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Sustainable Leachate Treatment Strategies for Municipal Solid Waste Management in Visakhapatnam

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Abstract - Municipal solid waste (MSW) management in urban areas like Visakhapatnam generates significant amounts of leachate, a highly contaminated liquid that poses environmental and health risks if not properly treated. This study explores effective leachate treatment methodologies to minimize pollution and ensure sustainable waste management in Visakhapatnam. The leachate characteristics vary based on waste composition, landfill age, and climatic conditions, necessitating a multi-stage treatment approach. The treatment process involves primary screening and sedimentation to remove large particles, followed by biological treatment methods such as aerobic activated sludge processes and anaerobic digestion for organic degradation. Advanced treatment techniques like reverse osmosis, activated carbon adsorption, and chemical oxidation ensure the removal of persistent contaminants, heavy metals, and ammonia. This research highlights the need for site-specific leachate treatment strategies, integrating sustainable and cost-effective solutions tailored to Visakhapatnam's waste management framework. Implementing efficient leachate treatment technologies will help mitigate groundwater contamination, protect ecosystems, and ensure compliance with environmental regulations.

***Key Words*:** Leachate treatment, municipal solid waste, Visakhapatnam, landfill management, wastewater treatment, environmental sustainability.

1.INTRODUCTION

Municipal Solid Waste:

Municipal solid waste management is an important as it impacts health, environment and aesthetic society if it is not managed properly. Hence to improve quality and standard of living in the state, the Government of Andhra Pradesh (GoAP) has proposed to strengthen the Municipal Solid Waste Management system covering collection, segregation, recycling, transportation, processing and disposal with option for composting, waste to energy, disposal in all 110 urban local bodies (ULBs) in Andhra Pradesh, which is in line with national objective of SWATCH BHARATH MISSION, a prestigious project of Govt of India.

The Swatch Bharat Mission (SBM) emanates from the vision of the Government articulated in the address of The President of India in his address to the Joint Session of Parliament on 9th June 2014:

"We must not tolerate the indignity of homes without toilets and public spaces littered with garbage. For ensuring hygiene, waste management and sanitation across the nation, a "Swatch Bharat Mission" will be launched. This will be our tribute to Mahatma Gandhi on his 150th birth anniversary to be celebrated in the year 2019" .SBM is being implemented by the Ministry of Urban Development (M/o UD) and by the Ministry of Drinking Water and Sanitation (M/o DWS) for urban and rural areas respectively.

The green economy promotes the minimization of waste production and by encouraging sustainability. The waste that is produced is usually reutilized by recycling or recovering valuable substances. This significantly reduces the waste that is disposed of the allocated land. According to The world bank(2019), 46 billion USD is spent annually by developed countries to manage the solid waste which most likely will double if sustainability is incorporated. Currently, the economy mainly exploits the non-renewable resources for economic growth. If the waste sector is utilized effectively by following a carbon neutral strategy, it can provide resourceful substances to the economy without overusing the non-renewable resources .

Furthermore, GHG emissions would also reduce notably. Additionally, by optimizing waste- to-energy will engage people through jobs and also allow recovery of material and energy which will lower the carbon footprint (Louwen et al.,2016).

Currently, there are various technologies and treatments available for MSW management. The different treatments and types reviewed in this study are illustrated in below..

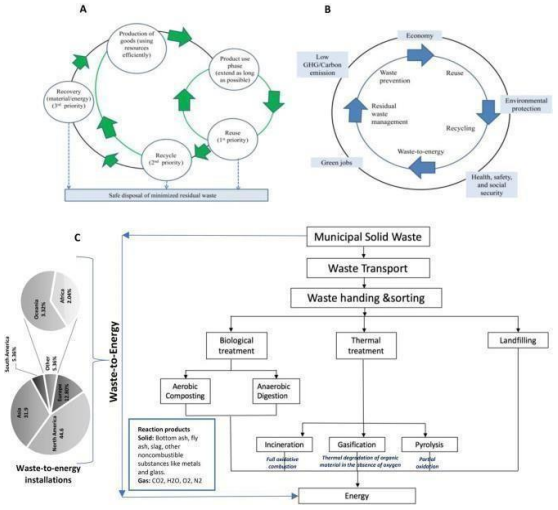

Fig: Flowchart of waste treatment

Table -1: Biodegradable and Non-Biodegradable Wastes & Degeneration Time

Category	Type of Waste	Approximate time taken to degenerate
Biodegradable	Organic waste such as vegetable and fruit peels, leftover foodstuff etc.	A week or two
	Paper	10-30 days
	Cotton cloth	2-5 months
	Woolen items	1 year
	Wood	10-15 years
Non-Biodegradable	Tin, aluminium and other metal items such as cans	100-500 years
	Plastic bags	1 million years
	Glass bottles	Undetermined

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II. MISSION OBJECTIVES:

1.Elimination of open defecation.
2.Eradication of manual Scavenging.
3.Modern and Scientific Municipal Solid Waste Management
4.To effort behavioral change regarding healthy sanitation practices
5.Generate awareness about sanitation and its linkage with public health
6.Capacity Augmentation for ULB's
7.To create an enabling environment for private sector participation in Capex (capital expenditure) and Opex (operation and maintenance)

Mission Components:

1.Household toilets, including conversion of insanitary latrines into pour-flush latrines
2.Community toilets
3.Public toilets
4.Solid waste management
5.IEC & Public Awareness

Capacity building and Administrative & Office Expenses Swatch Andhra Corporation (SAC)Swatch Andhra Corporation was incorporated from 1st May 2015 with a goal to achieve the "Swatch Bharat Mission" campaign launched on 2nd October 2014 by Hon'ble Prime Minister of India. Swatch Andhra Corporation has the mandate to fulfill the Mahatma Gandhi's dream of "Swatch Bharat" by eliminating open defecation, eradication of manual scavenging, Solid and Liquid Waste Management, Information, Education and Communication and Capacity Building activities to maintain the cleanliness and hygiene in urban and rural areas of Andhra Pradesh.

Swatch Andhra Corporation is taking up the activities of construction of Individual Household Toilets, Community Toilets and Public Toilets. For scientific processing and disposal of municipal Solid waste, waste to energy projects and waste to compost projects are taken up under public private partnership.To tackle the Construction and Demolition waste, C&D waste processing plants are under development through public private partnership mode. Steps are also taken to reclaim valuable municipal old dump sites through process of bio-mining. With political will, backed by a dynamic team and massive support from citizens, the Government of Andhra Pradeshis all set to achieve universal access to Sanitation and thereby make the Urban and Rural areas Smart, Clean, Safe and Healthy.

III. CHEMICAL CHARACTERISTICS OF SOLID WASTE MANAGEMENT:

Information of chemical characteristics is important in valuating alternative and recovery options. Typically waste is considered as combination of combustible and non-combustible components. If solid waste is to be used as a fuel or for any other use we should know its chemical components.

1.Lipids:

These are included in the class of fats, oils and grease. The principal sources of lipids in the garbage are cooking oil and fats. Lipids have high heating values about 38,000 Kj/Kg (kilojoules/kilograms), which makes the waste with high lipid content suitable for energy recovery. Since lipids become liquids at temperature slightly above ambient they add to the liquid content during waste decomposition. They are biodegradable, but they have low solubility in water and hence the rate of biodegradation is slow.

2.Carbohydrates:

These are primarily originated from the food sources rich in starch and celluloses. These readily biodegrade into carbondioxide water and methane. Decomposition of carbohydrates attracts the flies and rats and hence should not be left exposed for long duration.

3.Proteins:

These are the compounds containing carbon, hydrogen, nitrogen and oxygen and organic acid with amino groups. They are primarily found in food and garden wastes, but their partial decomposition result in the production of amines, which impart unpleasant odors.

4.Natural Fibers:

These are the natural products contain cellulose and lignins that are relatively resistant to biodegradation. These are found in paper products, food and yard wastes. Paper is almost 100% cellulose, cotton over 95% and wood products over 40-50%. These are highly combustible products most suitable for incineration. The calorific value of oven dried paper products are in the range 12000-18000 kj/kg.

5.Synthetic Organic Material

In the recent years plastics have become a significant components of solid waste, accounting for 1-10%. They are highly resistant to the biodegradation; hence their presence in the waste is objectionable. Currently much attention is given to reduce this component at disposal sites. Plastics have a high heating value, about 32000 kj/kg, which makes them very

suitable for incineration. However, among the plastics polyvinyl chloride (PVC) when burnt produces dioxin and acid gas**.**

Treatment :

The collected waste from Households will be deposited into the concrete/mild steel bins located in espective wards by sweeper. The sanitary workers of municipal corporation lifts waste from the bins, at a frequency of once in a day. The waste from the road side bins and street sweepings is collected regularly and transported to the disposal yard.

The waste generated from all the wards will be disposed at the dump site located near

Kapuluppada. Currently, GVMC disposes the entire waste generated at Kapuluppada disposal site. This site is operating for the last 7 years with about 80 acres. Three JCBs and one bulldozer are employed by GVMC for solid waste disposal management, including the operation of the waste disposal site.

The existing waste disposal site where crude open dumping is practiced with no leachate collection and treatment system and does not meet the current requirements of the MSW 2000 Rules. Open burning of waste, indiscriminate disposal, presence of stray animals & rag pickers at the disposal site and leachate migration into the subsurface are common occurrences

Fid: Municipal Waste Dump Area

The total quantity of waste generation and the quantity reaching the dump yard may not be same. The total waste dumped at Kapuluppada dump site is about 600-650 TPD, where as the total waste generation is about 920 TPD.

IV. LEACHATE TREATMENT

Leachate treatment is important for the elimination of harmful contaminants and organic substances that are capable of negatively impacting water sources such as surface water, groundwater, which ultimately can damage human health. The chemical make-up and characteristics of leachate differs between landfill sites .

The main objective of the leachate treatment is the elimination of organic matter and ammonia nitrogen and suspended solids as well as other toxic compounds , as a fundamental requirement to comply with the legal criteria for the discharge of leachate into the sanitation network for its final treatment and discharge .

It fractionates organic matter and helps in evaluating the predominant molecular mass in organic pollutants in leachate .UF may be effective as a pretreatment process for RO and can be used in the biological posttreatment of leachate. NF is a flexible approach to control organic, inorganic, and microbial pollutants.

A. LEACHATE TREATMENT PROCESS

Leachate treatment is a vast process in which the waste water is transferred ,recycled an treated using different bio-physical and chemical process . The leachate treatment is done in mainly three ways

1.Lechate transferring and recycling

2.Biological treatment

3.Physical-chemical treatment

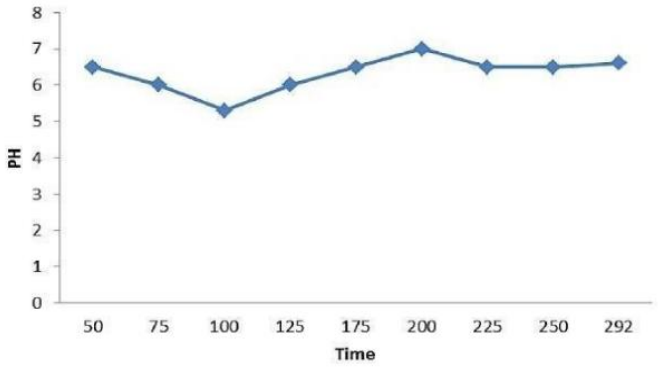
i) LEACHATE MANAGEMENT IN MUNICIPAL SOLID WASTE IN VISHAKHAPATNAM

Leachate is defined as any contaminated liquid that is generated from the water percolating through a solid waste disposal site, accumulating contaminants ,and moving into subsurface areas

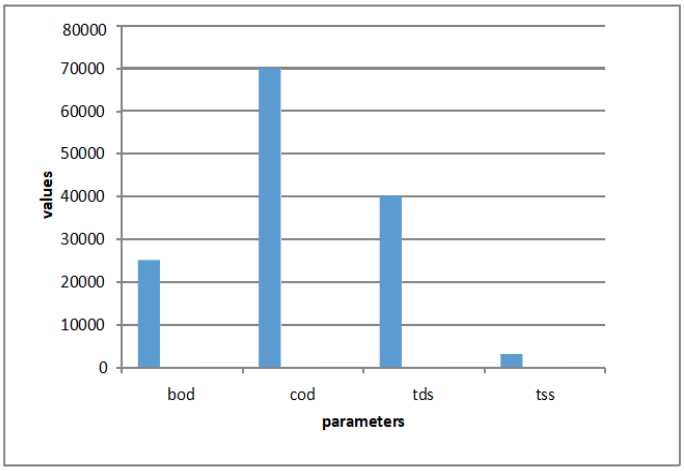
.A secondary source of leachate arises from the high moisture content of certain disposed wastes . Leachate will be generated wherever water can enter waste in a landfill or dumped . The quantity and strength of the generated leachate depends on several factors , the most important of which are

; a) the amount and characteristics of the discharged waste; b) climatic conditions; c)cell size and phasing of the disposal area; d) operational techniques applied at the landfill ; and e) the final top cover applied .

Leachate from MSW contains various contaminants at concentrations levels that may have an environmental impact on ground water and surface water and may therefore be a threat to the human health .Leachate may be highly toxic for several decades or even centuries before reaching the level where its is no longer a threat to the environment .“Eternal” leachate collection and treatment at MSW , however is not a realistic long term leachate management option because this approach requires external inputs of energy and maintenance . Hence , leachate management becomes an important issue in deciding which strategy to apply in any planning process involving closure of dumps .The options range from prevention of leachate generation ,to sophisticated leachate treatment options ,to controlled release of leachate into the environment



Graph illustrating the change of ph in a leachate sample with respect to the disposal time



Graph representing the composition of raw leachate in Visakhapatnam

ii) pH Range

Description of sample	Ph range
Raw leachate	5.5
LTP reject water	8.4
LTP product water	7.5

iii) TOTAL DISSOLVED SOLIDS (TDS)

DESCRIPTION OF SAMPLE	TDS
raw leachate	40,000
LTP reject water	4000
LTP product water	200

iv) TOTAL SUSPENDED SOLIDS

DESCRIPTION OF SAMPLE	TSS (mg/ltr)
Raw leachate	3000
LTP reject water	5
LTP product water	0

B. PROCESS

Leachate treatment is a vast process in which the waste water is transferred ,recycled an treated using different bio-physical and chemical process . The leachate treatment is done in mainly three ways

1.Lechate transferring and recycling
2.Biological treatment
3.Physical-chemical treatment

i) LEACHATE TRANSFERRING AND RECYCLING

Step 1 :Raw leachate is stored in the large storage tanks in the liquid for which infiltrates from the landfills .

Step 2 : **BAR SCREENS:**

Then the lechate is transferred through series of several pipes to the Bar Screen ans oil and grease chamber . The leachate is transferred to these bar screens to remove the suspended and floating material and oil and grease .The removal these debris and floating material reduces a ittle percentage of load on the further treatment process and also reduces nutrient imbalance .

Step 3 : **EQUILIZATION TANKS :**

After the removal of oil ,grease and debris from the leachate then the leachate sample is transferred to the equalization tanks .

The equalization (EQ) tank is an important part of the treatment process. Equalization provides hydraulics and pollutant load buffering for the dowsnstream process , Wastewater is typically pumped to the EQ tank from a lift station but in some cases waste enters the EQ tank via gravity flow.

The raw leachate is properly mixed and the correction of ph is done in these equalization tanks .

Fig Equilization tanks

STEP 4 **:FLASH MIXER**

The leachate sample from the EQ tanks are transported through pipes to flash mixer. Here the process of coagulation and flocculation takes place

Coagulation : The process of adding chemical called as coagulants to the tanks .these coagulants help bind together or coalesce suspended particles ,organic matter and contaminants present in the lechate ,forming larger particles called flocs

Flocculation : it is the process of bringing together the finer particles or colloids suspended in the leachate to form larger ,easily settleable flocs . this is achieved by adding chemicals know s flocculants

The lechate sample is added with some comm. Coagulants like alum and sow flocculants for these process so that the heavy suspended particles are removed and transported to sludge tank .

Flash mixers

STEP 5 : **PRIMARY CLARIFIER :**

These primary clarifiers are an essential component of leachate treatment plants designed to remove settleable solids and floating material .

The leachate sample from the flash mixers is transported to the primary clarifier ,then the velocity of the flow is reduced allowing gravity to take the effect ,this velocity reduction aids in settling more heavier solids ,in addition to settling of solid this priary clarifier also removes materials like oil and grease .

After this process ,the clarified liquid which is called as primary effluent ,is collected and transported to the INTERMEDIATE COLLECTION TANKS.

ii) BIO LOGICAL TREAMENT

Biological treatment of leachate involves using miscro organisms to breakdown the organic contaminants present in the leachate . this process is often carried out in specialized treatment systems designed to create optimal conditions for microbial activity .

***STEP 1 :* ANEAROBIC REACTORS**

Anaerobic reactors are specialized systems designed to facilitate the anaerobic digestion process, where micro organisms break down organic matter in the absence of oxygen .These reactors create an oxygen free environment to support the growth and activity of anaerobic bacteria ,which converts complex organic compounds into simpler substance like methane ,carbon dioxide ,and organic acids .

In these treatment process the anaerobic reactor used is ANAEROBIC MEMBRANE BIO REACTORS (AnMBRs)

a) **ANAEROBIC MEMBRANE BIO REACTORS** :AnMBRs combine anaerobic digestion with membrane filtration technology for solids liquid separation .Micro organisms digest organic matter in an anaerobic environment and membranes are used to separate treated effluent from biomass and suspended solids leachate that contains organic pollutants enters the membranes ,inside the bioreactor the anaerobic bacteria breaks down the organic matter in leachate in absence of oxygen .this process produces biogass which is primarily methane and carbondioxide this anaerobic digestion reduces the organic content and decreases it chemical oxygen demand (COD) and bio logical oxygen demand (BOD) The effluent gases from the anaerobic digestion membrane which are carbon dioxide and methane which are transported to DEGASSER TANKS . The sedimented material which the sludge is transported to the LAMELLA CLARIFIER

Fig: anaerobic membrane bio reactors

STEP 2 : AEROBIC REACTORS

Aerobic reactors are specialized in leachate treatment ,which is the liquid that drains or leaches from land fills or waste disposal sites . These reactors create an oxygen rich environment to support the growth and activity of the aerobic micro –organisms , which play a crucial role in degrading organic pollutants and reducing the environmental impact of leachate. The aerobic reactor used in the treatment process is Activated Sludge Systems .

b)ACTIVATED SLUDGE SYSTEMS : Activated sludge systems are widely used in leachate treatment for their efficiency in removing organic pollutants ,nutrients , and suspended solids .Heres how the process works in leachate treatment .

- At first the leachate sample which is primarily treated is introduced into the aerated tank or basin
- Aeration is process in which air or oxygen is supplied to the tank using aerators or diffusers ,this creates an oxygen rich environment
- Aerobic micro organisms in the activated sludge ,primarily bacteria ,begin to consume organic matter ,nutrients and pollutants present in the leachate as food source
- These aerobic micro organisms metabolize complex organic compounds in the leachate breaking them down into simpler substances
- This biological degradation process reduces the concentration of organic pollutants ,bio oxygen chemical demand (BOD)and chemical oxygen demand (COD) in the lechate improving its quality

After this the mixture undergoes settling and clarification ,the settles sludge which contains microbial biomass and any suspended solids ,settles to the bottom of the tank as sludge flocs . A portion of settled activated sludge known as return activated sludge (RAS) is recycled back into the aerated tank to maintain the health of the micro organisms After the aerobic reactors then the mixture is transported to secondary clarifier and flash mixer for the coagulation and flocculation as mentioned in clause 4.7.2.1 step 5 .

C) PHYSICAL AND CHEMICAL TREATMENT :

The physical and chemical treatment of leachate refers to the process used to treat the contaminated waste water that results from the decomposition of waste in landfills or other disposal sites .

Physical treatment process may include

- Filtration
- Sedimentation
- Activated carbon

Chemical treatment process may include

- Coagulation
- Flocculation
- Neutralization

***STEP 1 :* CHLORINATION PROCESS**

After the leachate is transported from the reactive clarifier to the STABILIZATION TANK ,where the settling and clarification takes place and aerobic or anerobic process also takes place and the mixture is then transported to chlorine contact tank The leachate mixture is entered into the contact tanks through series of centrifugal pipes The amount of chlorine required for disinfection is determined based on factors such as the effluent flow rate ,target disinfection level and the concentrations of organic and inorganic substances in the leachate .

Then the amount chlorine selected is added to the leachate stream at the specific point ,this injection of chlorine may done through metering pumps or by mixing chlorine solutions manually After adding chlorine to the stream then it is left for a certain time called as cotact time ,this contact times allows the chlorine to react with the leachate by killing the pathogens . Some times in environmental concern ,dechlorination process may be introduced

Fig chlorination tanks

***STEP 2* : FILTRATION PROCESS :**

Filtration is a process involves passing the waste water through various physical barriers to remove suspended solids ,fine particles ,and other contaminants .

It also helps in reducing the turbidity and enhance water quality Some of the filtration process which take place in the plant are

- Dual media filter
- Activated carbon filter
- Ultra filtration

D) DUAL MEDIA FILTER :

A dual media filter is a type of granular filtration system commonly used in leachate treatment to remove suspended solids and improve water quality . It involves the use of two different types of filter media with distinct particle sizes to achieve efficient filtration .

This dual media filter consists of two layers ,an upper layer and a lower layer . the lower layer consist of coarse media and the upper layer consists of fine media .

- Leachate is directed into the dual media filter , and it percolates downwards through the filter media layers .
- As the water passess through the coarse media ,larger particles and solids are captured and retained .
- The finer media than traps smaller particles and suspended solids ,futher improving filtration.
- The filtered effluent collected at the bottom of the filter is clearer , with reduced turbidity and lower suspended solids content, meeting effluent quality standards for discharge or further treatment .

E) ACTIVATED CARBON FILTER :

The activated carbon filter is a specialized filtration system commonly used in leachate treatment to remove organic compounds ,odours and certain contaminants . it utilizes activated carbon ,the highly porous material with a large surface area ,to adsorb and trap pollutants from the leachate .

It removes the pollutants like volatile organic compounds (VOCs) ,phenols and pesticides and it reduces odors .here is the process of activated carbon :

- Leachate is directed through the activated carbon filter ,where organic compounds and contaminants are adsorbed on to the surface of the activated carbon particles .
- The porous structure of activated carbon provides a high surface area for adsorption ,allowing it to capture a wide range of pollutants .
- The retention time of leachate with in the activated carbon filter is crucial for effective adsorption .
- Adequate contact time ensures that pollutants have sufficient opportunity to be absorbed on to the activated carbon media .

Fig activated carbon filter

Same of the process of dual filtration and activated carbon is followed for ultra filtration .

STEP 3 : REVERSE OSMOSIS :

Reverse osmosis (RO) is a crucial technology used in the treatment of leachate, which refers to the liquid that has percolated through a solid and leached out some of its constituents. Leachate is commonly generated in landfills or waste disposal sites, where rainwater percolates through the waste material, picking up various contaminants and pollutants along the way. It is essential to treat leachate to prevent environmental contamination and safeguard public health.

Reverse osmosis is a water purification process that uses a semi-permeable membrane to remove ions, molecules, and larger particles from water. It works by applying pressure to the leachate, forcing it through the RO membrane. The membrane allows water molecules to pass through while blocking contaminants, thus producing purified water on one side and concentrated waste on the other.

- The pretreated water is pressurized using a pump .this pressure is necessary to overcome the osmotic pressure and force water molecules through the semi permeable membrane
- The pressurized water is directed into the RO membrane module .The semi permeable membrane has very small pores that allow water molecules to pass through while rejecting larger ions ,molecules ,and contaminants.
- This separation process results in purified water on one side of the membrane and a concentrated solution containing rejected impurities on the other side .
- The RO reject water and the RO product water are transferred into two different process .
- The RO reject water is used for cooling of the boiler steams
- The RO product water is used for various purposes .

Fig reverse osmosis through series of pipes

STEP 4 : **SLUDGE THICKENER**

A sludge thickener is an important component in the treatment of leachate, particularly in the context of wastewater treatment plants or facilities that handle significant volumes of leachate. The primary function of a sludge thickener is to increase the solids concentration in the sludge or wastewater stream, thereby reducing the overall volume of sludge that needs to be handled or disposed of. In the context of leachate treatment, sludge thickeners play a crucial role in managing and processing the solid waste generated during the treatment process. The sludge from primary ,secondary ,lamella and Reactive clarifier and anerobic reactors get discharged into these sludge thickener .

So these are the different process of treatment the leachate will undergo .

Fig primary clarifier

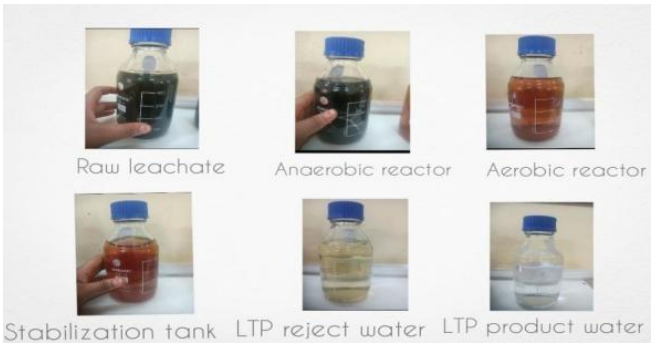


Fig: showing the leachate samples at different treatment stages

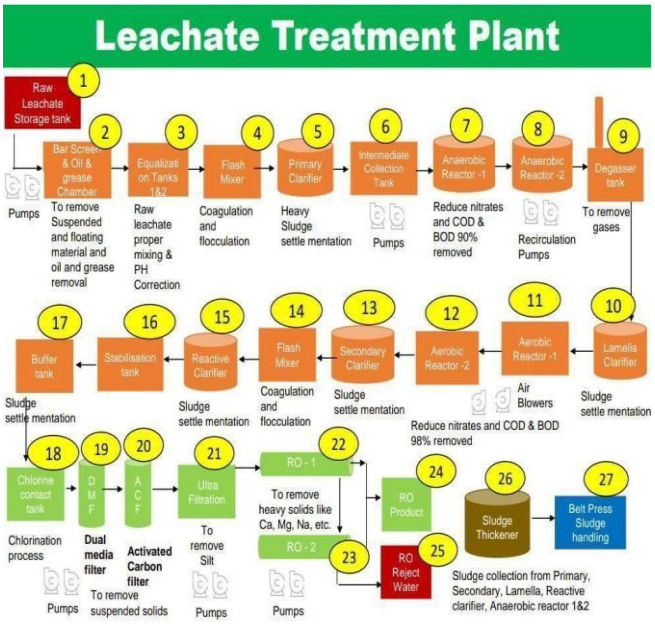


Fig flow chart showing the leachate treatment process

V. CONCLUSION:

Human ways of life have placed the pressure on the environment and have caused imbalance in the eco system by the producing, consuming and wasting of natural resources. Most countries evidently have major effects on the environment due to solid waste generation with economic development since the natural resources are used and then waste and pollution are produced.

Effective leachate treatment is crucial for sustainable municipal solid waste management, especially in urban areas like Visakhapatnam, where landfill leachate poses significant environmental challenges. A combination of physical, biological, and chemical treatment strategies is essential to ensure comprehensive pollutant removal. Advanced methods such as membrane filtration, aerobic/anaerobic biological processes, and advanced oxidation techniques enhance treatment efficiency, while integrated approaches like constructed wetlands and co-treatment with municipal wastewater offer sustainable solutions.

Selecting an appropriate treatment strategy depends on factors such as leachate composition, landfill age, treatment costs, and regulatory requirements. Implementing a hybrid treatment system tailored to local conditions can significantly reduce environmental risks, prevent groundwater contamination, and promote water reuse. Moving towards zero liquid discharge (ZLD) and resource recovery will further enhance the sustainability of leachate management in Visakhapatnam and other growing urban areas.

For long- term effectiveness, it is essential to integrate proper landfill design, leachate recirculation, and waste reduction strategies to minimize leachate generation at the source. By adopting a combination of these treatment methodologies, municipal authorities can ensure compliance with environmental regulations and protect public health while promoting sustainable waste management practices.

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