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CHARACTERISTIC STUDY OF INDUSTRIAL SLUDGE, TREATMENT AND THEIR DISPOSAL MECHANISM

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ABSTRACT

This research papers is the characteristic study and suggestive measure for disposal mechanism for the sludge. Sludge is one of the important common waste materials which is generated in tons per day from many industries. The different types of waste materials can undergo various treatment based upon its characteristics which also resulted in the variation for the treatment like Stabilization before disposal, Direct Landfill (DLF), Alternative Fuel and Raw material (AFRF), Incineration, Solvent recovery, Chemical treatment, Recycling of metals and others for the Hazardous waste management process. The various physicochemical, gravimetric and spot test were carried out in order to determine the quality of the waste and its suitability for the disposal by following different national and international methods. Further, Heavy metals were also analyzed by AAS obtained by following different methods in different forms like TM, TCLP and WLT which also indicated that the heavy metals are within the limits. Overall, the results obtained were found to be within the limits provided by the CPCB guidelines and the waste is suitable for the direct landfill disposal mechanism.

KEYWORDS: ***Industrial Sludge, Hazardous Waste Management, Heavy metals***

INTRODUCTION

India is a developing nation. The major contribution in India's GDP is through the sectors like Agriculture, Industries and Service. The different policies and strategies made by Govt. of India has attracted many investors, for the ease of industrial start-ups. With the rapid establishment and expansion of the industries the tonnes of the waste is also generating which if disposed untreated could lead to the environment pollution. Most common waste from the industries are sludge. Sludge is produced when the waste undergoes the various stages of the Primary, Secondary and Tertiary treatment. Further the quality of sludge defines the treatment for disposal.

India is known as an agricultural nation as after it's independence the five-year plan policy of Indian government was focused on the agriculture mostly as most of the population belongs to the rural area and known mostly engaged in agricultural practices. Slowly the policy changed to various other sectors which can be observed in the five year plans report prepared by Niti Aayog Planning Commission over the year [1]. The people are slowly moved to other sectors of services and industries. Now, India is an emerging developing country. The country is stepping towards the development by taking all big steps and decisions in different important pillars like economy, sustainable development and sectors like IT, agriculture and others. According to the Reports of the Ministry of Statistics and Programme Implementation, the Service Sector Contribute 53.89% GVA followed by Industries and Agriculture which contribute 25.92 % and 20.19 % in India's Development. According to the latest Report of Economy Survey 2021-22, the Industries will grow more 11.8 % followed by Service sectors and Agriculture by 8.2 and 3.9% [2].

The various policies were laid by the Department for Promotion of Industries and Internal Trade for the industrialist have helped in the rapid growth and ease for the industries [3]. The different Indian states were provided with different strategies for the industrial development [4]. Likewise, Govt. Of India has marked its success by Make in India Project which attracted the foreign investors, provided support to the local MSME industrialists [5]. As per the 2015 Report, Govt. of India through the Ministry of Skill Development under National policy for skills development and entrepreneurships provides various skills that help people to get employment in easy manner in different sectors of employment [6].

HAZARDOUS WASTE & SCENARIO IN INDIA

Irrespective of the policy, rules and regulation for the better development of industries there are concern for the environment as various accidents, case studies in India has shown the environmental pollution caused due to the industrial activities. It is due to the direct and untreated disposal/ discharge of waste into the environment [7].

Hazardous waste in India is defined as "any substance, excluding domestic and radioactive wastes, which because of its quantity and/or corrosive, reactive, ignitable, toxic and infectious characteristics causes significant hazards to human health or environment when improperly treated, stored, transported and disposed" [8]. Hazardous waste is mostly produced by industrial processes and must be treated in an environmentally responsible manner. Hazardous and Other Wastes (Management and Transboundary Movement) Rules,

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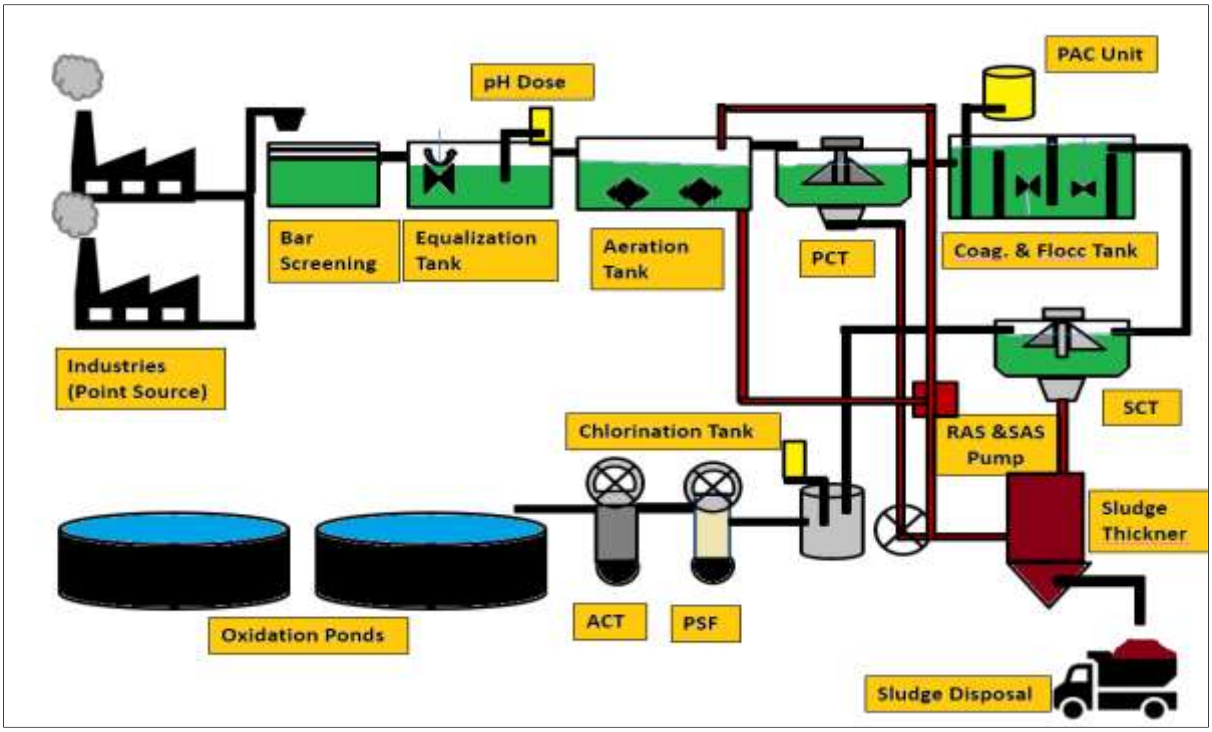
2016 (HOWM Rules, 2016), notified by the Ministry of Environment, Forest and Climate Change, Govt. of India under the Environment (Protection) Act, 1986, govern hazardous waste management [9]. Due to the country's rapid industrial expansion, hazardous waste is being produced. Indeed, industrialised states like Gujarat, Maharashtra, Tamil Nadu, and Andhra Pradesh are grappling with hazardous waste challenges. Gujarat, is one of India's fastest-growing industrial states, with an expanding chemical, petrochemical, medicines and pharmaceuticals, textiles, pesticides, paper, and fertiliser sectors. As a result, it is one of the country's leading producers of hazardous waste. The state's biggest source of pollution is untreated garbage from these enterprises [10, 11, 12].

Although precise data are difficult to come by, India produces around 51.1 million tonnes of waste each year, with 7.46 million tonnes of hazardous waste created by 43,936 industries. Landfilling accounts for about 3.41 MMT (46%), incineration for 0.69 MMT (9%), and recycling for 3.35 MMT (45%). Gujarat has the most hazardous waste generating facilities, accounting for 28.76 percent of total trash generation in the country. Hazardous waste accounts for 10–15 percent of all industrial waste. Solid hazardous waste volumes are increasing at a rate of 2–5% per year. Thermal power plants' coal ash accounts for more than 70% of all industrial hazardous waste [13].

SLUDGE GENERATION

The wastewater undergoes the process of preliminary, primary, secondary and tertiary process for the treatment [14]. The waste undergoes the bar screening process where all the solid materials get separated from the waste water. The wastewater further goes towards the primary treatment where pH is set by providing alkali or acidic treatment and also some retention time [15]. Some industries also perform the treatment in the equalization chamber. The wastewater goes towards the Secondary treatment where the waste materials are degraded with the help of micro-organisms [16]. Air blowers are also used in the secondary treatment. Some industries further use clarifiers to separate the organic matter and treated wastewater. For the chemical based effluent, the wastewater goes for the flocculation, coagulation process in order to separate the suspended particles by forming flocs [17]. Further the wastewater goes to secondary clarifiers to separate more efficiently and treat wastewater and sludge [18]. The sludge is then passed to the sludge thickner tank and in order to work more efficiently the sludge is added again in the secondary treatment by RAS and SAS pumps [19]. Further, the wastewater is passed through the Tertiary treatment where they undergo UV treatment, chlorination that kill the micro-organism [20]. The waste water is then treated by Sand Filter and Carbon Filter [21]. After which the water is discharged which is described in the fig.1

Fig 1 Flow chart in wastewater treatment



WASTE TRANSPORTATION

Solid waste collection, transportation, and disposal necessitate a large investment in waste management equipment and trucks, as well as the infrastructure that enables this technology to function properly [22].

a) **Dump Trucks and Trailers -** The trailers are typically composed of aluminium or steel and use hydraulic equipment to discharge rubbish off vehicles.

b) **Landfill Tippers -** Tippers can be linked with a truck or trailer to offload solid garbage at landfills using

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self-contained hydraulic power units to lift themselves. Tippers are separate equipment that attach to the trucks' trailers.

c) **Tractors –** These are most commonly used in rural and urban areas. They are used in wide range of waste as agricultural to building waste materials. While carrying the hazardous waste the vehicles are covered with heavy covers.

d) **Trucks –** In India, truck are commonly used for the transportation of waste. As they are manufactured in a such a way that they have high capacity to carry load and can run on tough, hilly roads.

e) **Tankers-** Irrespective of solid waste, many industries also generate liquid waste and semi-solid waste. So for the ease of transportation tankers are used.

WASTE TREATMENT

The HOWM Rules, 2016, establishes guidelines for the generation, packaging, storage, transportation, recycling/reprocessing, utilisation, treatment, and disposal of hazardous waste, as well as obtaining permission from the relevant State Pollution Control Board (SPCB) / Pollution Control Committee (PCC). The waste materials differ with different companies and thus the type of treatment also varies which includes Landfilling, Incineration, Recycling and Utilizable are some of the treatment suggested for the disposal mechanisms [23]. As per the Report, 10.92 million MT of hazardous waste was generated in 2020-21. Recycling, utilisation, co-processing, and disposal in common/captive Treatment Storage and Disposal Facilities have all been used to manage the amount of hazardous waste [24].

LANDFILL IN INDIA

The National Inventory on Generation and Management of Hazardous and Other Wastes (2020-21) Report by CPCB under MOEFCC has provided the data of top 10 states producing types of hazardous waste are depicted in Fig 2. The main 10 HW producing States are Gujarat (34.57%), Tamil Nadu (8.56%), Maharashtra (8.35%), Odisha (7.47%), Andhra Pradesh (7.02%), Rajasthan (6.97%), Uttar Pradesh (6.34), Telangana (3.61%), Karnataka (3.17%) and Madhya Pradesh (2.25%) which together contributed around 88% of complete HW [13].

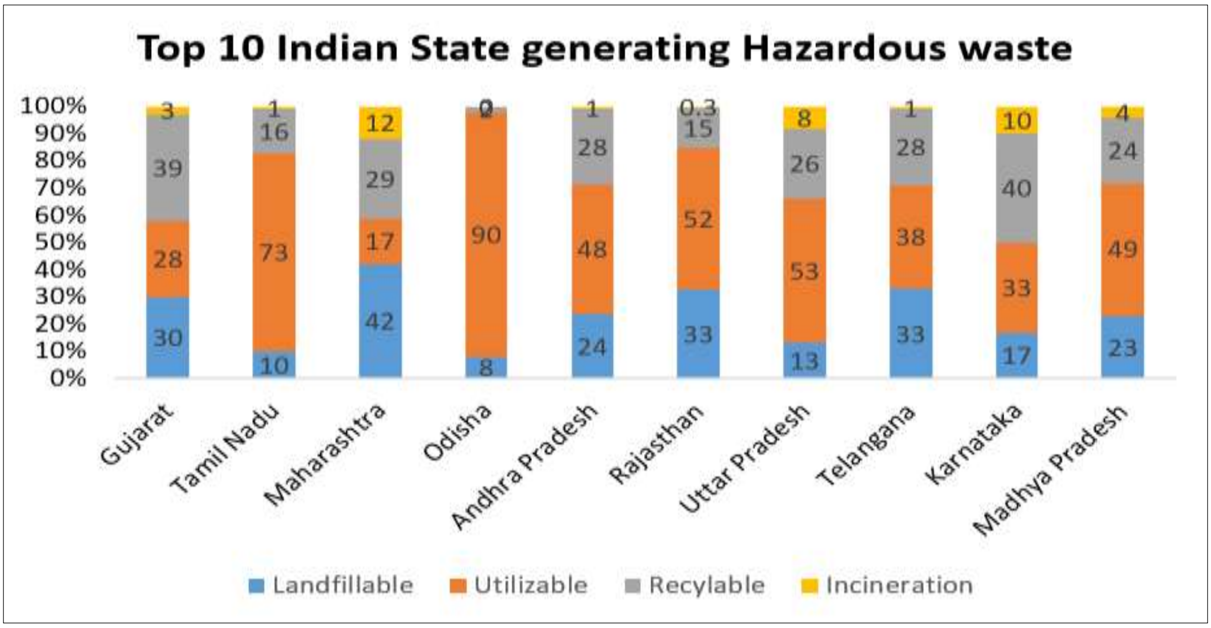

Fig. 2 Indian State generating Hazardous waste (Source- CPCB 2020-21 HW Report)

As per CPCB Report, out of the 9.24 million MT of waste created, 44 % HW was utilisable, 27 % was recyclable, 25 % was landfillable, and 4% was incinerated represented in Fig 3. The yearly increment of around 10% has been seen in the quantity of HW units when contrasted with the national inventory report of 2019-20. During the year 2020-21, around 9.24 Million MT of HW has been produced demonstrating 5% increment in age of HW contrasted with the earlier year for the year 2019-20 [24].

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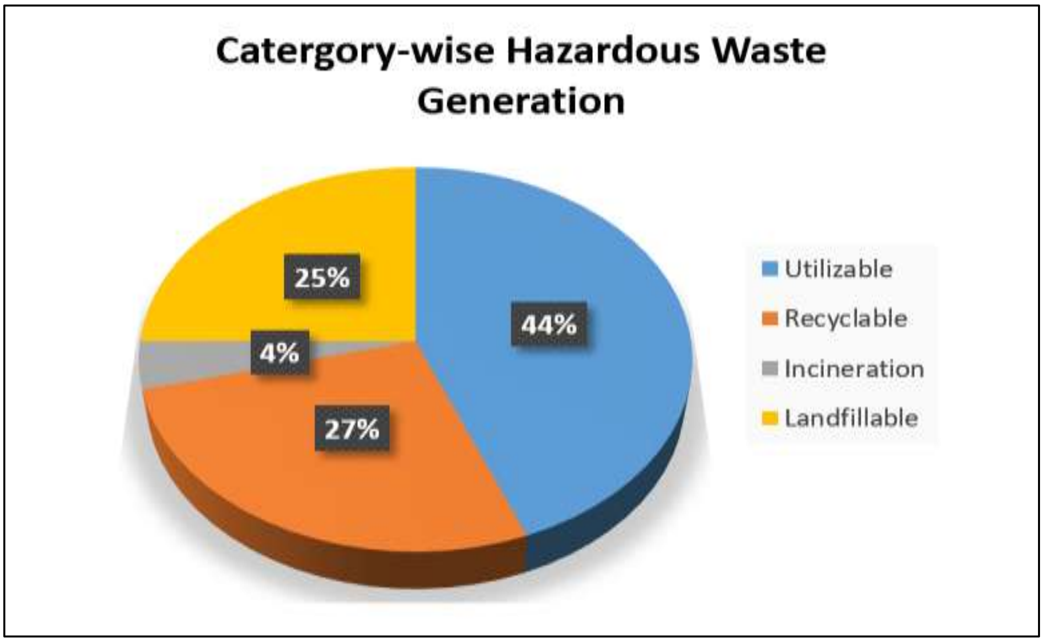

Fig 3 Category-wise Hazardous waste generation in India (Source- CPCB 2020-21 HW Report)

HEAVY METALS IN SLUDGE

Heavy metals (HMs) pollution in the air, soil, and water bodies is caused by anthropogenic and geogenic processes [25]. Weathering of metal-bearing rocks and volcanic eruptions are natural sources, whereas mining and different industrial and agricultural operations are artificial sources. Mining and industrial processing for mineral resource extraction, as well as their subsequent applications for industrial, agricultural, and economic development, has resulted in increased mobilisation of these elements in the environment and disruption of their biogeochemical cycles [26]. Heavy metals with higher densities include cadmium (Cd), lead (Pb), mercury (Hg), zinc (Zn), chromium (Cr), and arsenic (As), among others. Metals and metalloids are the same thing. Heavy metals in the soil and environment are poisonous, non-biodegradable, and extremely persistent components. Heavy metal contamination is a global issue, with the number of contaminated sites increasing over time as a result of growing populations, disorganised industry, and expanding economies [27]. The sludge being produced by undergoing various physical, biological and chemical process which resulted in the presence of heavy metals. The suitability for metals removal also helps in the disposal mechanism of the sludge.

Heavy metals are released into the combined drainage system by industry effluent and rainwater runoff. Their presence is the greatest impediment to sewage sludge being used in the natural environment. Land application was thought of as a more economical method for sewage sludge disposal than landfill and incineration. However, the presence of heavy metals in sewage sludge restricted the use of land application [28]. Contamination of the groundwater was studied by researchers from leachate near the Erode city, Tamil Nadu landfill site [29]. Similar studies resulted in the contamination of ground water near landfill site [30]. These elements may enter into human being through the foods and water via polluted water and soil by various anthropogenic and natural sources and is a concerning situation which could lead to various health impacts. [31].

STUDY AREA

The study was carried out at Visakhapatnam, Andhra Pradesh. According to the Ministry of Irrigation Department the States has 40 major, medium and minor like Godavari, Krishna, Vamsadhra, Nagavali and pennar are supposed to be major interstate rivers [32]. The Visakhapatnam city lies at the Latitude and longitude of 17.6868° N, 83.2185° E. Physiographically, Andhra Pradesh State is divided into three distinct zones, viz., Coastal plains, Eastern Ghats and Western pediplain. The Fig 4 depicts the physiography of the Andhra Pradesh State

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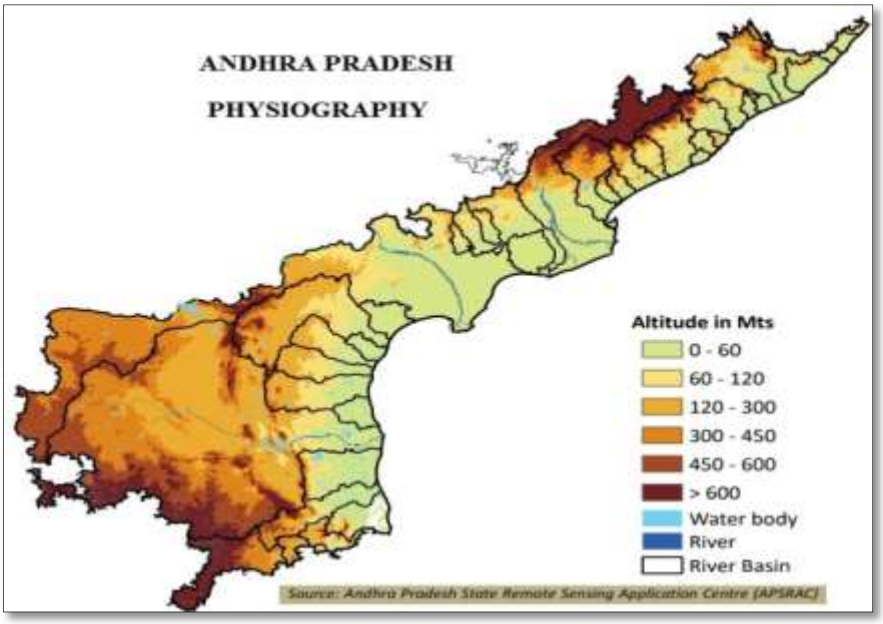

Fig 4. Physiography of the Andhra Pradesh State (Source-CGWB 2018-19 Report)

According to CGWB 2018-19 Report, the soil in the state varies from Red soil, Laterite soil, Cotton Soil, Deltaic alluvium soil, Coastal Soil and Saline Soil. Red Clayey soil found to be dominant in Visakhapatnam and other districts [33]. The rainfall pattern in Andhra Pradesh is mostly tropical as it is influenced by the topographical variations. As pert the 2018 Reports, Visakhapatnam received 1020 cm rainfall actually while 1121cm was expected normally. The Geology of Andhra Pradesh ranged from oldest Archean crystalline formation to new alluvium. The major portion is of gneissic complex which is overlain by basaltic lava flows in the northwestern part and is intruded by several younger rocks namely granites, dolerites, pegmatites and quartzite etc which is represented in Fig 5.

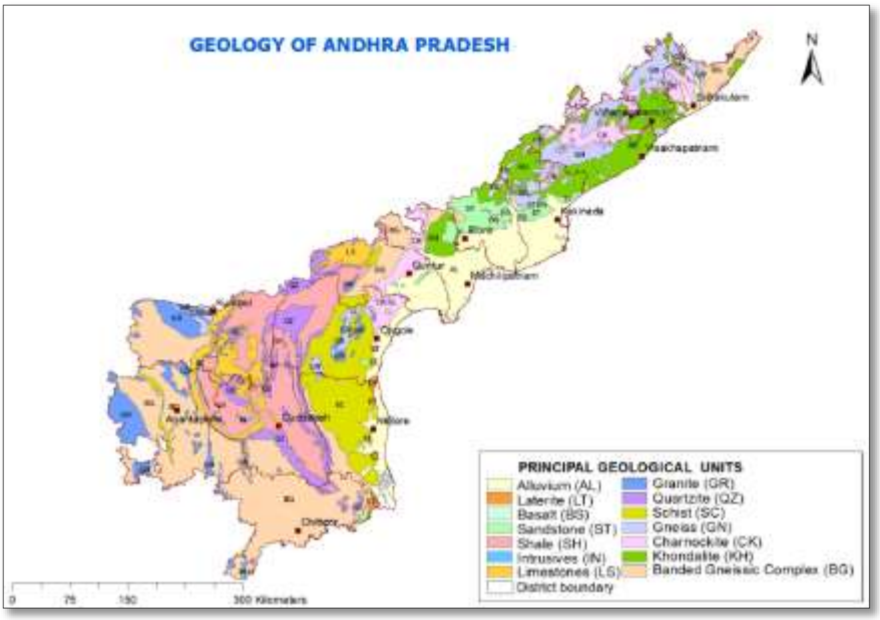

Fig 5. Geology of the Andhra Pradesh State (Source-CGWB 2018-19 Report)

The Charnockites and Khondalites occur in an extensive belt in Srikakulam, Vizianagaram, and Visakhapatnam districts and in upland areas of East Godavari and West Godavari districts. The alluvial deposits attain a thickness of more than 20 m in Visakhapatnam districts. The crops like Rice, Jowar, Bajra, Ragi, Maize, Pulses like Redgram, Bengalgram, Greengram and Blackgram while Fruits includes Mango, Coconut, Cashew nut, Banana, Guava and vegetables as Lemon, Batavia, Tomato, Onion, Ladyfinger, Brinjal and Turmeric are grown [34].

SAMPLING LOCATION

The sample was collected in the plastic bag from the APIIC, IALA Industrial Zone, Parwada village, Visakhapatnam, Andhra Pradesh which is represented in Fig 6, respectively.

Fig. 6 Google Earth image of the Industrial Zone, APIIC, Parwada, Vizag (A.P.)

MATERIAL AND METHODOLOGY

The sample was collect in the air tight plastic bags with the field data sheets by following the cone and quartering method prescribed by the SW-846 specially suggested for the solid waste. The sample was checked for various physicochemical, gravimetric and spot tests in in order to determine its characteristics. The various parameters were analysed by following the protocols of USEPA [35] and APHA [36]. While few parameters were analysed by following by book named "A Textbook of Soil Analysis by H.P. Barthakur and T.C. Baruah" [37].

RESULT AND DISCUSSION

The pH is significantly important because the hydrogen ion [H+] is involved in several chemical reactions, and minor variations in measured value equate to huge changes in H+ activity. The Sludge was found to be ranged as 10.31 which found be within the limit. The alkaline pH is due to the presence of the salts. pH during the study for Influence of Sulfur Concentration on Bioleaching of Heavy Metals from Industrial Waste Sludge was ranged as 6.98. [38]. The Electrical Conductivity was found to be 9.65 mS.cm-1 for sludge sample while El-Nahhal, I. Y., et .al (2014) found EC for the sludge as 2.49 mS.cm-1 [39] which is represented in table 1.

Table 1 - Physical characteristics of the Sludge

<table>
<tr><th colspan="6">Physical Parameters</th></tr>
<tr><th>pH</th><th>EC (mS/cm)</th><th>Bulk Density (g/cc)</th><th>Particle Density (g/cc)</th><th>Porosity (%)</th><th>WHC (%)</th></tr>
<tr><td>10.31</td><td>9.65</td><td>1.42</td><td>2.86</td><td>50.35</td><td>66.58</td></tr>
<tr><th colspan="6">Sludge Texture</th></tr>
<tr><th colspan="2">Fine Sand (%)</th><th>Coarse Sand (%)</th><th>Clay (%)</th><th>Silt (%)</th><th rowspan="2">Sandy Loam (SL)</th></tr>
<tr><td colspan="2">44.78</td><td>27.14</td><td>4.24</td><td>23.84</td></tr>
</table>

Particle Density and Bulk Density are two regularly utilised densities for soil characterization. The average value of particle density is 2.65 g cm3, which includes only the density of solid soil particles and excludes pore space (air space). Bulk density refers to the weight of a volume of soil in its natural state, which contains air, organic matter, and soil solids [40]. The Bulk Density and Particle Density was found to be 1.42 and 2.86 g/cc.

The bulk and particle densities can be used to compute porosity, which is one minus the solid volume fraction of a sample [41]. Porosity refers to the quantity of pore space found in soil, sediments, and rock, as well as the percentage of a material's total volume taken up by pores. Porosity for the sample was found to be 50.35 %.

The water holding capacity of sludge after electro-dewatering is an important index for landfill disposal, it should be evaluated [42]. Rainwater and melting snow move through the landfill and permeate into sludge, where some of the water is absorbed and the rest combines with the organic matter in the sludge to generate leachate [43]. The Water Holding Capacity was found to be 66.58% which was followed by Keen Box Method. El-Nahhal, I. Y., et .al (2014) found the WHC for sludge as 54.45 % [39].

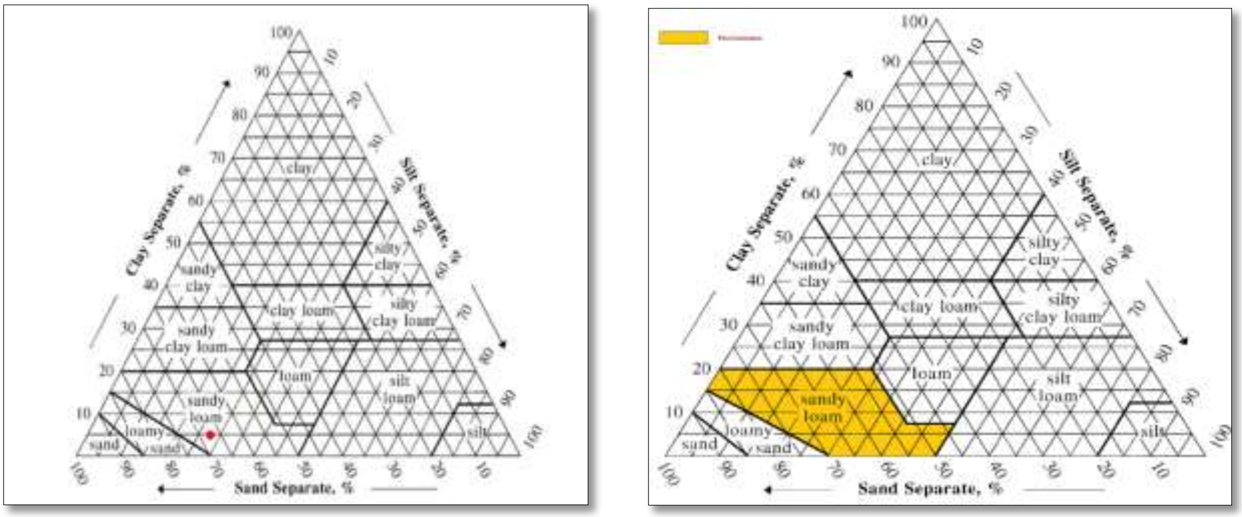

Fig. 7 (a) Sandy Loam Sludge Texture (b) Dominance of Sandy Loam in Sludge Texture

The Fig 7 represents the Sludge texture was found to be Sandy loam by following the International Pipette Method. The Fine Sand and Coarse Sand ranges as 44.78% and 27.14 % followed by Silt as 23.84% and Clay as 4.24 %, respectively according to table 1. Sludge biophysical parameters are influenced by sludge texture, which is a very stable property. The Texture is linked to porosity, which governs water holding capacity, gaseous diffusion, and water flow, which also influence its materials health [44].

Table 2 - Chemical Characteristics of Sludge

Chemical Parameters (meq/100 gms)						mmol(c)/L
Na	**K**	**Cal**	**Mg**	**Chlorides**	**SO4**	**SAR**
19.89	2.72	0.05	0.24	9.48	5.79	49.88

The Sodium Adsorption Ratio (SAR) is used to express the relative activity of sodium ions in the exchange reactions with the soil. This ration measures the relative concentration of sodium to calcium and Magnesium [45]. The Na, K, Ca and Mg are considered as the Macro nutrient for the growth [46]. The water soluble cations like Sodium, Potassium, Calcium, Magnesium, were found to be as 19.89, 2.72, 0.05 and 0.24 meq/100 gm whereas anions like Chlorides and Sulphate were found to be as 9.48 and 5.79 meq/100 gm. The SAR being an important parameter were found to be 49.88 mmol(c)/L.

Table 3 - Spot Tests of Sludge Quality

Spot Tests			
PFLT	**Cyanide**	**Sulphide**	**Chromium**
Pass	Negative	Negative	Positive

Paint Filter Liquid Test is used to determine the presence of free liquid as based upon its result the treatment and suitability depends on the disposal mechanism [47]. The leachability of the sample is determined by this test. Paint Filter Liquid Test was found to be positive.

Metal contamination is going on worldwide due to various natural and anthropogenic activities. The elements like Cyanide, Chromium and Sulphide have negative impacts on environment and human beings and that's why their detection is important. Hydrogen Sulphide is tested as it pollutes the environment and the human's health. The H_2S converts into various forms like S^{2}-, SO_2/SO_3, H_2SO_4 by different factors like mineralization, Combustion, bacteria which make it form dangerous for the environmental pollution which ultimately affects the living beings. [48]. Chromium, on the other hand is also harmful as excessive exposure could lead to higher levels of accumulation in human and animal tissues, leading to toxic and detrimental health effects. [49] While similar studies also refer the same for the Cyanide. The cyanide are produced by natural and anthropogenic activities in various forms which affects the soil, water, air food, biological organisms and lastly the living beings [50]. The spot test for Cyanide, Chromium

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and Sulphide were also carried out where results were found to be negative.

Table 4 - Other Parameters for Further Studies

Other Parameters			
Calorific Value(Cal/g)	**Flash Point (^{O}C)**	**Moisture Content (%)**	**Ash Content (%)**
NA	>60	21.32	1.12

According to Table 4, the flash point of a flammable liquid is defined as the lowest temperature at which it emits enough vapour to generate an ignitable mixture with air near its surface or within a vessel [51]. The flash point of flammable material is the most essential combustible property used to identify the potential for fire and explosion dangers [52]. Flash point was found to be within the limit.

The Moisture Content and Ash Content were found to be within the limits prescribed by CPCB.

Calorific value, also known as heating value or heat of combustion, is a measurement of the total energy content released as heat when a substance is entirely burned with air or oxygen [53]. The Calorific Value (CV) was determined by using Bomb Calorimeter for the sludge which is found to be within the limit.

The natural sources of fluoride are fluorite, fluorapatite, and cryolite, whereas anthropogenic sources include coal burning, oil refining, steel production, brick-making industries, and phosphatic fertilizer plants, among others. The groundwater is more susceptible to fluoride accumulation and contamination than are other environmental media, primarily because of its contact with geological substrates underneath. As a result, drinking water is considered to be the potential source of fluoride that causes fluorosis. When consumed in adequate quantity, fluoride prevents dental caries, assists in the formation of dental enamels, and prevents deficiencies in bone mineralization. At excessive exposure levels, ingestion of fluoride causes dental fluorosis skeletal fluorosis, and manifestations such as gastrointestinal, neurological, and urinary problems. [54].

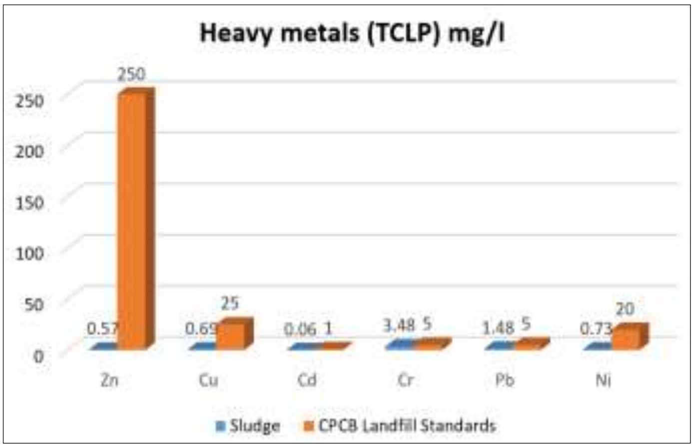
Chloride is found in nearly all waters and is derived from a number of sources, including natural mineral deposits; seawater intrusion or airborne sea spray; agricultural or irrigation discharges; urban run-off due to the use of de-icing salts; or from sewage and industrial effluents [55]. Increased salinization and chloride concentrations can induce a variety of ecological effects within both aquatic and terrestrial ecosystems. It can lead to the acidification of streams, mobilize toxic metals from soils through ion exchange, affect mortality and reproduction of aquatic plants and animals, alter community composition of plants in riparian areas and wetlands, facilitate the invasion of saltwater species into previously freshwater ecosystems, and interfere with the natural mixing of lakes [56].

The sulphur enters through various sources as of natural and anthropogenic into various forms which further involves in Sulphur cycle and pollutes the environment if exceeded the limit [57]. After the testing of sampling for CV, the sample was further used to test the Fluoride, Chloride and Sulphate Contents which were found to be less than <0.3%.

Table 5- Heavy metals in Sludge

Heavy metals (mg/kg)					
Cd	**Cu**	**Cr**	**Pb**	**Ni**	**Zn**
10.47	14.38	2851	20.66	7.84	38.51

The Samples were tested for heavy metals using AAS. The metals are tested for TM, TCLP and WLT forms where the samples were found to be within the limits when compared with the standards. The Table 5 represents the metals in Total Metals extracted form which ranges for Cadmium as 10.47 mg/kg, followed by other metals ranging as Copper (14.38 mg/kg), Chromium (2851 mg/kg), Lead (20.66 mg/kg), Nickel (7.84 mg/kg) and Zinc (38.51 mg/kg). Since there is no standards for the sludge comparison could not be made.



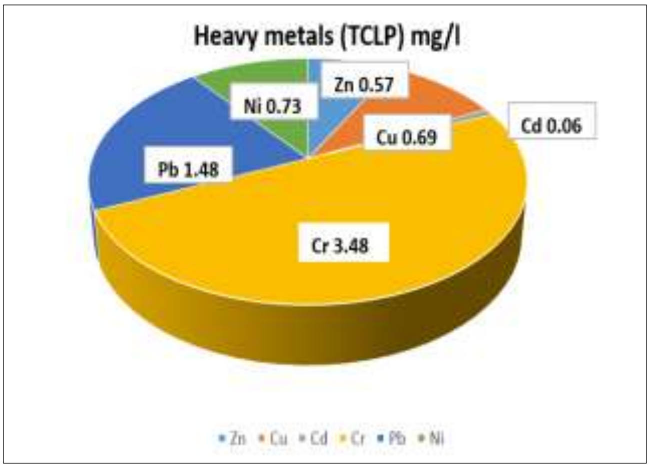


Fig 8. (a) Heavy metals in TCLP compared with the CPCB Landfill Standards (b) Metals in TCLP of Sludge.

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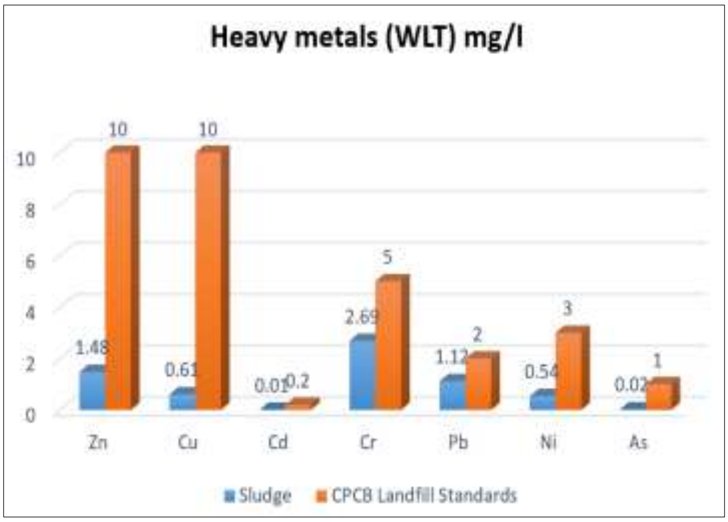
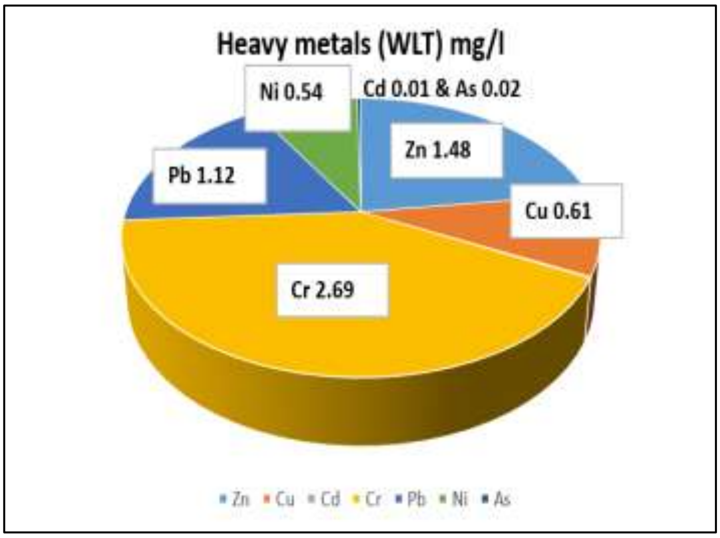
The Fig 8 (a) depicts that the metals are within the limits while Fig 8 (b) represents the Chromium (3.48 mg/l) was found to be higher than other metals which is followed by Lead (1.48 mg/l), Nickel (0.73 mg/l), Copper (0.69 mg/l), Zinc (0.57 mg/l) and Cadmium (0.06 mg/l) in TCLP extracted method.

Fig 9. (a) Heavy metals in WTP compared with the CPCB Landfill Standards (b) Metals in WLT of Sludge.





The Fig 9 (a) depicts that the metals are within the limits while Fig 9 (b) represents the Chromium (2.69 mg/l) was found to be higher than other metals which is followed by Zinc (1.48 mg/l), Lead (1.12 mg/l), Copper (0.61 mg/l), Nickel (0.54 mg/l), Arsenic (0.02 mg/l) and Cadmium (0.01 mg/l) in WLT extracted method.

CONCLUSION

Industrial sludge is most common waste generated by industries. The sludge is considered as Hazardous waste and so a proper disposal mechanism is required as treatment part. The various physico-chemical parameters were studied which shows the characteristics of sludge is within the limits prescribed by CPCB for landfill. For further studies heavy metals were also determined. The metals were extracted by various methods to get the TM, TCLP and WLT forms of sludge for heavy metals concentration and were analysed by using AAS. The result obtained indicates the metal concentration are within the limits. The Hazardous waste based upon its characteristic need to undergo various types of disposal as per CPCB guidelines. The studied sludge can be directly disposed to landfill site which is the easiest and effective way for the disposal of such kind of hazardous waste. But further sampling, monitoring and analyses should be followed routinely in order to check its characteristics for the safe disposal.

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