system which process emotions and memory response of the body. The second major pathway is to frontal cortex. This is where conscious sensations take place, as the information is processed with other sensation. And is compared with accumulated life experiences for individuals to possibility recognise the odour and make the decision about the experiences. This entire activity from nostril to signal in the brain is completed within 500 milli seconds.

As odour is a perception, it is difficult to measure by any instrument or chemical method. However, conversion of equivalent sensory signal into a measured value is the basic behind odour measurement, termed "OLFACTOMETRY".

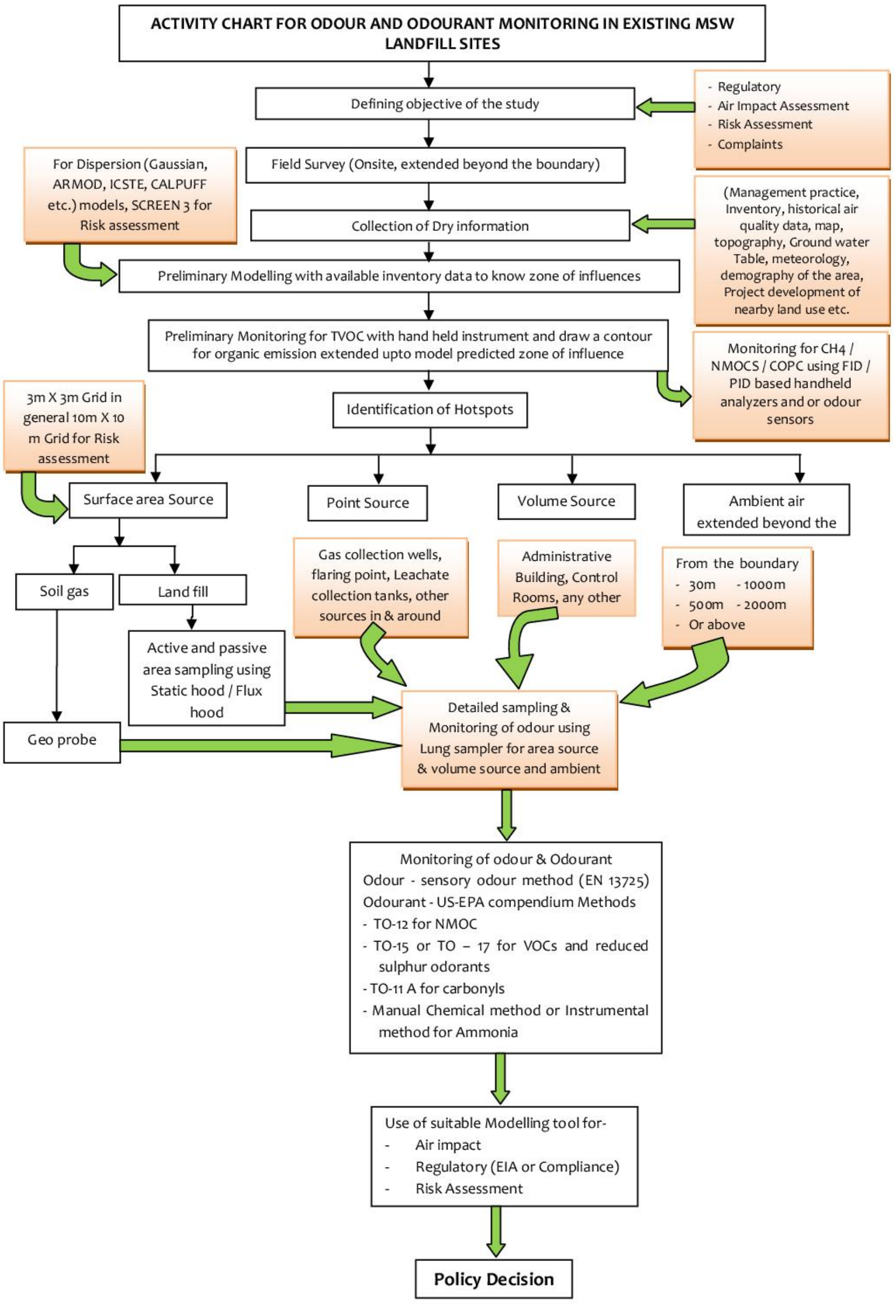
Considering the odour menace at MSW landfill site in India, this pioneer study was planned to prepare a guideline for better management of MSW in the country. This document is prepared based on the experience from this study and in-depth research on worldwide best management practices available, which could be adopted for the country in terms of odour control and abatement from MSW landfill sites.

****

CHAPTER-II
ODOUR MONITORING FOR URBAN MSW LANDFILL SITE

After detailed literature survey and identification of their adaptability in Indian context, protocol for sampling and analysis of odour and odourous compounds has been developed and the same Can be accessed from **here**

An activity chart detailing the outline for conducting the monitoring as below.



****

CHAPTER-III
ODOUR MANAGEMENT IN URBAN MSW LANDFILL SITE

3.0 ISSUE RELATED TO ODOUR MANAGEMENT IN URBAN MSW LANDFILL SITE IN INDIA

In Indian scenario it has been taken as granted that the resident in and around the MSW site are supposed to live within an odourous environment. The main reason for inconvenience is lack of awareness, regulation and mismanagement of MSW waste and inappropriate site selection. Some of the responsible factors for miss management of urban MSW sites causing odour problem areas under:-

a. No segregation of the solid waste in biodegradable, non- biodegradable and inert waste is done at site or by generator.
b. The area earmarked for MSW disposal is inadequate to cope up with the demand of MSW generation and are located in the habituated areas due to improper town planning.
c. Inadequate collection of waste at the community level by the local bodies.
d. Waste such as plastics, E- waste, hazardous waste, construction and demolition waste is not segregated at community level.
e. Inadequate number of vehicle deployed for the collection of the MSW.
f. The vehicle deployed for collection and transportation of MSW are not properly designed, fabricated and operated.
g. The problem in existing landfill site is the encroachment of the site in and around by new development and residential areas in absence of guideline for proper definition of buffer zone.

3.1 IDENTIFICATION OF ABATEMENT GOALS WITH RESPECT TO LIMITATIONS

The abatement goals are universally same for all the countries; however Indian scenario these should be extended further considering the MSW management practices. The indentified goals are as under;

a. Improvement of environmental aesthetic value by odour management,
b. Protect both the workers and residents in and around MSW landfill site from health hazards,
c. Prevent contribution to green house gases; so as to control global warming,
d. Avoid explosion and fire hazards,
e. Prevent soil and ground water contamination.

In countries like India existing MSW management practices particularly in landfill site also support the livelihood of a poor sector (rag pickers), hence, the health of this sector is a matter of concern.

3.2 PREVENTIVE MEASURES FOR ODOUR ABATEMENT AT MSW LANDFILL SITE

As it is a well known fact that odourants are generated through biochemical activity on biodegradable material of MSW at landfill sites, below are the preventive measures that can be adopted at the different stages of MSW management,

A. Odour control by site selection and design

B. Operational management

C. Minimization of odour release through physical prevention

D. Odour counteractants

A. Odour control by site selection and design

Site selection and designing of landfill site may help in abatement of odour at the inception of the project through scientific analysis of available data. The following factors should be considered while designing and selecting a site.

- The selection and number of sites for a city shall be considered in a holistic way. The requirement of land for the disposal site shall be assessed considering the present population and projected growth for at least 20 years.
- It is better to plan for development of more than one site for a city to provide better accessibility of the site, optimize the travel distance of loaded trucks and minimize the time duration of waste kept dumped at primary collection centre.
- The care should be taken during identification of site that the selected land is free from influence of other odourous sources.
- Topography and other geological conditions.
- Selection of landfill site should be clubbed with the urban development plan so that even expansions of city in next two or three decades are not encompassing the selected MSW site. Restriction in new development near the disposal site for commercial and residential activities.
- Urbanization development near to the site is to be permitted keeping a reasonable “buffer zone” between the development areas and disposal site.

Buffer zone could be decided based upon the area of influence through the modeling techniques or in compliance with the existing legislation.

- Green belt development in the buffer zone should be mandatory and the civic bodies should work in close association with scientist, environmentalist for selection of suitable flora to be planted in buffer zone. The model describing preventive measures for odour abatement is depicted in **Figure. 1.**

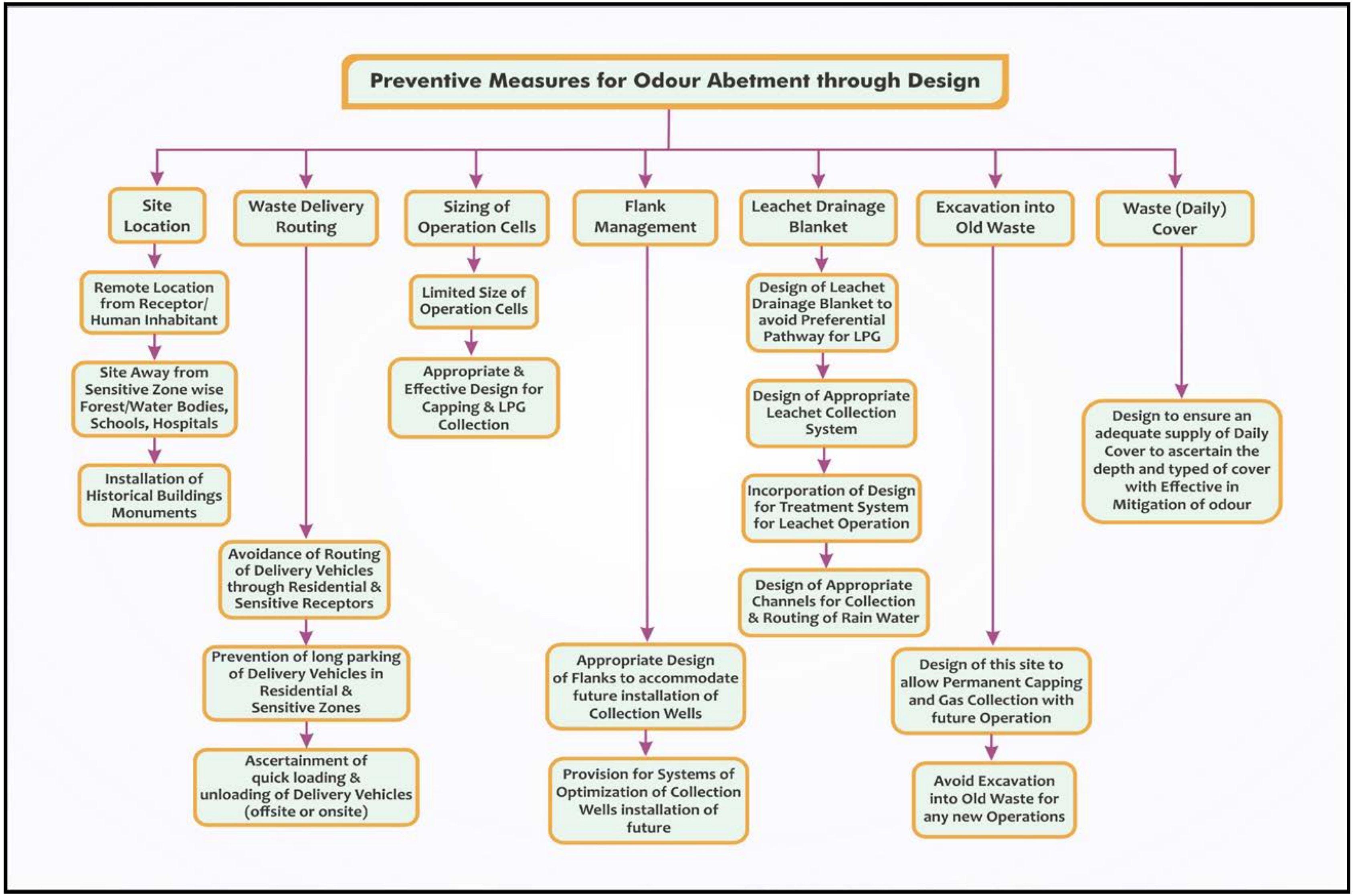


Figure 1: Preventive Measure for Odour Abatement

B. Operational Management

Prevention and minimisation of odour release can be achieved by adopting odour control practices by landfill operators, the details of the operational control of MSW landfill site is given here under:

a) Municipal solid waste acceptance: Each site will have its own waste acceptance criteria and protocols.

b) Municipal solid waste handling: Worldwide, the segregation of waste is being practiced at source; however, in India MSW is never segregated. Un-segregated waste increases and thus lowering the utilization efficiency of land earmarked for land filling. Pre-processing (sorting) of waste may also help in enhancing the efficacy of treatment process and land utilization.

c) Area of active cell (Tipping area): The size of tipping area must be optimized in order to minimise the odourous emission from MSW. It must be

i. Sufficiently large to allow waste to be tipped and compacted in a shape manner

ii. Adequately large to allow received waste to be tipped without delay as this prevent trucks from waiting on the site or on the public road network

iii. The worldwide the tipping area is around 900 to 1200 m^2 at most of the site, but as per US-EPA working plan for the site and health & safety aspects; it may be as low as 625 m^2 and as large 1600 m^2.

d) Rapid and effective capping: The engineering design shall ensure rapid and effective capping to prevent fugitive release of gases, which in turn improve the collection efficiency of the LFG (Land fill gases).

e) Design of landfill gas collection system and operation: Depending on the waste type, its condition and the expected life span of the operational area, temporary extraction system may be required in operational area. The system generally consists of impact wells, horizontals or drilled wells and pipe work may be flexible or rigid, temporary and permanent. Careful planning has to be made in order to minimise the release of odourous gases through the above mentioned system.

f) Leachate management: Leachate should be stored or collected on case to case basis and transported to the leachate treatment plant through suction pipes, buster's pumps or through sealed tanks which indeed not only treat the leachate but also prevent the odourous menace.

g) Maintenance of LFG (collection and capping): There must be a system established for identification of leaks by visual observation, odour monitoring and requisite repair system (like LDAR). In absence of direct monitoring the mass balancing may be considered to estimate the efficiency of treatment.

h) Restoration of Soil: The restoration of soil is carried out when landfill cell has been capped and permanent gas collection system has been placed. The landfill operator must have the planning permission from the regulatory authorities for restoration of the soil over the cap and plantation of appropriate species over the soil cover.

The summarised operational control of MSW landfill site in **Figure: 2 & 3**

i) Besides above, following best management practices (BMP) for odour prevention & control should be adopted;

- Segregation of waste to prevent entry of unwanted industrial, metallic, biomedical waste at disposal at site.
- Ensure that all the trucks transporting MSW are covered.
- Development of adequate internal roads with in site area for easy movement of transportation and mechanical vehicles
- Development of fencing around the disposal sites to prevent unauthorized entry of person and stray animals.
- Dumping and disposal functioning through expert contractors only.
- Computerized monitoring of the waste batch from collection up to its disposal or utilization.
- Development of facilities for feasible utilization of waste.
- Monitoring by authenticated organizations or institute to monitor the health, risk and environmental effects (air, water and odour) due to operation of the disposal site.
- Safety and environmental compliances in accordance with the MSW Rules (M&H) 2016.

The implementation pattern of the best management practises (BMP) may vary to an extent on case to case basis.

The model BMP is detailed in **Figure. 4.**

Figure 2: Operation Control as Preventive Measure for Odour at MSW Site

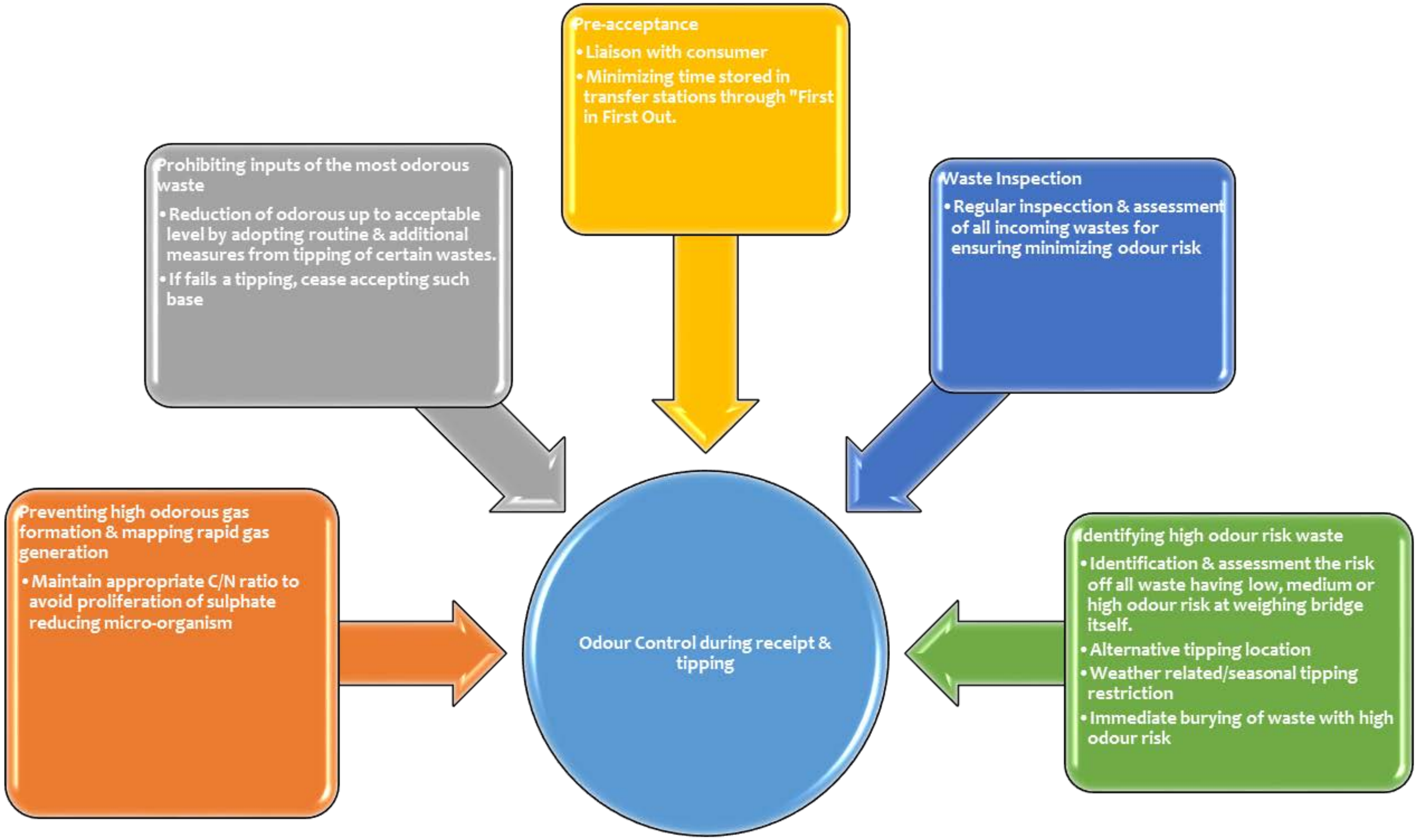


Figure 3: Odour Control during Receipt & Tipping

Figure 4: Best Management Practices

C. Minimization of Odour Release through Physical Prevention

The physical prevention of the odour release may be achieved by adopting different devices or technique for various process and stages of waste.

- For Tipping and loading operations: - Better engineering practices may be adopted if tipping and loading operation is carried out in a closed building with remote controlled fast acting doors. Slightly negative air pressure shall be maintained within the process building to reduce the odour nuisance. In the tipping area maximum waste handling and storage time should be minimize to 24 hrs. The main extraction air pipe should be fitted in the building to collect odourous emissions which may be connected to further controlled devices.
- For active and passive area sources:- Capping of the areas having potential odour generation with suitable cover shall be adopted. There are different types of material available for capping having varied efficiency. Use of any of the following material like composite of Isopthalic polyester resin and glass fibre, composite of vinyl ester resin and glass fibre, sail cloths- Type material made of polyester and PVC are good to prevent odour emission.
- For waste utilization process where onsite shorting of waste is required use of properly designed closed system with vents for emitted gases should be adopted.
- For final capping of the landfill site after civilization concrete, wooden or highly corrosion resistance aluminium/ copper alloy material are useful.

D. Odour counteractants

The counteractants use for prevention of odour release from MSW Landfill site includes:-

- **Masking agents**- Terpenic compounds and some oxygenated molecules like coumarin masks the odourous emission nuisance and blocks some specific malodourous receptors.
- **Surfactants:**- Amphiphathic molecules such as alcohols, glycerol and esters compounds increase the apparent solubility of odourous compound in aqueous media, thus reducing the odour emission.
- **Neutralizers:** Aliphatic and aromatic aldehyde reacts with odourous compounds including viz. Ammonia, TRS etc. which decreases the odourous annoyance. Further fibre degrading enzyme and plant extraction have also been use as a

neutralizer. The enzymes and plant extract decrease the nutrient extraction of mono gastric lives stock, and there for odour emission.

3.3 BENEFICIAL UTILIZATION OF MSW

The beneficial utilization of MSW is major concern to efficiently operate and maintain MSW management. Waste to energy not only gives economical benefit but also help in waste minimization. A treated waste can also be used for other purposes including growth in agriculture yield. Few processes are described below:-

A. Compositing of biodegradable MSW waste

Composting of MSW is carried out using different approaches to produce organic manure. The organic manure can be utilized in agriculture sector for achieving higher productivity and yield of the crops. The utilization of horticulture waste in compositing minimizes the load of MSW land fill site.

B. Energy production from MSW

- **Green briquettes:** The biodegradable part of MSW after segregation is mixed with appropriate biodegradable mass to produce the briquettes size up to 20 mm with a moisture content of less than 10%. Such briquettes are called green briquettes or bio coal with a calorific value of approx 4000 Kcal/kg. It can be replaced by any kind of coal, lignite fire wood, steam wood etc. This will help in partial disposal of MSW with energy recovery.
- **Refused Derived Fuel (RDF):** - Similarly sorted MSW must be treated with hot dried air to produced RDF which also have high calorific value.
- **Methane and Hydrogen Production:** Different processes viz. Biological and chemical are also practicable for energy generation from MSW. In biological processes the 30 to 40% of bio- degradable part of MSW is converted in to biogas with methane content of 50 to 60 %. The biogas can be enriched with methane up to 80% by removing CO_2 and traces of odourous sulphurous constituents, by adopting pre-emptive desulphurization process.

C. Recyclable materials and its composites from MSW

Upon proper sorting of MSW, 10-20% of the recyclable materials such as paper, plastics and metals can be extracted by an active informal sector & different products can be made from the sorted materials of the MSW. This will partially help in curtailment of odour emissions from MSW.

D. Land filling

The inert part of the MSW may be well utilized in land filling for construction mining and other purposes.

Different options for beneficial utilization of MSW is depicted in **Figure. 5**

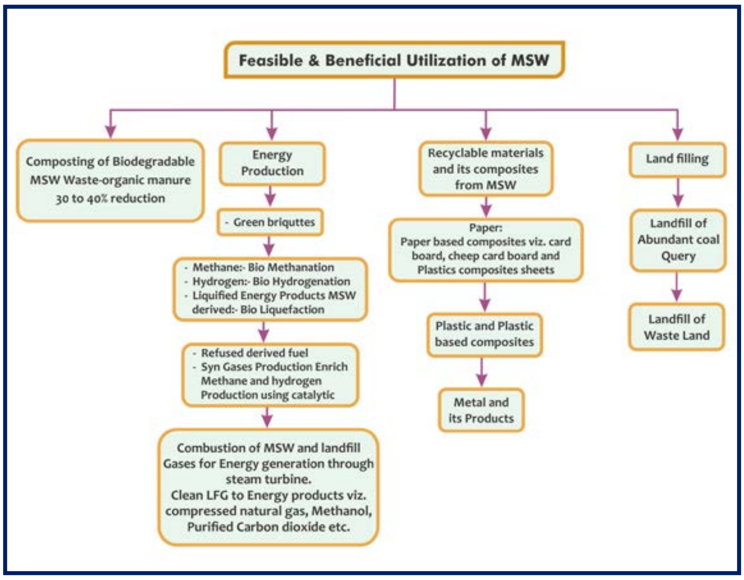


Figure 5: Feasible & Beneficial utilization of MSW

3.4 ODOUR CONTROL TECHNOLOGIES

A. Adsorption processes:

Adsorption is a surface phenomenon where treatable waste is adsorbed on suitable adsorbents. The effective and commonly used adsorbents for odour control are activated carbon, Graphene, carbon-neon hybrid materials etc. There are different processes in adsorption technology for odour control.

I. **Dry Scrubbers:** Dry scrubbing systems uses containerized media that reacts with specific compounds in landfill gas, such as acidic gases and forms solid compounds that can be then disposed of. In general, these processes utilize replaceable dry media to extract acidic gases until the media becomes saturated and needs to be separated.

II. **Chemical Scrubbers:** Chemical scrubbers consist of vessel with an air inlet, scrubbing solution bed, and an air outlet. In these systems landfill gases comes into a direct contact with scrubbing solution that chemically reacts, absorbed and removes the odour causing targeted molecules from the landfill gas.

B. Incarnation: Incarnation, based on the gaseous pollutants at a high temperature (also at the presence of catalyst), is still a commonly applied technique for industrial gas emissions containing high concentration of VOCs. In the case gaseous emission is loaded with high concentration of VOCs, the incarnation process will be self sustainable and self maintained. However this not techno-economically feasible at gaseous emission with low concentration of odourants as it requires input of fuels for Incarnating the odourants.

Incarnation is the most common and more effective technology for controlling the landfill gas with odourants as it has inherent methane which is highly inflammable and support the Incarnation process. In the presence of methane the sulphurous odourants and other VOCs are gets converted to SO_x, NO_x and CO_2. These tail gasses can be effectively treated at the end of Incarnation in a suitable scrubber.

C. Filtration Technique:

I. **Bio-filters:** Bio-filtration is a biological process using some media such as soil, compost or other media as a substrate for microbes that removes odourous contaminants from landfill gas. Venting landfill gas through such bio-filter can be used to reduce odours. Landfill gas is collected and vented through a bio-filter of bacterial slime. As long as oxygen is present, bacteria will decompose landfill gas under aerobic conditions, producing carbon dioxide and water.

II. **Bio-trickling filter:** Bio- trickling filter consist of a column pack with an inert packing material viz. Plastic rings, resins, ceramic materials, etc. The micro organisms are immobilized on the inert surface and get attached to it. A nutrient solution is continuously trickled and also recycles at the rates 10 to 30 Liters for a minute. These system present high specific surface areas to the tune of 100 to 400 m^2 or m^3, which allows for mass transfer with a lower pressure drown. Odourants are initially absorbed in aqueous field trickling over the bio-film and degraded after wards by micro organisms present in the bio-film. An efficiency of more than 99% has been reported for removal of H_2S.

D. Bio- Scrubber: The mal odourous emission can be directly purged into aeration tank with appropriate bio mass having potential to degrade the odourants. The mal odourous compounds defuse from the gas phase to liquid phase and get degraded in the liquid phase having microorganism along with a nutrients.

E. **Chemical treatment:** Injecting controlled quantities of chemicals such as chlorine or hydrogen peroxide into process-gas stream can control odour. Similarly, unlike various other "odour control" treatments, chlorine dioxide will destroy the odour at source. Chlorine dioxide is several times more effective than chlorine and other commonly used treatments, and will not form any hazardous by products.

i. **Odour Control with Chlorine Dioxide & Hydrogen Peroxide:**

1. **For Hydrogen Sulphide:-**

a. $5H_2S + 8\ ClO_2 \rightarrow 5H_2SO_4 + 8\ Cl- + 4H_2O$

- pH 5-9, min 2.7 ppm of ClO2 oxidizes 1.0 ppm of sulfide.
- No colloidal sulfur formed.

b. $5H_2S + H_2O_2$ acidic pH$\rightarrow S° + 2H_2O$

$HS^- + H_2O_2$ neutral pH$\rightarrow S° + H_2O + OH^-$

$HS^- + 4H_2O_2$ neutral pH$\rightarrow SO^{2-} + 4H_2O + H^+$

$S^{2-} + 4H_2O_2$ neutral pH$\rightarrow SO^{2-} + 4H_2O$

- Alkaline pH = 10-11 conditions give fast reaction with removal efficiencies 97- 99.9%.

2. **Mercaptans RSH:-**

RSH + NaOH → RSNa + H2O <u>Oxidation</u> 2RSNa + H2 O2 → RSSR + 2NaOH (dialkyldisulfide)

- Reaction is very fast and can occur in the scrubber. RSSR is odourous and must be oxidized further.

$RSSR + 5\ H_2\ O_2 + 2NaOH \rightarrow 2RSO_3Na + 6H_2O$

(The disulfide has very low solubility in water and thus the reaction is slow).

F. **Irradiation / Neutrapol:-** Basically ultra-violet radiation forms ozone. Ozone, is a very re-active form of oxygen, it exchanges electrons with target molecules. Ultra-violet applications for waste purification require generally high capital expenditure to form chambers to hold gases requiring treatment for about 3-4 minutes. If the rate of gas flow is variable, the treatment may be ineffective. Now days, neutrapol is used instead of ozone which is harmless and non-toxic. Neutrapol is a monomer. It forms long chain molecules which carry a positive charge.

Deodourization Mechanism for Various Gases

a) **Ammonia type:** The volatile, odourous elements are combined with an organic acid radical to form a non- odourous compound which is non-volatile. -N H + R - COOH → R + COON H b)

b) **Hydrogen Sulfide**: The hydrogen sulfide is converted into a complex organic sodium salt incorporating sodium metabysulfide, resulting in a nonvolatile, non-odourous and non-poisonous compound.

H S + R-COONa → Na S + NaHS

c) **Methyl Mercaptans:** The mercaptans are very unpleasant and are commonly produced by rotted proteins (e.g. smells of rotten fish, public urinals)

CH SH + R – COONa → CH S Na

The gases are converted to a complex organic salt.

Neutrapol is distinguished from other neutralizers by its ability to deodourize not just one type of gas but a wide range of gases, acidic, neutral and alkaline, automatically and simultaneously.

G. **Hybrid processes:** The hybrid processes either operate in a combination with chemical + Biological processes or Bio filter + Bio trickling filter, or Bio scrubber + Bio trickling filter in a sequence. This enhances the efficiency of odourants removal. In hybrid processes, some of the non biodegradable odourants gets partially modified in chemical processes and bio degraded in biological reactors. The sequence of removal of odourants may be ascertained after preliminary experiments.

H. **Vegetative cover:** Development of vegetation growth to cover of the open areas of the landfill site also reduces odours. Good plantation cover form a surface capable of sorbing and forming sinks for odourous gases. Leaves, with their large combined areas in a tree crown, sorbs pollutants on their surface, thus effectively reduce odourous compound concentrations in area emissions of MSW landfill site.

3.5 THREE TECHNO FEASIBLE REMEDIAL OPTIONS FOR ODOUR ABATEMENT

Municipal solid waste hierarchy ranks the different ways in which we can treat and dispose off MSW in order of sustainability, or relative environmental benefits. From an economic point of view, applying the waste hierarchy on the collected MSW, under conventional circumstances, is useful for energy recovery, recycling, reusing and reducing waste at the minimum. For the final disposal inevitably, landfill has become the largest component in the waste management pyramid and indirectly for odour management. In addition due to its simple and low cost technology, landfill and its gasses is highly preferred consumption in most developing nations. The waste hierarchy must be used as a basis of waste management strategy, focuses to minimize and reduce the pre landfill quantity of waste. This simplified the list of priorities helps some waste management of some over others (reused over recycling, recycling over disposal). If this hierarchy is adopted, it will help in minimization of odour generation at the MSW landfill site. However it is essential to effectively achieve odour abatement at MSW landfill site to avoid above manifestation with reference to mal odourous. The general hierarchy of waste disposal is depicted here under:

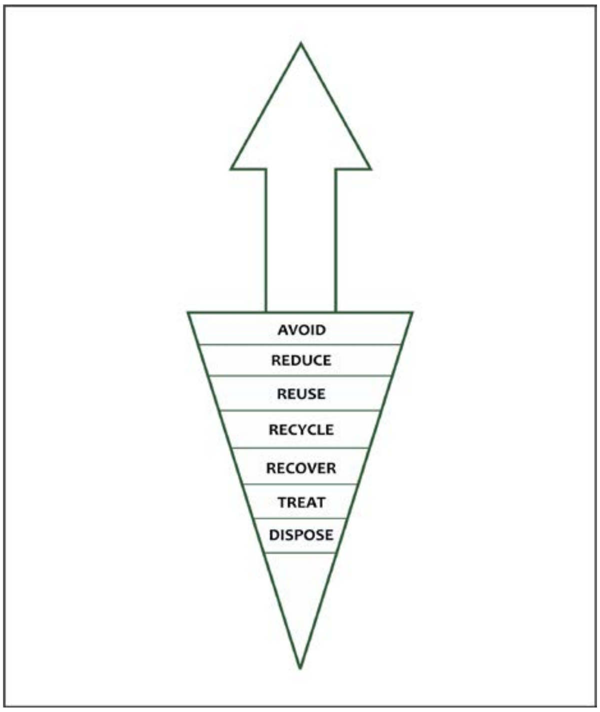


Figure 6: Waste hierarchy

Based on the literature survey and techno economical feasibility of existing MSW disposal along with odour management, the following 3 technologies are recommended for adoption in developing countries like India.

1. Decentralized MSW collection & active composting without generation of mal odourants.
2. Anaerobic digestion of biodegradable part of MSW with production of biogas with in-situ control of mal odourants generation.
3. Development of well designed MSW landfill with collection of LFG followed by de sulphurisation and Decarbonation for enriched production of methane with recovery of elemental sulphur and CO_2.

3.5.1 Decentralized MSW collection & active composting without generation of mal odourants

Decentralized technologies with reference to MSW disposal are gaining importance with reference to countries like India.

In Decentralized MSW management, MSW is collected at the house hold or community level into separate dustbins. The first dustbins having green colour marking collects the MSW separately and transport. The segregated material is taken to a small composting plant with appropriate cover to avoid the mal odourants generation. Prior to cover, the bio degradable MSW is mixed with potential anaerobic cultures for achieving effective composting in a short duration. The compost manure generated in the process may be used in the garden at house or community level. The ideal flow chart for decentralized MSW collection & active composting without generation of mal odourants is depicted in Fig. 7.

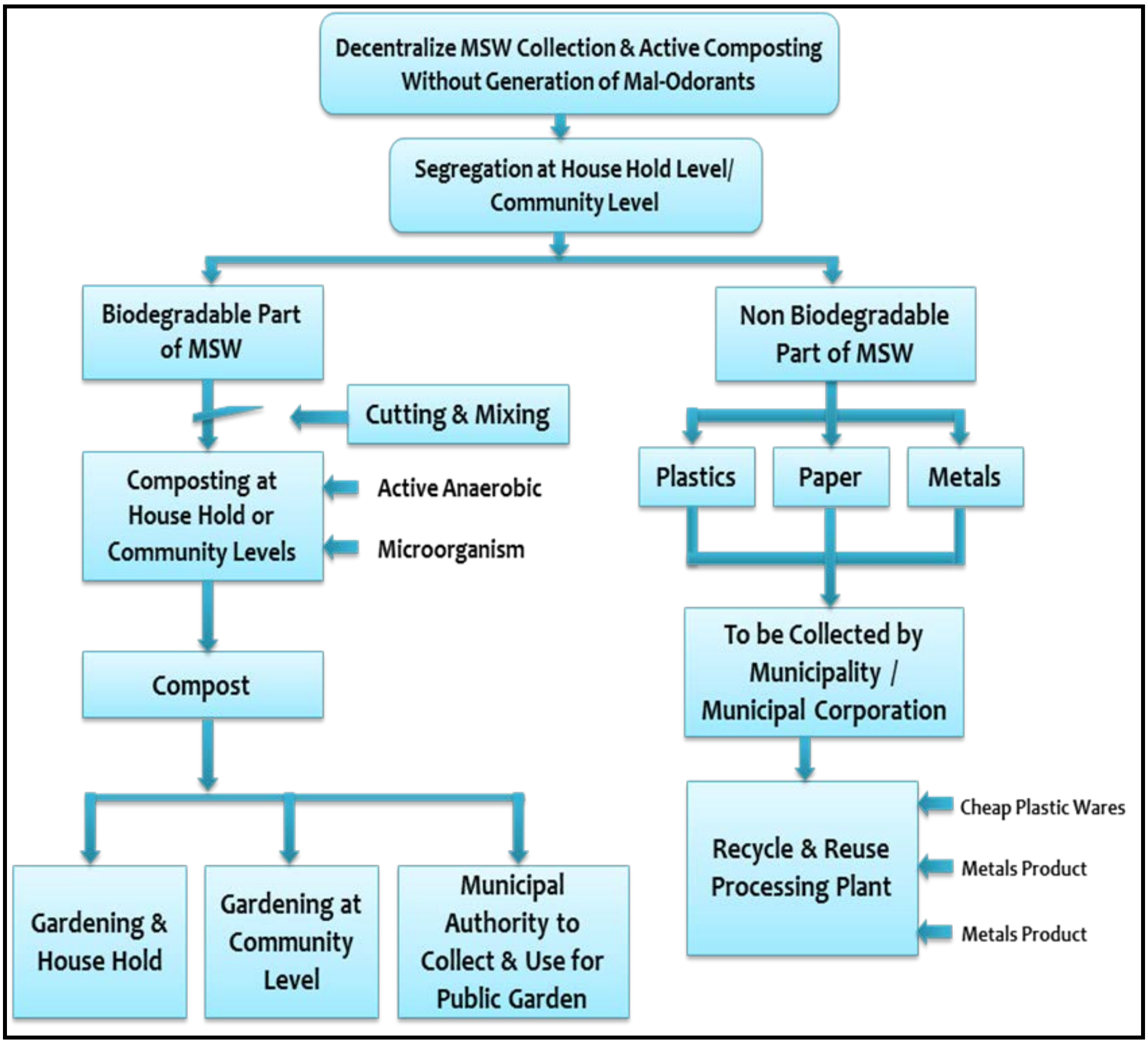


Figure 7: MSW Collection & Active Compositing

3.5.2 Anaerobic digestion of biodegradable part of MSW with production of biogas with in-situ control of mal odourants generation

MSW is segregated into biodegradable and non-biodegradable components. The biodegradable components of MSW are cut into uniform sizes and milled to a size in the range of 100 to 200 mm. The milled bio degradable material is made into slurry using some minimal nutrient medium containing nitrogen and phosphorous. This slurry is fed into anaerobic digester with appropriate mixing device which will give a uniform distribution of the waste into the reactor. Further the anaerobic biomass is developing in the reactor using specific consortium having potential for hydrolysis, acido-genesis, aceto-genesis and bio methanation. This anaerobic digester is seeded with ferric salt to encapsulate the obnoxious odourants specially reduce sulphur constituents. The addition of ferric salt is helpful in situ arrest of odourants in acid digestion reactor itself. The relevant flow chart is depicted in Fig. 8.

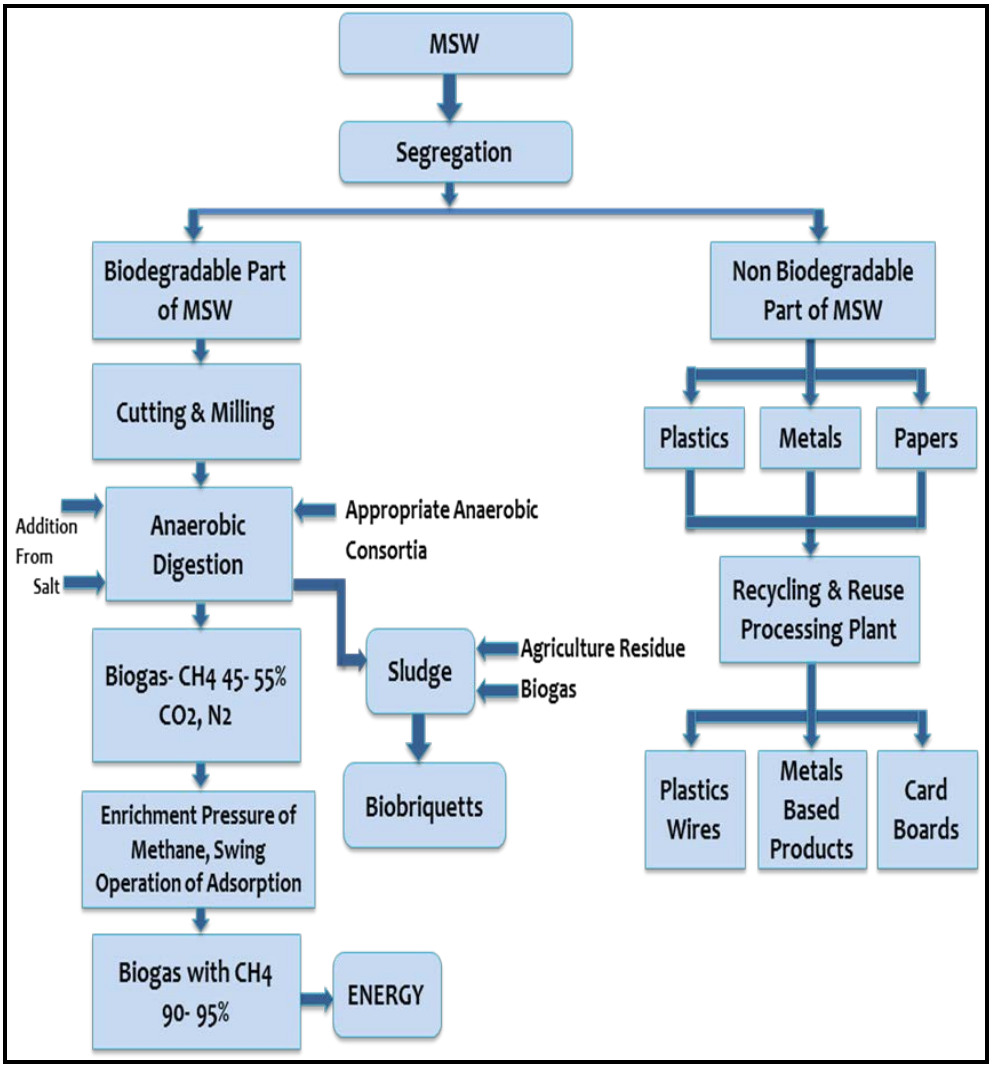


Figure 8: Anaerobic Digestion of Biodegradable

The sludge produced in the anaerobic digestion unit may be mixed with biogas or agriculture residue (Biomass) to produced green briquettes.

3.5.3 Development of well designed MSW landfill with collection of LFG followed by de sulphurisation and decarbonisation for enriched production of methane with recovery of elemental sulphur and CO_2

MSW landfill site may be designed as specified by Ministry of Urban Development Govt. of India under Swatch Bharat Mission (2016).

Segregated MSW has potential to generate LFG containing methane in the range of 40 to 45% (v/v). However the efficiency of methane generation may be reduced (30 to 35%) in heterogeneous waste. However, in both the cases it is recommended that the LFG may be processed for recovery of valuable products elemental sulfur and pure CO_2 including enriched methane. The schematic of the recommended process is depicted in the Fig. 9. The technical detail for both the cases are given in following paragraph.

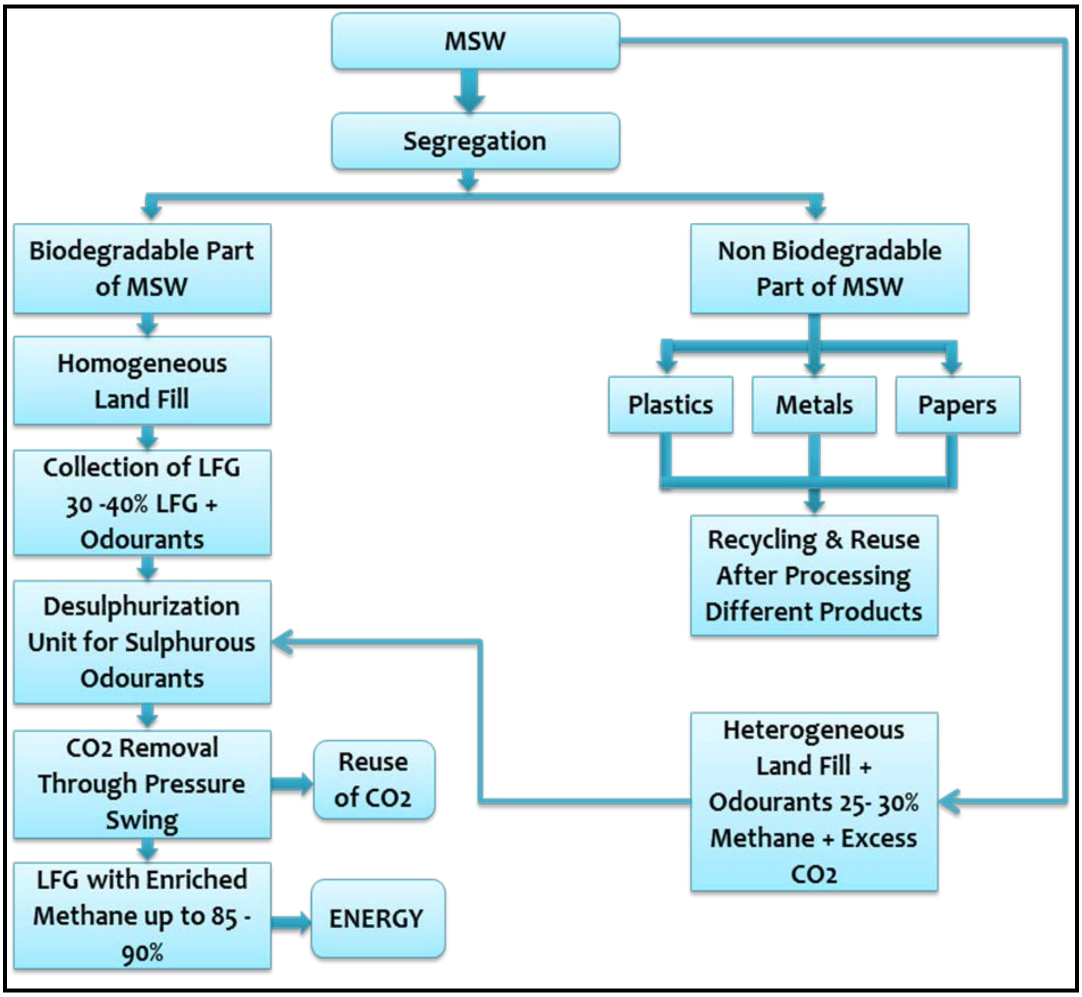


Figure 9: Sulphurisation and Decarbonisation of MSW

3.4.3.1 Collection of LFG from MSW

As gases are generated in the landfill, the collection wells offer preferred pathways for gas migration for beneficial utilization or their destruction through flaring. Landfill gas including odourous gaseous compounds can be collected by either by a passive or an active collection system. A typical collection system, either passive or active, is composed of a series of gas collection wells placed throughout the landfill. The number and spacing of the wells depend on landfill-specific characteristics, such as waste volume, density, depth, and area.

a. ***Passive Gas Collection Systems.*** Passive gas collection systems use existing variations in landfill pressure and gas concentrations to vent landfill gas into the atmosphere or a control system. Passive collection systems can be installed during active operation of a landfill or after stabilization and closure of site. The collection wells are typically made of perforated or slotted plastic and are installed vertically throughout the landfill to depths ranging from 50% to 90% of the waste thickness. The construction of passive gas collection system should ensure that the horizontal and vertical pipe lines laid are connected to or very closed to ground water table to prevent contamination. Vertical wells are typically installed after the landfill, or a portion of a landfill, has been closed. Horizontal wells may be appropriate for landfills that need to recover gas promptly (e.g., landfills with subsurface gas migration problems), for deep landfills, or for active landfills. Sometimes, the collection wells vent directly to the atmosphere. Often, the collection wells convey the gas to treatment or control systems (e.g., flares).

The efficiency of a passive collection system depends on how well the biodegradable fraction converted to gas in available conditions at surface and below the ground. Gas production can be enriched by the landfill collection system design. Use of liners on the top, sides, and bottom of the waste with an impermeable liner (e.g., clay or geosynthetics membranes) will prevent dispersion of landfill gas within the deposited waste and provide better trapping through redirecting preferred gas migration pathways. The efficiency also depends on environmental conditions, which may or may not be controlled by the system design. If pressure is inadequate to push the gas for venting passive systems fail to remove landfill gas effectively. High barometric pressure, sometimes results in outside air entering the landfill through passive vents and counter the LFG pressure to escape through vent pipe. In these cases the methane gas may built-up causing auto ignition and fire hazardous.

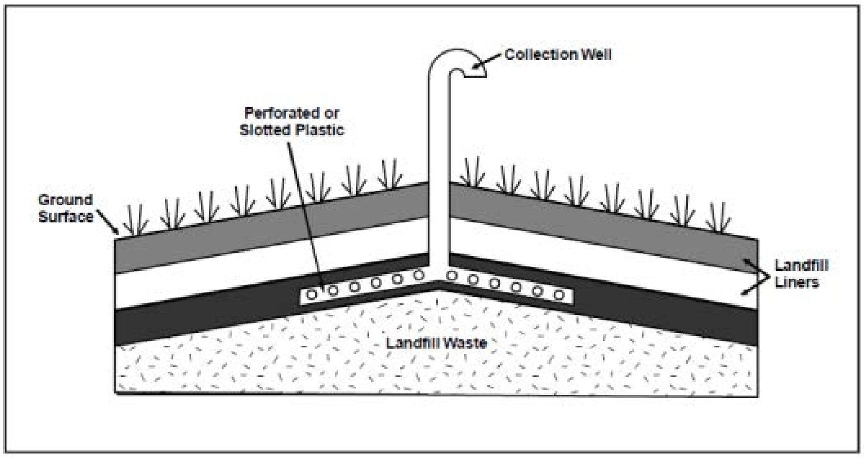


Figure 10: Passive gas collection system

b. Active Gas Collection. Well-designed active collection systems are considered the most effective means of landfill gas collection. Unlike passive system wells in the active system should have valves to regulate gas flow and to ensure proper venting of gas produced through vent pipes, this vents may serve as a sampling port.

Active gas collection may work under vacuum or forced draught. The size, type, and number of induced or forced withdrawal system required in an active system to pull the gas from the landfill depend on the amount of gas being produced. The system design should also account for future gas management needs, such as those associated with landfill expansion.

3.4.3.2 Odour control option for LFG

a. Deodourization /Desulfurization:-

As proposed the processes developed by CSIR, National Environment Engineering Research Institute Nagpur 'chemo biochemical desulfurization', two stage treatment of LFG shall be adopted to reduced odour and odourous compounds containing reduced sulfur. In the first stage gasses laden with reduced odourants is reacted with ferric sulfate which oxidizes reduce sulfur odourants into elemental sulfur and ferric sulfate is reduced to ferrous sulfate. In the second stage of the process, elemental sulfur is separated and ferrous sulfate solution is immobilized in packed bed reactor with specific microorganism. This ferric sulfate solution is recycled back to the first stage of the process. Thus this process operates in a closed loop with recovery of elemental sulfur and consequently deodourization of gasses. The efficiency of recovery of elemental sulfur in this process is reported to be more than 95% with reference to reduced sulfur odourants. The schematics of the process are presented in the Figure 11.

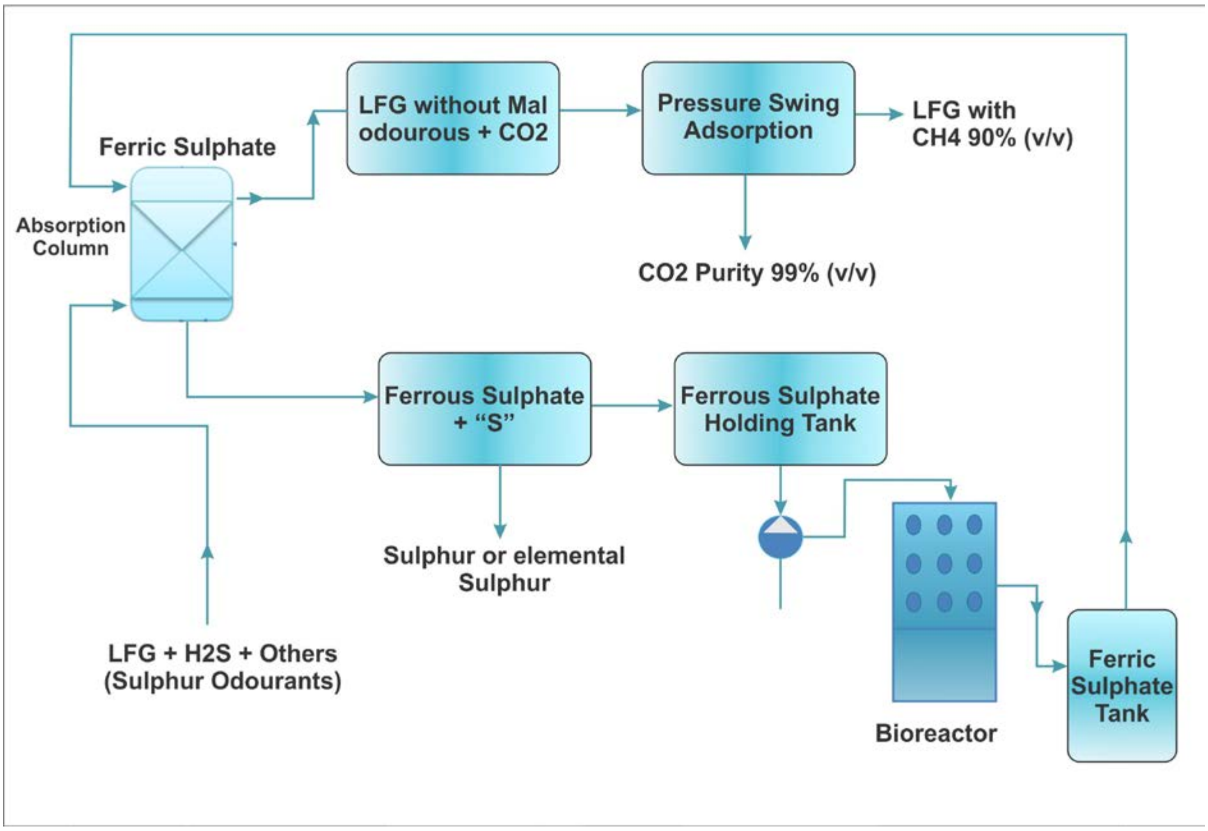


Figure 11: Deodourization /Desulfurization of the LFG

b. Decarbonation of deodourized LFG for enriched methane

The Decarbonation of LFG may be recommended as a high end technique where methane utilization is prime objective. Here methane is enriched by removal of co2 from the gas stream and Co2 is collected as a byproduct. The LFG is processed through a pressure swing adsorption column for selective adsorption of CO_2 present in the LFG. The adsorbed CO_2 will be desorbed and more than 99% pure CO_2 is separated from the stream.

The combination of technique 'a and b' may help in deodourization and Decarbonation of LFG with useful byproduct of sulphur, Co2 and enriched methane to the tune of more than 80% (v/v).

After in depth discussion on three techno feasible remedial option for odour abatement following mat be concluded

- The first process may suffers a set back during the rainy and the winter seasons as composting activities is reduced as biochemical activities of microorganism may be affected.

- The recommended second and third process may be operated after suitable controls mechanisms.

3.6 SALIENT ODOUR ABATEMENT STRATEGIES

After thorough review of national and international documentation and field experience acquired during execution of present study the following strategies are formulated for effective management of odours generated during the different stages of disposal of MSW:-

- The civic bodies (municipalities/ municipal corporation) shall plan, augment the basic infrastructure available to collect and transport the MSW fitting to demand.
- Further awareness training shall be provided by civic bodies through RWAs, school & collages, NGOs and community service centers for handling and sorting of biodegradable component of waste.
- For community based composting system the management should ensure that :-
    - the waste must processed first in and first out basis
    - appropriate cover may be provided to the household composting unit in order to avoid to odour dispersion.
    - the excess produced compost may be collected and transported by municipalities/ municipal corporations for appropriate usages at their own cost and mechanisms.
- In the second recommended process, the anaerobic digestion system may be installed with partial economic support from households, communities and major economical support from municipalities and municipal corporations. The major capital cost support may be collected from the households and communities through proper taxation. The operational cost of the anaerobic digestion system may be contributed by households and communities as produced gas and products will be utilized by the communities
- In third recommended process the municipalities / municipal corporations may bear the capital cost for installation of the plant. The operational cost of the plant may be met through the Govt. stack holders (municipalities and Municipal Corporation). The capital and operational cost may be recovered through sails of the products, viz. elemental sulfur, CO_2 and methane.

****

CHAPTER IV

CRITERIA FOR SELECTION/DESIGNING OF MSW LANDFILL SITE

4.0 PLANNING AND DESIGN OF A LANDFILL

The concept and design for management for LFG and odour abatement for both existing and propose or New landfill site has already been discussed. Accordingly to the requirement stated in official document of the government of India some basic criteria has to be fulfilled while designing a landfill site.

Steps for designing, implementation and operation of a Sanitary Landfill are:

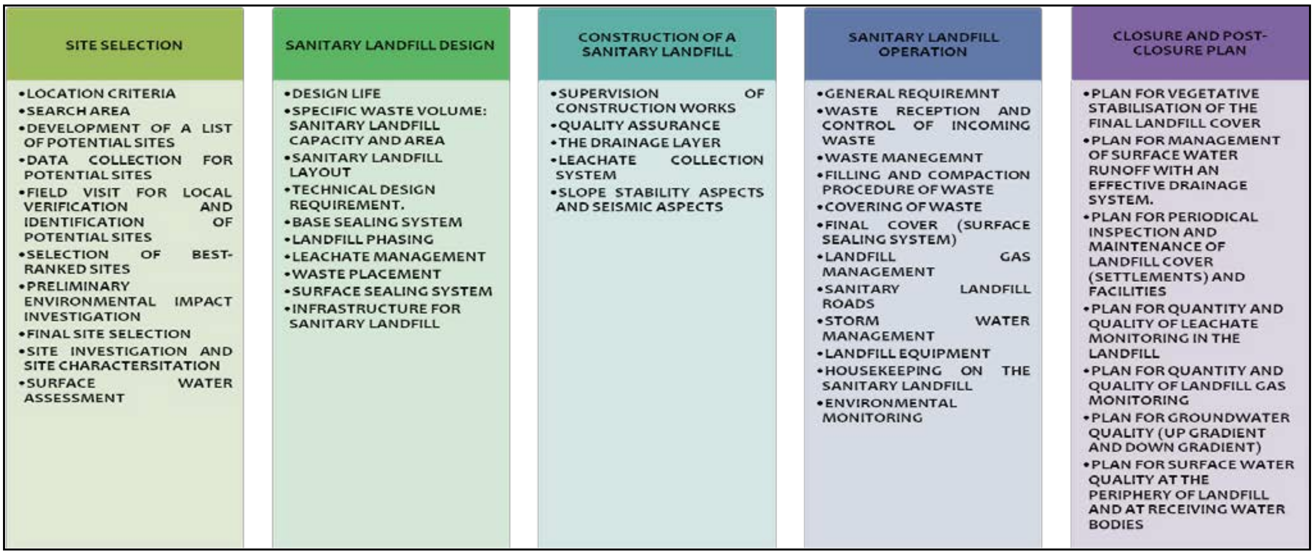
1. Site selection,

2. Sanitary landfill design,

3. Construction of a sanitary landfill

4. Sanitary landfill operation, and

5. Closure and post-closure plan.



4.1 SITE SELECTION

Selection of a sanitary landfill site shall be governed by the strategy identified in the state policy and SWM strategy and the municipal solid waste management (MSWM) plan of the urban local body (ULB). Decisions on constructing local landfills in relation to utilizing regional landfills are based on these strategies or planning documents.

Site selection usually includes the following steps, which are described in the section below:

A. **LOCATION CRITERIA:** - The location must be adhere with reference to SWM rules 2016 (Section 4.1 of Part II). Further it may be also verified if any criteria are specified by regional regulatory agencies (e.g., SPCB and PCC). "Guidelines for the Selection of Site for Land filling" from the Central Pollution Control Board (CPCB) (Annexure 6) should also be referred. It also includes guidance for developing site sensitivity index potential sites. Please refer the below Table:-

Table 1: Location Criteria of MSW Site

S.No.	Place	Minimum Sitting Distance
1.	Coastal regulation, wetland, critical habitat areas, sensitive eco-fragile areas, and flood plains as recorded for the last 100 years	Sanitary landfill site not permitted within these identified areas
2.	Rivers	100 metres (m) away from the flood plain
3.	Pond, lakes, water bodies	200 m
4.	Non-meandering water channel (canal, drainage, etc.)	30 m
5.	Highway or railway line, water supply wells	500 m from center line
6.	Habitation	All landfill facilities: 500 m
7.	Earthquake zone	500 m from fault line fracture*
8.	Flood prone area	Sanitary landfill site not permitted
9.	Water table (highest level)	The bottom liner of the landfill should be above 2 m from the highest water table
10.	Airport	20 km**

SEARCH AREA: - area decides the identification of the potential sites for MSW landfill by delineating waste generating unit as a centre. In the case potential site for MSW landfill site are not indentified by town planning department. The ULB should delineate an appropriate search area, which should ideally be located within the municipal boundary. It is governed by the economics of waste transportation (Section 2.3.12 of Part II).

B. DEVELOPMENT OF A LIST OF POTENTIAL SITES: - After demarcating the search area and considering the various location criteria, areas having potential for site development should be identified while mapping. Potential sites for sanitary landfill development should also conform to the long term land use goals.

In areas where land in scarce city, degraded sites such as abandoned quarry sites or old waste dumpsites can be considered.

The values in below Table can be used as rough guidance or estimation for the required sanitary landfill area including the related infrastructure.

Table 2: Rough Guidance for Sanitary Landfill Sizes.

Waste quantity (Tones per design life of landfill)		Required site area (ha)
In million	**In lakhs**	
<1.0	<10	15-20
1.0-2.0	10-20	20-30
2.0-3.0	20-30	30-40
>3.0	>30	>40

Source- All India Institute of Local Self Government (2012). Reference Material on Municipal Solid Waste Management for Urban Local Bodies – Processing Options. Part II. Mumbai: India

C. DATA COLLECTION FOR POTENTIAL SITES: - this is a secondary selection process which result in excluding the one suitable area which do not meet specified criteria as presented in table. Maps and other available sources and information as mention in the table must be used for a ascertaining this site.

Table 3: Data Collection and Sources

S.No.	DATA	INFORMATION	SOURCES
1.	Topographic maps	The topography indicates low and high areas, natural surface water drainage patterns, streams, and rivers as well as roads, railways, and location of airports.	Survey of India
2.	Soil maps	These maps, primarily meant for Agricultural use, show the types of soil near the surface.	Indian Agricultural Research Institute (IARI)
3.	Land use plans	These plans are useful in delineating Areas with definite zoning restrictions. There may be restrictions on the use of agricultural land or forest land for Sanitary landfill purposes.	Town planning authority or Municipality.
4.	Water use plans	The plans indicating the following items: • private and public drinking water • wells, • drinking water supply line(s), • wells located on surface water bodies and open wells, and • protection areas for drinking water	--
5.	Flood plain maps	These maps are used to delineate areas that are within a 100 year flood plain	Irrigation Department
6.	Geologic maps	These maps indicate geologic features and bedrock levels. They may be used to identify predominantly sandy or Clayey areas.	Geological Survey of India (GSI)
7.	Aerial photographs, satellite imagery, Google maps	These can identify surface features such as small lakes, intermittent stream beds, and current land use, which may not have been identified in earlier map searches.	--
8.	Groundwater maps	These maps indicate the depth to groundwater as well as regional groundwater flow patterns.	Ground water boards or minor irrigation tube well corporations
9.	Rainfall data	Precipitation data are used for designing the amount of possible leachate in cities.	Indian Meteorological Department (IMD)
10.	Wind rose maps	Wind rose maps indicate the predominant wind direction in the area, based on which the location and orientation of the landfill footprint has to be decided.	Indian Meteorological Department (IMD)

S.No.	DATA	INFORMATION	SOURCES
11.	Seismic data	The seismic activity of a region has to be considered in the design of sanitary landfills; landfills should ideally not be located in zone 5 seismic zone. However, in case of siting in zone 5, complete structural analysis should be carried out for designing the landfill and the design should include appropriate structural controls.	GSI or National Geophysical Research Institute (NGRI)
12.	Road maps	Road maps indicate accessibility of the potential site.	--

Source- *Anthena Infonomics (2012). Public Private Partnership in Municipal Solid Waste Management- Potential and Strategies. India.*

D. FIELD VISIT FOR LOCAL VERIFICATION AND IDENTIFICATION OF POTENTIAL SITES

A visit must be planed as a part of preliminary data, collection and map screening. This will help in ascertaining all the features observed in various map for confirmation. The possible sites should be evaluated on the basis of the topographical conditions and the suitability of the landfill site, namely:

- Sufficient land size
- Flat area with low inclination
- Connection to highways and conditions of the access roads
- Flooding during monsoons
- Land use and soil type
- Depth to groundwater table (as observed in open wells or bore wells)
- Information on the sub-ground from clay, stone, or sand pits
- Crossing of electrical lines; and
- Actual settlement patterns (eventual new or informal settlements).

E. SELECTION OF BEST-RANKED SITES

The guideline developed by CPCB for selection of site of land filling must be adhered (CPCB, 2003). These will help in selection of most appropriate sites based on a Site Sensitivity Index. After identification of sites they can be ranked on the basis of defined criteria for the preliminary environmental impact investigation and final site selection.

F. PRELIMINARY ENVIRONMENTAL IMPACT INVESTIGATION

On the basis of the ranking scores of various sites, two or three sites may be chosen for a preliminary environmental impact investigation. The impact of the sanitary landfill should be asses and potentially may be quantified according to the national rules and the local conditions.

G. FINAL SITE SELECTION

The available best-ranked alternatives site should be compared on the bases of following criteria:-

- Environmental impact
- Social acceptance
- Land availability
- Transportation costs
- Sanitary land filling costs (site specific costs are to be considered).

Transportation costs of the waste to landfill play a critical role in selection of landfill site and it must be compared on the bases of average handling distance from the centre of waste generating area.

In general, the material costs for liner system, leachate collection system, daily covers, final cover system, and all facilities are similar for all sites, considering normal site conditions (this shall change in areas of high water table, in hilly areas, and other peculiar issues). The main differences include:

- Distance of the access road to regional road system
- Sub-ground conditions for earthworks to prepare the base of filling area
- Distance to waste generators and waste processing facilities.

The detail information on site parameters beyond those of the site selection process as it is a necessary for formulating the design criteria for the sanitary landfill.

H. SITE INVESTIGATION AND SITE CHARACTERSITATION

The adequate design of the sanitary landfill at the selected site. Proper site investigations:-

- Subsoil investigation,
- Groundwater or hydro geological investigation,
- Surface water investigation,
- Topographical investigation,
- Environmental investigation, and
- Traffic investigation.

Hydro geological and surface water investigations are most critical for determining the detailed design of the landfill, and groundwater and surface water quality are required to be monitored regularly during the active life and post-closure of the landfill to ensure fail-safe performance of the landfill.

MSW rules must be adhering while assessing the hydrological setting of a landfill site. A critical assessment should also be used to developed effective ground water and leachate monitoring plan with following objectives:-

- Obtaining samples to characterize soil or bedrock conditions,
- Mapping groundwater depth and pressure within the site, and
- Assessing baseline groundwater quality.

An analysis of the groundwater flow and pressure will result in the determination of groundwater flow paths and inform leachate control mechanisms and contingency plans for failure of the leachate liner. Future monitoring of groundwater quality should be against a reference of baseline conditions.

The hydro geological investigation report for a site should include the details which has been prescribed as a prerequisite for the designing for the selection of the site for landfill disposal as per *Technical Aspects: Municipal Sanitary Landfills, 2016.*

I. SURFACE WATER ASSESSMENT

The base line for surface water quality of the different resources following within the boundary of 500 meter requires to be characterized as per the detail mentioned in the *Technical Aspects: Municipal Sanitary Landfills, 2016.*

4.2 DESIGN OF SANITARY LANDFILL SITE

The following design criteria should be considered while sanitary landfill disposal site:-

A. Design Life
B. Specific Waste Volume: Sanitary Landfill Capacity And Area
C. Sanitary landfill layout
D. Technical design requirement
E. Base sealing system
F. Landfill phasing
G. Leachate management
H. Waste placement
I. Surface sealing system
J. Infrastructure for sanitary landfill

A. DESIGN LIFE

The life of sanitary landfill consists of three phases of its Span of existence:-

a. Active period (20-25 years)

b. Closure period

c. Post-closure period

The closure period and post closure period starts after end of the active period and it life is for 15 years. Extensive monitoring is required in all the three phases of landfill.

B. SPECIFIC WASTE VOLUME: SANITARY LANDFILL CAPACITY AND AREA

Another design criteria waste volume landfill capacity and area of the landfill site the following points may be considered:-

a. 1 tonne of waste is equivalent to 1 cubic metre (m^3) of sanitary landfill volume. (In reality, the specific weight of waste in a sanitary landfill is 0.8 t/m^3 during the first years and will increase after settlement over the time to 1.2 t/m^3.)

b. Covering of waste will use about 10% more volume.

Keeping the above facts one can design the volume of landfill capacity and area required for MSW landfill based on magnitude of the solid waste generation.

C. SANITARY LANDFILL LAYOUT

The general layout the landfill consists of area where actually a landfill is carried out while there are area where accessories structures viz. access roads, equipment shelters, office space, location of waste inspection and transfer station (if used), areas to be used for waste processing (e.g., shredding), weigh bridge, gate, recycling area, compactor garage, pre-treatment area etc. will installed as depicted in the following Figure:-

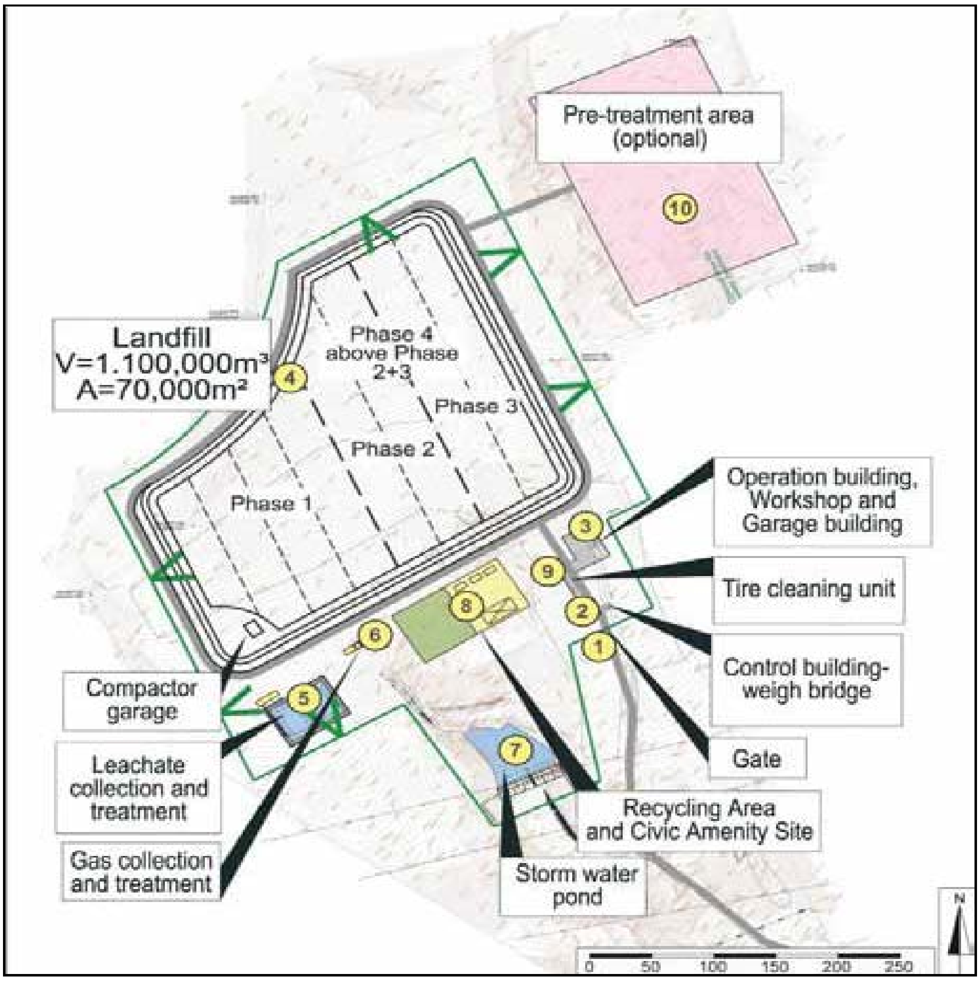


Figure 12: Sanitary Landfill Layout

D. TECHNICAL DESIGN REQUIREMENT

The technical design specification of sanitary landfill focus on efficient leachate collection and management. There are three types of leachate situations:-

- The landfill may have the hydro geological situation where abundant query are to be used as a potential landfill sanitary site. The landfill could be below the ground.
- Landfill site above the ground have advantage as leachate flows by gravity according to natural surface slope. In such case leachate is collected in main leachate pipe which can be extended beyond the area of landfill and pumped outside the landfill resulting in reduction in footprint.
- In the case is the water table is sufficient below the ground surface, landfill can be located at a level below the ground by excavation, accommodate more

waste per unit area of land. But it should be engineered and constructed appropriately to address the following issues:

1. Extra costs for excavation
2. Energy Input for pumping leachate during and beyond the active life of landfill.
3. Environmental risks during non functional of pumps.
4. Potential for retention of leachate in the waste body
5. Pipe cleansing and controlling an impossible task.
6. Pumping cost for the leachate (during the lifetime and the aftercare phase of the landfill).

I. DESIGN CRITERIA FOR LANDFILL HILLY REASON:- TWO TYPES OF LANDFILL ADOPTED:-

- Slope sanitary landfills:-Placement of waste along the sides of existing hilly slope.
- Valley sanitary landfills:-the placement of waste in of valley

The above system may be adopted based on the topographical conditions of the site. In hilly reason generally additional layers of geosynthetics, geocomposites, or other type of geosynthetics-geocomposites mixture of clay is used. As there is a problem of soil permeability in hilly reason. The requirement of 90 cm clay (of best available quality locally) should be complied with, and the overall equivalence of such design of soil and additional layers will be checked and certified by geotechnical experts.

II. SANITARY LANDFILLS IN MARSHY REGIONS: -

Should not be constructed in marshy areas; the local authority should access a regional landfill facility outside the marshy area.

E. BASE SEALING SYSTEM

i. Adoption of shape of site as per the existing condition with minimum of fills and cuts but the mass which will be replaced by the sealing system has to be excavated.

ii. Excavated soil could be used as a potential base sealing system and can also be

iii. Compacted to be used as overlying clay liner.

iv. The natural soil should be levelled and compacted to achieve 90% maximum dry density as obtained from Proctor compaction tests. This is sufficient to compact the overlying clay liner.

v. The base area must be kept appropriately for achieving sufficient slope to guarantee draining of leachate and storm water.

THE COMPOSITION OF BASE SEALING SYSTEM HAS TO BE IN COMPLIANCE WITH SWM RULES 2016 AND SHOULD CONSIST OF THE FOLLOWING:-

- **Mineral sealing liner:-** three layers of clay or equivalent amended soil, at least 30 centimetres (cm) thickness each. Adequate clay is not found in the vicinity, amended soil mixed with bentonite can be used. The permeability of the mineral sealing must be less than kf ≤1 x 10-7 cm per second (cm/s).
- **Geosynthetics clay liner:** In hilly regions, the mineral part of the sealing system can be reinforced by a geosynthetics clay liner.
- **High-density polyethylene geo membrane:** The high-density polyethylene (HDPE) geo membrane should have a standardised thickness of 1.5 millimetre (mm).
- **Protection layer:** Silty soil with thickness of 20–30 cm thick or, geotextile with 400 grams per square meter (g/m^2) for bottom liner and 200 g/m^2 for top cover, depending on the landfill height. In the case of land height in the landfill is more than 20 m, geotextile should be 800 g/m^2.
- **Leachate drainage layer:** A leachate drainage layer should be 30 cm thick made of filter gravel, ensuring permeability greater than 10-2 cm/se

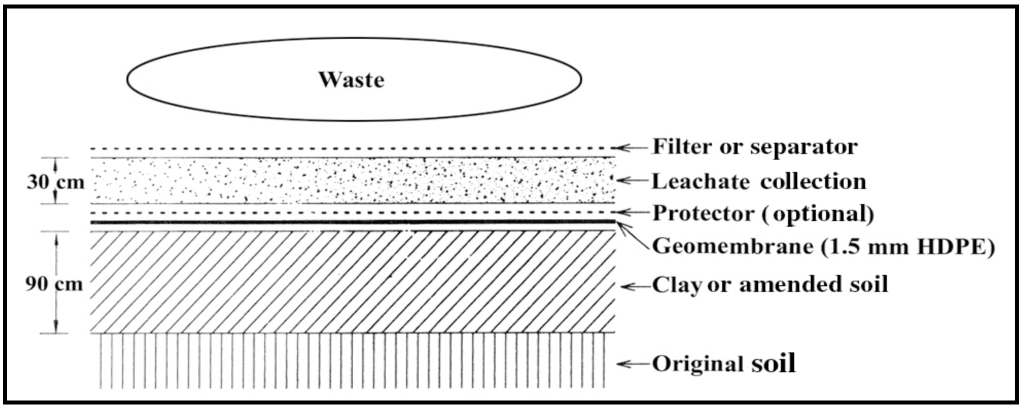


Figure 13: Leachate drainage layer

F. LANDFILL PHASING

The important criteria and must be adopted as per the pre determine plan. Landfill phasing is essential to:-

- To minimise damage to the landfill base layers
- ensure continued integrity of base layers over the lifetime of the landfill
- Minimise potential rainfall infiltration.

However phasing must be as per site specific decision, site condition and care must be taken in design so that the proposed landfill volume should be large enough for at least one year.

G. LEACHATE MANAGEMENT

It must be carried out by indentified leachate generating sources and appropriate collection and management as per the standard norm documented in the Municipal Solid Waste Management Manual, Ministry Of Urban Development Government Of India, 2016.

H. WASTE PLACEMENT

It should follow the following steps:

- A 30 cm thick layer of select waste without compaction will be placed on the geotextile as and when the laying is completed.
- In order to dump subsequent layers of waste, soil should be pushed gently by a light dozer to make a path.
- One or two main routes of soil should be created for use by heavier equipment for soil moving with 60–90 cm.
- Care must be taken to avoid the damage the geo membrane due to traffic.
- The first lift of waste should be spread and slightly compacted with light vehicles.
- No bulky items should be dumped in the first lift.

I. SURFACE SEALING SYSTEM

The surface sealing must follow the following sequence from waste surface to top of the surface during the sealing:-

- **Gas drainage layer-** 30 cm thick formed by crushed gravel or crushed demolition waste to facilitate gas collection.

- **Mineral clay layer:- mineral clay layer should be a 60 cm:** either of clay or amended soil with a permeability requirements of k = 10 cm/s. if the permeability is more and higher than 1.5 mm HDPE may be installed over 60 cm thick soil layer. 1.5 mm HDPE liner should be covered with a 20 cm protection layer or geotextile.
- **Water drainage layer:** The water drainage layer should be 30 cm thick formed by crushed gravel. The gravel layer should be covered by a geotextile or alternate separator to prevent clogging of the drainage layer by the overlying soil.
- **Vegetative soil layer:** The top layer should be 45 cm thick vegetative soil.

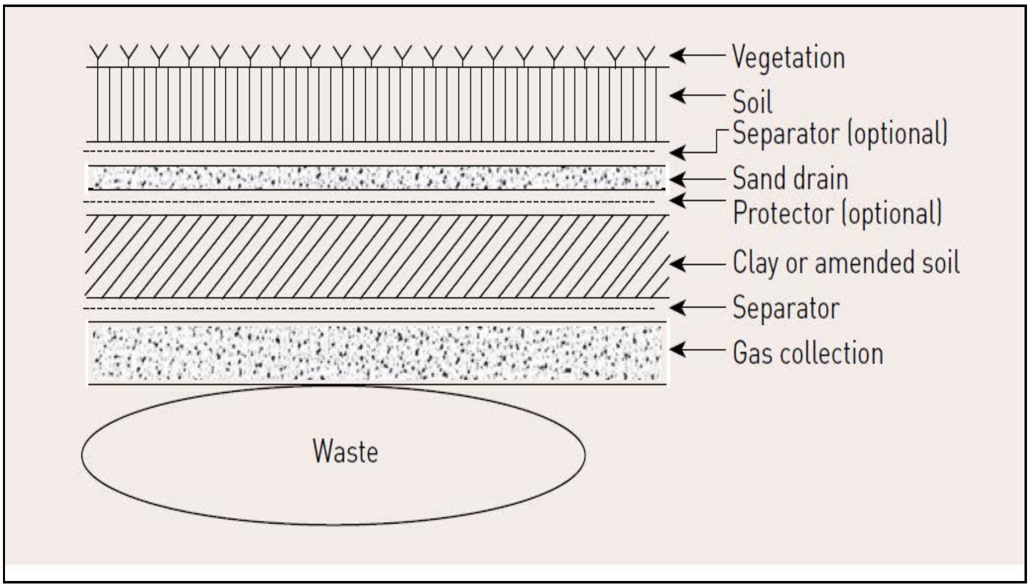


Figure 14: Surface liner system

J. INFRASTRUCTURE OF SANITARY LANDFILL

- Road Construction
- Equipment and Resources
- Waste Inspection Area or Emergency Area
- Security and Fencing
- Tyre Cleaning Unit
- Sanitary Landfill Buildings

4.3 CONSTRUCTION OF THE SANITARY LANDFILL

Construction of sanitary landfill must be carried under the supervision of the engineering with following assign task:-

- Supervision of Construction Works

- Quality assurance
- The drainage layer
- Leachate collection system

A. SUPERVISION OF CONSTRUCTION WORKS

The construction of a sanitary landfill should be supervised by an independent engineer on behalf of the municipality or the employer.

- Approval of the drawings and the final design.
- Quality assurance of all operations related to the landfill and there.
- Compliance with the SWM Rules, 2016.
- Time scheduling, steering, and coordination of the construction sites.
- Acceptance of the construction work and supply.

B. QUALITY ASSURANCE

Quality assurance and quality control are integral parts of a landfill design scheme. Quality assurance/quality control plans should be used to ensure that the design and construction of the facility is carried out to a satisfactory standard.

C. THE DRAINAGE LAYER

The drainage layer is built on the protection layer. The drainage layer must comply with the following requirements:

- The chemical, physical, and mechanical stability of the material selected for the drainage layer must ensure that there is no negative effect on the drainage efficiency from the chemical and physical leachate characteristics and the mechanical load of the landfill body.
- For the drainage layer, washed material should be used and rounded grains preferred.
- Grain-size distribution of the material should be used for the drainage layer, with permeability greater than 10-2 cm/sec.

D. LEACHATE COLLECTION SYSTEM

It must be carried out by indentified leachate generating sources and appropriate collection as per the standard norm documented in the Municipal Solid Waste Management Manual, Ministry Of Urban Development Government Of India, 2016.

E. SLOPE STABILITY ASPECTS AND SEISMIC ASPECTS:-

The stability of a landfill should be checked for the following cases:

- Stability of excavated or filled slopes,
- Stability of liner system along excavated or filled slopes,
- Stability of temporary waste slopes constructed to their full height (usually at the end of a phase),
- Stability of slopes of above-ground portion of completed landfills,
- Stability of cover systems in above-ground landfills.

All the above assignment must be carried out as per the specification mention in the "Municipal Solid Waste Management Manual, Ministry Of Urban Development Government of India, 2016".

4.4 SANITARY LANDFILL OPERATION

A. GENERAL REQUIREMNT

- Operation Manual
- Employee Assignments and Responsibilities
- Staff Responsibilities and Qualifications
- Hours of Opening and Operation
- Site Notice Board
- Site Security

B. WASTE RECEPTION AND CONTROL OF INCOMING WASTE

All deliveries from collection vehicles of the municipality and from private service providers should be documented by checking the (registered) license plate number, the respective labelling on the vehicles, or the respective license. Corresponding lists with the license plate numbers have to be compiled before hand by the landfill supervisor to help the weighbridge operator identify the vehicles.

C. WASTE MANEGEMENT

The spotters have to inform the deliverer about the location for waste unloading at the landfill. The following unloading areas should be available:

- Waste disposal area;
- Temporary storage areas for building materials, demolition waste, and earth excavation (cover material)

D. FILLING AND COMPACTION PROCEDURE OF WASTE

A high degree of waste compaction extends the lifetime of the landfill, reduces the need for cover material, reduces litter problems, and minimises long-term land requirements.

E. COVERING OF WASTE

Cover material includes imported cover such as (i) soil and other inert waste; and (ii) other material such as fine portion of C&D waste, street sweepings, and dry drain cleaning silt. The cover soil should be pushed by a bulldozer or wheel loader up the slope and spread out as evenly as possible. When constructing a body in an open area, the side slopes also require soil cover.

Landfill must be covered with following thing:-

- Daily Cover
- Intermediate Cover
- Temporary Surface Cover
- Covering during the Monsoon

F. FINAL COVER (SURFACE SEALING SYSTEM)

To minimise infiltration of storm water in the landfill body and to allow storm water runoff, a surface sealing system has to be installed after the final completion of each landfill part.

G. LANDFILL GAS MANAGEMENT

A large part of mixed waste (50%–60%) consists of biodegradable parts which produce methane gas. With a view to reduce GHG emissions and thereby reduce environmental impacts, it is mandatory to install a degassing system for the sanitary landfill. The gas management strategies should follow one of the following options:

- Controlled passive venting; or
- Controlled active collection and treatment or reuse.

H. SANITARY LANDFILL ROADS

An important part of the landfill operation activities is enabling vehicles to reach the land filling area, which is progressing every day, and to cover the waste once it is land filled. Therefore, continuous road construction is required.

- Road Construction
- Main and Temporary Roads
- Road Maintenance

I. STORM WATER MANAGEMENT

All surface water ditches, culverts, drainage channels, and settling ponds (storm water ponds) should be designed by a hydrologist using hydro meteorological data.

- Surface Water Collection
- Storm Water Retention Pond
- Maintenance of the Storm Water System

J. LANDFILL EQUIPMENT

- Required Equipment
- Maintenance of Mobile Equipment

K. HOUSEKEEPING ON THE SANITARY LANDFILL

Housekeeping should be conducted in such a manner that it protects the public and surrounding environment from risks and nuisance emanating from landfill operations. A well-controlled landfill operation will enhance public perception and acceptance of the landfill site.

The following general measures should be considered:

- Health and Safety
- General Safety Measures
- Person Related Safety Measures
- First Aid
- Personnel Accidents
- Fire Prevention and Protection

L. ENVIRONMENTAL MONITORING

The environmental monitoring of landfills should be performed as per SWM Rules, 2016 requirements.

4.5 CLOSURE AND POST CLOSURE PLAN

Determination of the end use of a landfill site is an essential part of the plan for landfill closure and post-closure maintenance. A closure and post-closure plan for landfills involves the following components:

- Plan for vegetative stabilisation of the final landfill cover,
- Plan for management of surface water runoff with an effective drainage system.
- Plan for periodical inspection and maintenance of landfill cover (settlements) and facilities,

- Plan for quantity and quality of leachate monitoring in the landfill.
- Plan for quantity and quality of landfill gas monitoring,
- Plan for groundwater quality (up gradient and down gradient), and
- Plan for surface water quality at the periphery of landfill and at receiving water bodies.

The post-closure care of landfill site shall be conducted for at least 15 years in line with the SWM Rules, 2016 as mentioned above. The authority or concessionaire that operated the sanitary landfill shall be responsible for post-closure activities and monitoring.

- Plantation at Landfill Site.
- Considerations for Landfill Costing.

All the above assignment must be carried out as per the specification mention in the "Municipal Solid Waste Management Manual, Ministry Of Urban Development Government Of India, 2016".

4.6 RECOMMENDATION ASPECTS FOR DESIGN AND OPERATION OF LANDFILL SYSTEM TO CONTROL ODOUROUS EMISSION IN INDIAN CONTEXT-BASED ON PRESENT STUDY

- In the present situation in India, the segregation of MSW must be adopted appropriately so that biodegradable and non biodegradable component of MSW must be separated. Design, construction and operation of MSW must be carried out as per the guideline specified in the manual "municipal solid waste management manual, ministry of urban development government of India, 2016".
- Landfill must be operated in such a way so that biodegradable component of MSW may be stabilised through composting mechanism with minimum generation of odourous constituent.
- Going through the experimental observation in the present study, the odourous emission constituents are:-

  a. Ammonia
  b. Sulphides
  c. Hydro carbon
  d. Volatile organic compound

The minimal concentration of such odourous emission can be achieved by adopting:-

- Appropriate C/N ratio in the MSW landfill system
- Operating the landfill in such way that the population of sulphur reducing microorganisms should be minimum. This will lead to formation of minimum reducing sulphur odourants
- Process design and operation of the landfill should be in such way that partial aerobic condition may prevail which will help in generation of minimum VOCs which help in minimum generation of odourous constituents as since aerobic conditions will help in solubilising the sulphur and nitrogen constituents in the form of leachate (Solubilised for of nitrogen as NO_3 and Sulphur as SO_4). This will help in keeping the low availability of nitrogen and sulphur to anaerobic microorganism to transform to ammonia and reduced sulphur odourants.
- Some of the chemical agents viz enthro quenone, ferric salt are spread over the MSW landfill site to reduce the operation of the landfill site it low sulphedity and also cage the sulphurous odourants
- Selection of appropriate plant species for vegetation cover over the surface of landfill may reduce the formation of odourous constituents by channelizing the solubilised nitrate and sulphate as uptake for their growth.
- MSW Landfill system should be deign meticulously by providing appropriate network of LFG collection system as this will avoid the fugitive emission of odourous constituents
- In design of the MSW Landfill, appropriate arrangement may be made for spraying inhibitory agents or masking agent or neutralizers in scenario of intermittent odourous emissions or whether the implementation of other measures is difficult. The Rationale underline this technology is spraying of additives that mask, inhibit or neutralized the inherent unpleasant hedonic tone the landfill emissions
- The materials used for high and low covers must be non corrosive and be put in appropriate configuration of the landfill system which will avoid the fugitive emissions from the landfill and will act as a preventive measures for odour emission
- In design of the landfill system, attention has been made for designing the efficient gas collection and treatment system in order to reduce the odour concentration in the industrial off gas emission before it reaches the atmosphere.

Figure 15: Ghazipur Landfill site before closure

Figure 16: Ghazipur Landfill site after closure (Some Area)

WAY FORWARD

The above draft guidelines have been prepared keeping in view the various mandatory and statutory provisions available nationally and globally. People participation is the key ingredient for the planning process. We hope and trust that people at large will give their valuable suggestion which will be helpful in modification of the "Draft Guidelines of Odour Monitoring & management in Urban MSW Landfill site". It will be then helpful for the regulatory authorities and the people at large.

The first initiative of CPCB to address odour problem by a scientific investigation may be taken forward to achieve the objective of providing better air quality for the nation following may be taken up:-

I. Inclusion of odour as a parameter under regulatory framework may be initiated.
II. Proposal for amendment of MSW rules, BMW rules and HWM rules may be considered and odour nuisance may be included for compliance.
III. Till the odour is brought into regulatory framework at least the odour criteria may be included in Environmental Clearance (EC) conditions for upcoming MSW, BMW, HWM and CETPs & STPs.
IV. National Programme for promotion of additional Monitoring Projects on odour assessment, management and short term/ long term solution for Urban MSW Landfill Sites of metropolitan cities in different region of country with help of State Pollution Control Board and Municipal Corporations.
V. Optimization of available models in Indian conditions for odour Dispersion and mapping.
VI. Development of technical and analytical capabilities and competence of State Pollution Control Boards and Municipal Corporations and accredited laboratories for odour and odourous compound monitoring for analysis for very low concentration of odourous compounds like Mercaptans, Butyric Acid, Dimethyl sulphide etc.
VII. Sincere efforts by the Municipal Corporations to achieve optimal reduction in odour pollution by adoption of Best Management Practices for Landfill sites.
VIII. Establishment of Online monitoring systems for odour and odourous compounds, initially such systems may be installed at one or two Urban Landfill sites to assess their utility.

IX. Separate Studies for odour monitoring & management in odourous industries such as Pulp & Paper, Fertilizer, Pesticides, Tanneries, Sugar & Distillery, Chemical, Dye & Dye Intermediates, Bulk Drugs & Pharmaceuticals and Waste Water Treatment Plant etc. to evolve time bound standards for odour emission.

X. Defining and developing barriers at landfill sites by plantation and Green belt on the boundary of with suitable species of plants / trees as natural media for reduction of odour pollution and restriction of odour nuisance in and around landfill sites.

****

BIBLIOGRAPHY

- MSWMHR (2000), Ministry of Environment and Forests, Govt. of India.
- Kurian Joseph, Nagendran, R., Palanivelu, K., Thanasekaran, K. and Visvanathan, C. (2004), Dumpsite Rehabilitation and Landfill Mining , CES, Anna University, Chennai-600 025, India
- Singhal,S., and Pandey,S., Solid waste management in India: status and future directions.
- TERI Information Monitor on Environmental Science,2001,6:1-4
- Department of the Environment (1994) Protection of New Buildings and Occupants from Landfill Gas, Government Publications, Dublin
- CPCB (2001): "Status of Municipal Solid Waste Generation, Collect ion Treatment, and Disposal in Class -I Cit ies", Central Pollution Control Board, ministry of Environment and Forests, New Delhi.
- Down to Earth (2012): "Delhi Municipality Constructs get Another Waste -to-Energy Plant at Gazipur", April 16-30, Down to Earth, 2012.
- IL & FS Ecosmart Limited, Report (2005): City Develop ment Plan of Delhi, Municipal Corporation of Delhi.
- Guidelines on odour pollution & its control. Central Pollution Control Board. Ministry of Environment & Forests, Government of India, CPCB 2008.
- Ku mar, S., Gaikwad, S. A., Shekdar, A. V., Kshirsagar, P. S. and Singh, R. N. (2004): "Estimat ion Method for National Methane Emission fro m Solid Waste Landfills. Atmospheric Environment, 38, pp. 3481-3487
- US EPA (2007b), Report of the pump test and pre-feasibility study for landfill gas recovery and utilisation at the Deonar landfill Mumbai, India. Washington DC,2007.
- CPHEEO (2000): Manual in municipal solid waste management, Central Public Health and Environ mental Engineering Organizat ion, Min istry of Urban Develop ment, New Delhi.
- Ahmad, K. (2012): "A System Dynamic Modelling of Municipal Solid Waste Management System in India", IJRET, Vo l. 1, Issue.4, pp. 628-641.available@http://www.ijret.org
- Ansari, J.H. (1999): Solid Waste Management in Delhi- Need for Partnership Arrangements, Congress Paper at 27 th National Congress, 19-22 September.
- The Environment (Protection) Rules. Pollution Control Acts, Rules and Notifications issued Thereunder. Sixth edition. Central Pollution Control Board. 2010.
- Nath, K.J., "Solid Waste Management in the Present Indian Perspective", proceedings of ISWA 1993 Annual Conference, Jönköping, Sweden, September 1993.
- U.S. Environmental Protection Agency. Characterization of Municipal Solid Waste in the United States: 1990 Update. (EPA/SW-90-042). June 1990

- USEPA (1997). "Landfill Reclamation", United States Environmental Protection Agency, Solid Waste and Emergency Response (5306W), EPA530-F-97-001, July 1997
- DOE. 1995. U.S. Department of Energy. Greenhouse gases 1987-1994. http://www.eia.doe.gov/oiaf/1605/95 report/chap3.html.
- The ISWA publication – "Field Procedures Handbook for the Operation of Landfill Biogas Systems".
- World Bank (1999)," What a waste – Solid waste management in Asia" Urban and Local Government Working Papers, The International Bank for Reconstruction and Development/THE WORLD BANK, 1818 H Street, N.W. Washington, D.C. 20433, U.S.A
- Rushbrook, P. (2001). "Guidance on Minimum Approaches for Improvements to Existing Municipal Waste Dumpsites" WHO Regional Office for Europe, Copenhagen.
- LANDFILL MANAGEMENT IN ASIA - NOTIONS ABOUT FUTURE APPROACHES TO APPROPRIATE AND SUSTAINABLE SOLUTIONS by C. VISVANATHAN, J. TRÄNKLER*, B.F.A. BASNAYAKE, C. CHIEMCHAISRI, K. JOSEPH°° AND Z. GONMING
- Discussions with MCD Officials. November 2006, Delhi and discussions with an official of Delhi Waste Management company, April 2006. Delhi
- Improving Management of Municipal Solid Waste in India: Overview and Challenges. 2006. The World Bank
- Chintan Environmental Research and Action Group, Informal-formal: Creating opportunities for the informal recycling sector in Asia. 2005
- Adapted from Space for Waste: Planning for the Informal Recycling Sector. Chintan Environmental Research and Action Group. 2004
- Jorstad L.B., Jankowski J and Acworth R.I., „Analysis of the distribution of inorganic constituents in a landfill leachate-contaminated aquifer Astrolabe park, Sydney, Australia", Environ Geology Vol 46, (2004)
- Paper presented on Characterization Of Leachate At Various Landfill Site Of Delhi, Indiaby Syed Shakeel Afsar, Sanjeev Kumar , Pervez Alam in International conference of science, technology & management, University of Delhi.

****