Bioreactor Landfilling of Oil Sludge

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Abstract--Waste to Energy can be pursued biologically, chemically, or thermally, leading to the production of chemicals of high caloric value or sensible heat. The petroleum industry has been generating an alarming amount of solid waste in the form of oily sludge. It is a hazardous of complex emulsion of various petroleum hydrocarbons (PHCs), solid particles, water and heavy metals. Recovery of PHCs via extraction and thermochemical has been widely investigated; however biological treatment for recovery and safe disposal is less fortunate. This work focuses on the anaerobic PHC decomposition in a well-controlled landfill bioreactor for the generation of landfill gas (LFG: CO2 and CH4). It is found that on the basis of 100kg of PHC, nearly 4.5 kg and 11.8 kg of CH_4 and CO_2 are generated. This is fairly equal to what would be generated from Municipal waste (MSW). Practically, co-digestion with MSW can enhance the biodegradation and the yield, contrary to WWTP sludge which only enhances the biodegradation.

Keywords: Bioreactor;Landfill-gas; Sludge; Anarobic-digestion

I. INTRODUCTION

Ranking 7th internationally in the total proven oil reserves and the 10th highest producers of crude oil and natural gas [1], dealing with petro chemical waste in UAE is vitally important. For example. Production of 200–500 barrels of petrochemicals may generate as much as 10,000 m^3 of hazardous oily sludge [3-4]. The oily sludge is described as remnants obtained from the water, oil, fat and solids, organic compounds and minerals, with alkanes heading the list [5]. Different treatment methods, such as incineration, gasification, pyrolysis, and biodegradation, [6] have been explored to stabilize oily sludge waste. In Abu Dhabi, BeAAT, a specialized treatment facility for petrochemical waste, established ways to safely receive, manage, treat and dispose the hazardous industrial petrochemical waste. BeAAT implements the following waste treatment: Solidification, Centrifugation, Thermal Desorption, Incineration, Physical/Chemical Treatment, Mercury Distillation, Drum handling and cleaning and dry-dumb landfilling at an annual capacity rate of 25,000 tones. Their method of treatment focuses more on the thermochemical and stabilizing of metals in landfilling, but no bioremediation method. In the present work, anaerobic digestion of oily sludge is proposed and assessed on the basis of its gas production and comparison with MSW and co-digestion, with waste water treatment sludge as a source of bacterial nutrition.

II. OPERATION OF BIOREACTOR LANDFILLS

The operations of a bioreactor landfill are comparable to modern municipal waste water treatment plants in pursuing a controlled decomposition of organic waste, but also differ from classical dry and slow landfill with moist and faster biodegradation. Fig. 2 summarizes the biodegradation processes and shows the elements of the anaerobic bioreactor which consists of bottom geomembrane (LDPE), a gravel layer a leachate conveyance system, gas collection wells, hosting cells, and toping dirt and clay. It is also instrumented with sampling ports for gas, leachate, sample dirt or compost etc. Rain or brackish water is trickled to keep the waste within the stipulated moisture content to enhance the hydrolysis and subsequent steps of decomposition. Bioreactor landfill has the potential to fully degrade waste in ten years instead of many decades, as in the case of classical dry tomb landfill. It generates faster Landfill gas (LFG) for fuel utilization.

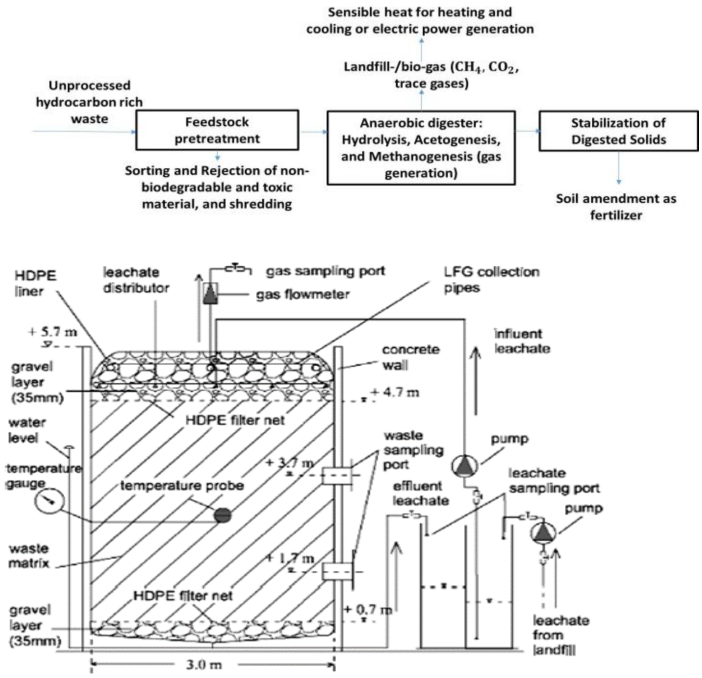

Fig. 1: Bioreactor process & schematic of it components [7]

The reactor observes 1st a quick depletion of entrapped air due to loose waste/soil compaction and the needed soil-LDPE permeability. This step activates the aerobic microorganism's biodegradation and production of CO2, H_2O, heat and biomass [8]. A shift to anaerobic will take a short time following a declination in aerobic microorganism activities. This new activity involves four sequenced biochemical reactions that are associated with different colonies of anaerobic microorganisms leading to the formation of landfill gas and intermediate organic acids. These are hydrolysis, acidogenesis, acetogenesis and methanogenesis. The hydrolysis is vital for the biodegradation, in which the organic compounds are solubilized by the extracellular enzymes into smaller sized organic compounds that would diffuse through the microorganism's membrane cell [9]. Shorter molecules of sugar, alcohol, fatty and amino acids results from the solubilization of carbohydrates, fats and proteins according to the following reaction [10]:

$$(C_6H_{10}O_5)n + n\ H_2O \rightarrow n\ C_6H_{12}O_6 \quad (1)$$

Acidogenesis oxidized sugar and fatty acids into other organic acids, which latter tended to crack into acetic acid according to these reactions [9]:

$$C_6H_{12}O_6 \rightarrow CH_3\ (CH_2)_2\ COOH + 2H_2 + 2\ CO_2 \quad (2)$$

$$C_6H_{12}O_6 + 2H_2 \rightarrow 2\ CH_3CH_2COOH + 2H_2O \quad (3)$$

$$C_6H_{12}O_6 + 2\ H_2O \rightarrow 2CH_3COOH + 4H_2 + CO_2 \quad (4)$$

Acetic acid formation signifiy the onset of acetogenesis step in which propionic and butyric acids are converted into acetic acid according to the following reactions [10]:

$$CH_3(CH_2)_2COOH + 2H_2O \rightarrow 2\ CH_3COOH + 2\ H_2 \quad (5)$$

$$CH_3CH_2COOH + 2H_2O \rightarrow CH_3COOH + 3\ H_2 + CO_2 \quad (6)$$

The final stage, methanogenesis, involves the formation of methane either from CO_2 reduction with H_2 or acetate cracking the acetate lead to the methanogensis following these elementary reactions [9]:

$$CH_3\ COOH \rightarrow CH_4 + CO_2 \quad (7)$$

$$4H_2 + CO_2 \rightarrow CH_4 + 2\ H_2O_2 \quad (8)$$

III. MATERIALS ANALYSIS AND LANDFILL GAS ESTIMATION

Numerous samples of the PHC sludge from BeAAT were obtained and subjected to homogenization. This is followed by TGA proximate and Flash200 elemental analyses. Two other samples of MSW and waste water treatment sludge (WWTS) were obtained and subjected to the same process. Their unit molecular formulas are computed as $CH_{1.2676}O_{0.5651}N_{0.21}$ for PHC, $CH_{1.58}O_{0.63}N_{0.016}$ for MSW, and $CH_{2.071}O_{0.565}N_{0.0621}$ for sludge. Furthermore, the organic fraction, moisture contents, the fraction of volatile solid of the organic solid, biodegradable volatile solid fraction and its share to be converted into biogas are estimated following the work of Kreith and Goswami [11] and summarized in Table I.

TABLE I. SUMMARY OF THE PROXIMATE ANALYSIS

Mass Fraction (%)	PHC	MSW	WWTS
Weight of organic material in the feedstock	37	78	10
Moisture content	3.6	20	90
VS of total organic solids	85	83.5	100
BVS of the VS	95	75	90
Biodegradable VS to be converted to biogas	95	90	95

The estimated theoretical yield follows the biodegradation stoichiometric eq. (9). Thus, given the feedstock unit formula in the form of $C_aH_bO_cN_d$, which is inferred from the proximate and ultimate analysis, provides the basis of theoretical estimation of the gas volume that could be produced from oily sludge. The anticipated landfill gas values, both in unit mass and volume, are summarized in TABLE II. It should be noted that a higher volume fraction of CH_4 is typically produced than CO_2 which can reach twice the volume. These values also are in the vicinity to 10% by weight to dry BVS. Also, because the PHC is not as rich of a nutrition compared to the WWTP slug or MSW, co-digestion with either can promote its biodegradation to the theoretical value.

$$C_aH_bO_cN_d + (4a\text{-}d\text{-}2c\text{-}3d/4)\ H_2O \rightarrow (4a\text{+}d\text{-}2c\text{-}3d/8)\ CH_4\text{+ } 4a\text{-}d\text{+}2c\text{-}3d/8)\ CO_2 + dNH_3 \quad (9)$$

TABLE II. SUMMARY OF THE LANDFILL GAS GENERATION

Yield	PHC	MSW	WWTS
Weight of the methane (kg)	4.49201	5.68399	0.19523
Weight of carbon dioxide (kg)	11.8502	13.6771	0.29230
Volume of the methane (m^3)	6.25953	7.92052	0.27205
Volume of carbon dioxide (m^3)	5.99015	6.91362	0.14775
Percentage of the methane %	51.0995	53.3938	64.8040
Percentage of carbon dioxide %	48.9004	46.6061	35.1959
Total theoretical amount of gas unit weight of dry BVS (biogas/ton)	8.65188	10.4772	0.29651

IV. CONCLUSION

Estimation of landfill gas due to the anaerobic digestion of PHC waste is evaluated, which otherwise is destined to the landfill or thermochemical treatment pathways. On the basis of 100kg of PHC, nearly 4.5 kg of CH_4 and 11.8 kg of CO_2 are generated. This is roughly what would be generated from MSW. Due to the low nutritional value of PHC, co-digestion is required for practical reasons. The co-digestion of PHC with MSW would enhance the biodegradation and the yield, contrary to the WWTP sludge which only enhances the biodegradation.

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