A Review on Enhancing Anaerobic Degradation Rate of Municipal Solid Waste Using Micro-Organisms Along with Leachate Recirculation

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***Abstract*—The generation of Municipal Solid Waste (MSW) has turn into a gradually more important worldwide issue over the last decade, because of the escalating growth in municipal populations, and the concomitant increase in waste generation per capita. Even though increases in recycling, composting, and incineration, the sanitary landfill is still the major MSW disposal substitute. Nowadays, "Bioreactor Landfill" is one concept that has gained considerable attention. But the presence of lignin is the limiting factor at later stages of biodegradation of MSW under anaerobic conditions. Therefore, inoculation with lignocellulolytic fungi can be useful for enhancing degradation. Two types of white- rot fungi (*Phanerchaete chrysosporium* and *Trametes versicolor*) have properties of lignin degradation. This paper reviews the details about degradation, process of anaerobic decomposition and aspects for enhancement of decomposition through enzymes and microorganisms at later stages of anaerobic bioreactor operation using cow dung manure as an inoculum for Indian conditions.**

I. INTRODUCTION

Municipal Solid Waste (MSW) management has turn out to be the subject of main concern due to ecological and economical concern. Although landfilling is least favored alternative in integrated solid waste management hierarchy, it is still the most practiced methodology of waste management (US EPA, 2016) [7],[15] . Some methods have been considered over the earlier years to facilitate and improve waste degradation in the landfill site. These include waste shredding, waste compaction, pH adjustment, nutrient stability, sludge addition and leachate recirculation [8], [10], [16].

India is having second largest population in the world after China with more than 1.27 billion population contributing 17.6% of world's total population (Official population clock). Currently, 1,27,486 tons per day of municipal solid waste is generated because of various household activities and other commercial & institutional activities (CPCB, 2012) [3] ,[11] .

Table I

MSW classifications [15]

Organic Waste	Putrescible	Food waste, Animal waste, Garden waste, Material contaminated by such waste
	Non-putrescible	Paper, Wood, Textiles, Leather, Plastic, Paint, oil, Grease, Chemicals, Organic Sludge.
Inorganic Waste	Degradable	Metals (corrodible to varying degree)
	Non- Degradable	Glass, Ceramics, Mineral soil, Rubbles, Tailings, Slimes, Ash, Concrete, Masonry (C & D)

According to CPCB and NEERI, 2010 the composition of MSW in the North, East, South and Western regions of the country varied between 50-57% of organics, 16-19% of recyclables, 28-31% of inerts and 45-51% of moisture[Table1]. The calorific value of the waste varied between 6.8-9.8 MJ/kg (1,620-2,340 kcal/kg)[Figure1].

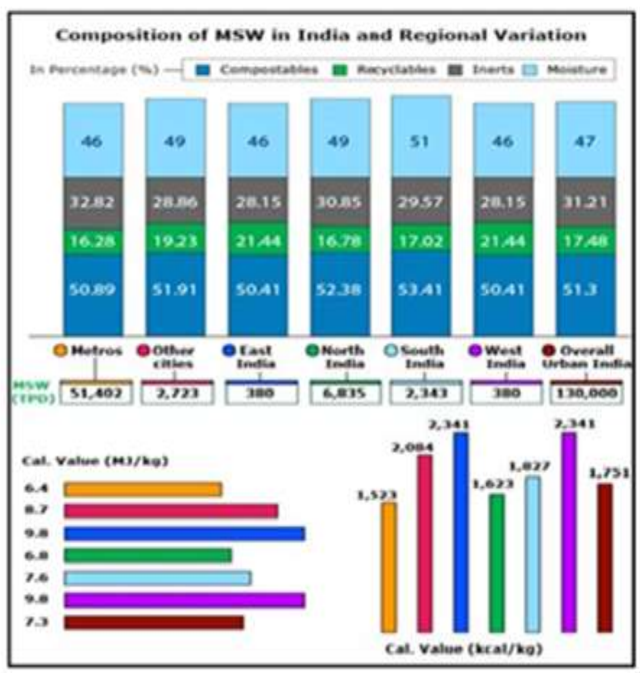

Fig. 1 Composition of MSW in India and regional variation[10].

The Bioreactor landfills offer an economical way to attain increased waste degradation along with profit such as improved landfill gas (LFG) recovery, reduction in leachate contamination potential and rapid enhance in landfill volumetric capacity [12] [Figure2]. Bioreactor landfill is a sanitary landfill that changes and stabilizes the readily and fairly decomposable organic waste constituents within few years by enhanced microbiological processes and increase in effective organic waste decomposition, conversion rates of complex organic compounds and process effectiveness [12], [16] ,[18].

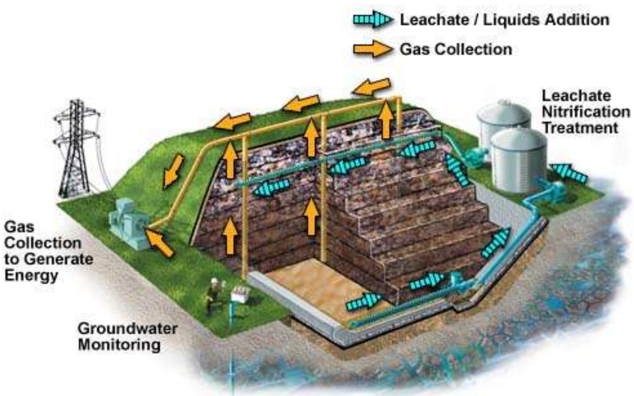

Fig. 2 Anaerobic Bioreactor [19]

Another important feature to take into consideration when evaluating technologies to facilitate waste degradation is the waste composition of landfill sites. Within the waste mass, lignocellulosic materials are considered recalcitrant as difficult to degrade under anaerobic conditions. A technique to enhance the degradation of residual waste fractions, is the addition of enzymes [8], [4]. Addition of inoculum is necessary with the substrate to start reaction [5]. Cow-dung contains soluble, particulate, and fibrous components. Nearly 40-50% of Volatile Solid in manure are biodegradable lignocellulosic biomass which can be converted to CH_4. Maximum COD elimination consequently shown high amount of CH_4[6].

II. DISCUSSION

A. The Anaerobic waste degradation and itsphases

Anaerobic degradation is a process by which a complex mixture of advantageous microorganisms changes organic materials under oxygen-free conditions into biogas, nutrients and extra cell matter, leaving salts and refractory organic matter [2]. Various factors like biogas potential of feedstock, design of digester, inoculum, kind of substrate, pH, temperature, loading rate, hydraulic retention time (HRT), carbon nitrogen ratio, volatile fatty acids (VFA) etc. influence the augmentation of degradation [12].

Stabilization of waste includes four keys of biological and chemical reactions within the bioreactor landfill [10] [Figure 3].

Phase I: Hydrolysis/liquefaction: During this phase, complex compounds are hydrolyzed into dissolved com- pounds with a low molecular weight. Protein is degraded to amino acid, carbohydrate is changed to monosaccharides and disaccharides and lipid are trans- formed to long-chain fatty acid [2].

$C_6H_{10}O_4+2H_2O \rightarrow C_6H_{12}O_6+2H_2$ (1)

Eq. (1) shows an example of hydrolysis reaction where organic waste is broken down into a simpler sugar, glucose.

Phase II: Acidogenesis: Simple organic compound such as volatile fatty acid, alcohol, lactic acid and mineral compounds such as carbon hydroxide, hydrogen, and ammonia and hydrogen sulphide are generated from the dissolved compounds.

Eqs. (2)– (4) represent three usual acidogenesis reactions [3]. In Eq. (2), glucose is transformed to ethanol. Eq. (3) shows glucose is converted to propionate and Eq. (4) shows glucose is transformed to acetic acid [2].

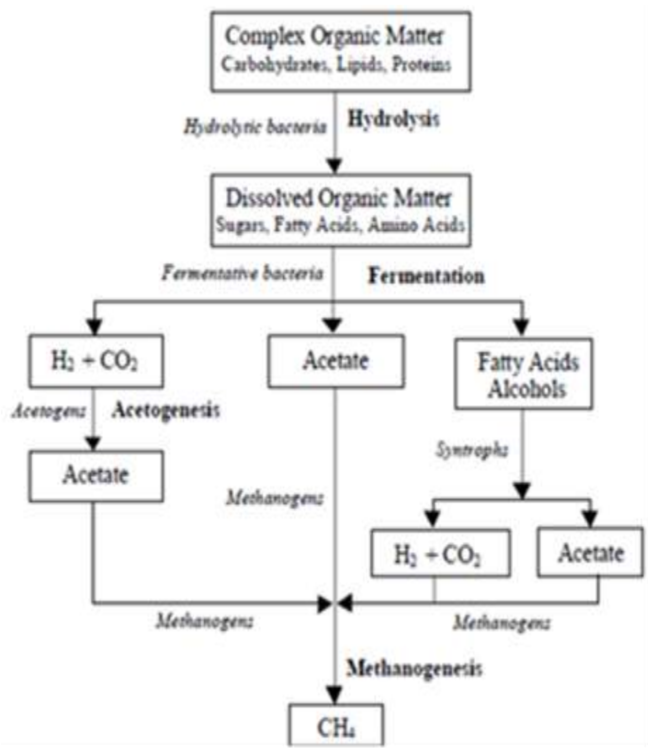

Fig. 3 Simplified substrate degradation pathways in anaerobic waste degradation process [11]

$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2OH+2CO_2$ (2)

$C_6H_{12}O_6+2H_2 \leftrightarrow 2CH_3\,CH_2COOH+2H_2O$ (3)

$C_6H_{12}O_6 \rightarrow 3CH_3COOH$ (4)

Phase III: Acetogenesis or fermentation: The products from acidogenesis phase are converted to suitable substrate of methanogen microorganism such as acetate, hydrogen and carbon dioxide.

$H_3CH_2COO^{-}+3H_2O \leftrightarrow CH_3COO^{=}H^{+}+HCO_3^{-}+3H$(5)

$C_6H_{12}O_6+2H_2O \leftrightarrow 2CH_3COOH+2CO_2+4H_2$ (6)

$CH_3CH_2OH+2H_2O \leftrightarrow CH_3COO^{-}+2H_2+H^{+}$(7)

Eq. (5) represents the conversion of propionate to acetate, only attainable at low hydrogen pressure. In Eq. (6) Glucose is transformed to acetate. The acetogens cannot convert ethanol directly to methane and carbon dioxide; first it must convert the ethanol to acetic acid and subsequent release of molecular hydrogen. Eq. (7) shows the ethanol is changed to acetate [2].

Phase IV: Methanogenesis: It is the restricting step of anaerobic digestion. In this step, hydrogenotrophic bacteria converts carbon dioxide and hydrogen to methane and methanogenic bacteria converts acetate to methane.

$CO_2+4H_2 \rightarrow CH_4+2H_2O$(8)

$CH_3COOH \rightarrow CH_4+CO_2$(9)

CO_2 and H_2 are converted to methane (Eq. (8). In the second type of methanogenesis, the aceticlastic methanogenesis, acetate is directly converted to methane (Eq. (9) [2].

B. Factors governing anaerobic degradation

*1) Waste Composition:*The general characteristics of the landfill is controlled by the waste composition. The waste composition changes with geographical conditions, depending on economic conditions, lifestyle, industrial structure and waste management methods. organic degradable waste constitutes the maximum portion of total MSW generation.

The higher proportion of organics corresponds to higher decomposition and loss of mass resulting in the higher landfill gas generation such as methane, carbon dioxide, nitrogen, and hydrogen sulfide[15].

*2) Moisture Content:*Moisture content is considered the most essential factor which plays an important role in waste microbial activity and decomposition. The moisture within the landfill acts as a medium to transfer the nutrients, microorganism, and to supply the favourable environment for gas generation and waste decomposition [15].

The benefits of augmented water content in a landfill include limiting oxygen transport from the atmosphere, encouraging exchange of substrate, nutrients, buffer, and dilution of inhibitors and spreading of microorganisms inside the landfill [18]. Study by Anuja Sapkota showed the effect of moisture circulation on wastes and detailed that utmost methane content is produced by daily circulation of water which resulted in increased gas generation.

*3) pH:*Optimum pH for the wastes depends on the stage of the included bacterial activities. The best pH range for the gas production is 6.8 – 7.4 and the methanogenic bacteria are most effective at pH value of7.0. The bacterial activity gets slower at pH value lower 6.8 or above 7.4.

Study by M. Warith et al. showed a higher pH relates to more decomposed refuse reflected by the relationship be- tween cellulose and hemicellulose to lignin and pH. Anuja Sapkota proposed, for improving biodegradation of MSW, pH of the leachate before recirculation ought to be neutralized with buffer solution.

4) Temperature: With the raise of temperature in mesophilic and thermophilic conditions, microbiological degradation rate increases [18]. Anuja Sapkota studied that the consequence of temperature on waste decomposition by choosing 25°C, 37°C, and 60°C and reported a temperature of 37°C is the mainly favourable for the enhanced methane generation.

5) Particle size of waste: The shredding has an affirmative influence on the waste degradation. Anuja Sapkota studied that the rate of decomposition and methane generation increases with the shredding of waste and shredded waste had the lowest COD and VFA. The shredded and well-mixed waste gives better contact between the key refuge particles (moisture, substrate, and microorganisms) necessary for methane generation [18].

C. Factors enhancing degradation in anaerobic bioreactor

1) Leachate recirculation and Moisture control: Leachate recirculation is the method of recirculating the leachate which is formed during the waste degradation process [15]. Mansi Rastogi et al. studied that increase in moisture content along with leachate recirculation has shown improved biological activity (methanogenesis) and decomposition. A similar study states that the fast growth of methanogen bacteria in bioreactor landfill is the result of high moisture content. Because of leachate recirculation, liquid movement distributes the inocula, minimizes local shortages of nutrients, gives improved contact between insoluble substrates, soluble nutrients, and the microorganisms, dilutes potential toxins, and transfers heat [18].

Mansi Rastogi et al. studied the daily recirculation methodology has a positive result related to COD removal, pH stabilization and other parameters and reduction in heavy metals. Jenjira S. et al. established leachate recirculation with pH control further enhanced landfill stabilization and treatment efficiency and buffering the leachate prior to its recirculation is a significant process strategy for the maintenance of the needed pH values in the system [13].

2) Addition of inoculum – Enzymes (Microorganisms): Lignin, is a 3D polymer linked by several acid-resistant carbons-carbon linkages [10]. Lignocellulose is composed of carbohydrate polymers, cellulose (most important) and hemicellulose as well as aromatic polymer, lignin [8].The components of lignocellulosic material, lignin is the mainly resistant to degradation. Though lignin resists attack by mostly microorganisms, basidiomycetes white-rot fungi, can degrade lignin well [1]. Their generation of extracellular enzymes known as lignin-modifying enzymes (LMEs) encourage the degradation process[Figure5].

In nature, degradation of cellulosic biomass is performed by mixtures of hydrolytic enzymes collectively identified as cellulases [3]. Cellulases included in substrate degradation are endoenzymes and exoenzymes [Figure 4]. Endoenzymes are formed in the cell and degrade soluble substrate in the cell. Exoenzymes are too produced in the cell but are released through the "slime" coating the cell to the insoluble substrate attached to the slime. Once in contact along with the substrate the exoenzymes solubilize particulate and colloidal substrate. When solubilized, these substrates enter the cell and are degraded by endoenzymes [2].

Fungi degrade lignin by emitting enzymes collectively named "ligninases". LMEs comprise mainly two ligninolytic enzyme families; i) phenol oxidase (laccase) and ii) heme peroxidases (Lignin peroxidase (Lip), Manganese peroxidase (MnP) and Versatile peroxidase (VP).

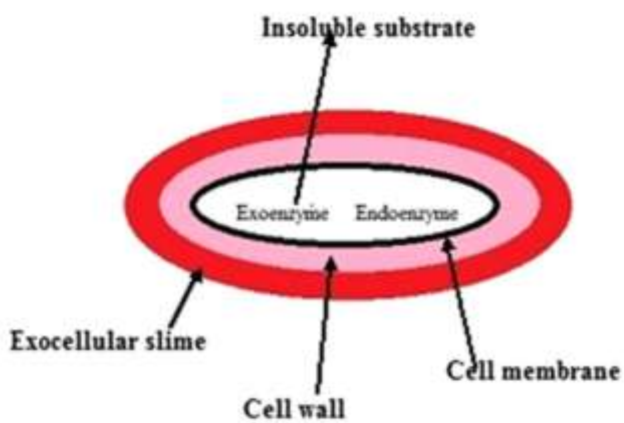

Fig 4 Schematic representation of cellulases (exo and endo enzymes) involved in substrate degradation [2].

Phenol oxidases (laccases) (benzenediol:oxygen oxidoreductases, EC 1.10.3.2) are glycosylated blue multi-copper oxidoreductases (BMCO) that utilize molecular oxygen to oxidize numerous aromatic and nonaromatic compounds through a radicalcatalyzed reaction mechanism. Lignin peroxidases (LiP) (1,2-bis (3,4dimethoxyphenyl) propane-1,3diol: hydrogenperoxide oxidoreductases, EC 1.11.1.14) heme-containing glycoproteins and play a central role in the biodegradation of the cell wall element, lignin. Manganese peroxidases (MnP) (Mn (II): hydrogen- peroxide oxidoreductases, EC 1.11.1.13) are extracellular glycoproteins and are emitted in multiple isoforms which have one molecule of heme as iron proto- porphyrin IX [4].

Study by Stanislava et al. states that enzymes as inoculum can be utilize in actual condition i.e. on landfill. Lignocellulolytic enzymes-producing fungi are common spread, basidiomycetes phyla such as white-rot (e.g. *Phanerochaete chrysosporium* and *Trametes Versicolor*) has been found to be the most effective lignin-degrading microorganisms studied [17]. It has been revealed that *P. chrysosporium* produces some Lip and MnP isoenzymes but no laccase. Respectively, the genome of *P. chrysosporium* contains ten Lip and five MnP genes. The effectiveness of *Phanerochaete chrysosporium* increments with increasing activity of fungal peroxidases; so, the produced culture can be used for more effective degradation [14].

Table II

The features of two main groups of fungal ligninolytic enzymes [4]

Types of Enzymes		Metals or Ions[2]	Range of optimum temperature	Range of pH optimum
Phenol oxidase (laccase)		Ca^{2+}, Cd^{2+}, Cu^{2+}, H_2O_2	20-80	2-10
Peroxidases	Lignin peroxidase	Iron	35-55	1-5
	Manganese peroxidase	Ca^{2+}, Cd^{2+}, Mn^{2+}, Sm3[+]	30-60	2.5-6.8

However, for the most part, laccases have been found and studied in white-rot fungi, *T. versicolor*. *T. versicolor* can be utilized for leachate decolorization and removal of BOD and COD [13].

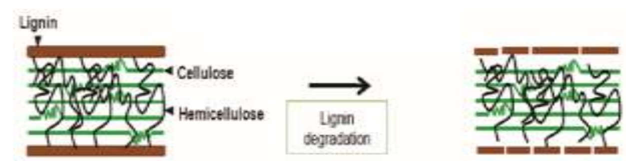

Fig 5 Lignin Degradation [4]

Combination of *Trametes versicolor* and *P. chrysosporium* at the same time degrade all cell wall components [4]. Study by Xiaoqiang G. et al. states that Compared to the control, inoculation enhanced the temperature, reduced the maturity time, quickened the decomposition of lignin and cellulose, and improved nutrient concentrations. The fungi can be immobilized on media for the option of repeated use [9].

3) Addition of inoculum – Manure: Livestock manure is prosperous in nutrients nutrient (Carbon, nitrogen, phosphorus etc.) as well as the microorganism. The utilization of manure inoculum, rich in nutrients as well as the microorganism, upgrades the buffer capacity making an environment to neutralize the pH to some level and decreases the inhibition time or lag phase [15].

Cow-dung contains soluble, particulate and fibrous components. It contains carbohydrates (cellulose and hemicellulose fiber), lipids, fats and proteins [5]. Study by Hiya Dhar et al., it was observed that biogas yield had an affirmative connection with VS reductions [6].Kondusamy D. et al. studied that inoculation with CD had shorter initial time and accomplished higher methane generation and best degradation than other inoculums [4].

4) Lift Design: The depth of lifts, whether or not compacted, and with or without daily cover are significant components influencing the waste degradation. Leachate

COD concentration is a purpose of waste depth i.e. shallow ones (1.2 m) [18].

M. Warith et al. studied that the improved MSW compaction not only decreases waste ability to move moisture in waste but also makes the waste attain level of saturation with less moisture accumulation because both waste hydraulic conductivity is conversely related to waste density [18]. To quicken waste degradation and facilitate compaction, waste should be shredded to a diameter of 5 cm [10]. Applying of daily or intermediate cover of low permeability (soil) can direct to horizontal movement and the probable for leachate ponding or side leaks [18].

III. CONCLUSIONS

The effectiveness of waste degradation depends on the type of microorganism used for inoculation. From research it can be concluded that inoculation using lignocellulolyticfungi could be a useful strategy for enhancing the properties of a waste degradation. The presence of inoculants, such as *Phanerochaete chrysosporium* and *Trametes Versicolor* led to a higher degrading ratio.

Leachate recirculation with enzymes inoculation method offers significant benefit comparative to the conventional leachate-recirculation method currently in use, including the enhanced gas generation and land reuse opportunities through rapid waste stabilization.

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