Contribution of Biodegradable Plastics to Global Methane Production

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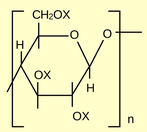
Abstract

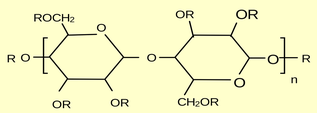
Majority of plastics we use today are synthesized materials extracted from crude oil, coal and natural gas. Property of high persistency (very slow biodegradation rate) of this material has raised concerns of proper disposal and end of life management options. To overcome these environmental problems many different types of biodegradable plastics (BDPs) have been successfully produced and have been available in the market as packaging materials, surfactants, in biomedical applications and in the agricultural sector. At the end of the service life, these bio plastics will be managed as part of the existing waste disposal systems (e.g., compost plants, landfills), potentially producing methane, which is one of the greenhouse gases being regulated and monitored very closely around the world. Biodegradable plastics are synthesized using plant extracted polymers or/and microorganisms. BDPs with tailored properties by chemical modifications and polymer blends have given rise to various types of BDPs with a broad range of beneficial characteristics. After the first invention of BDPs in the year 1990, it has been used in various applications such as packaging materials, surfactants, biomedical materials and agricultural compounds. There's an upsurge in manufacture of BDPs globally with an estimated global growth of 38% from 2003-2007. And in 2007, it was 0.3% of overall petrochemical plastic production. Most feasible and economic way of the end of life option of BDPs is landfilling. Landfilled BDPs will ultimately undergo anaerobic biodegradation, where materials are disintegrated into large and small organic/inorganic molecules, including methane gas. Methane gas is a well-known and important by product which public attention has turned as a global warming gas and also as an economically viable biofuel. The study is a preliminary attempt to investigate the levels of additional methane gas released, if end of the life option is chosen to be landfilling using commonly available types of BDPs globally, with different biodegradability levels. Literature was reviewed related to brand names, quantity, polymer types incorporated and biodegradability (especially in terms of methane production) of BDPs commonly found in the global market. Landfill methane production levels were estimated based on the methane production data published so far for the individual polymer substances. Estimated theoretical global methane production in year 2007 was 7.58 x$10^5$$m^3$ and global contribution was 0.012%. According to PROBIP (Product overview and market projection of emerging bio-based plastics, 2009) estimations, during maximum BDP substitution over petrochemical plastics (90%), calculated methane release was 1.52% of global methane production. This was 118% of the total landfill methane generation in year 2006. However, the percentage of experimental methane emission was 3.1-4.1% of the theoretical value. Even though currently BDPs have not much influenced to the global methane release, is likely to appear as a one of the major methane contributor in the future.

Introduction

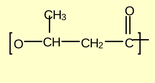
Types of polymers involved in manufacture of BDPs



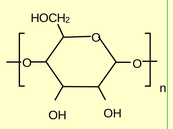
Cellulose



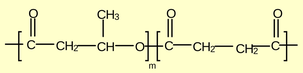
Cellulose Acetate Butyrate (CAB)



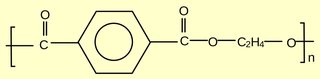
Polyhydroxy Butyrate (PHB)



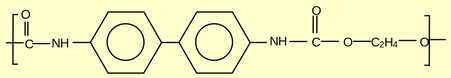
Starch



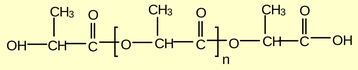
Poly hydroxy butyrate valerate (PHBV)



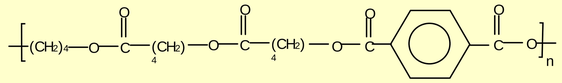
Poly ethylene terephthalate (PET)



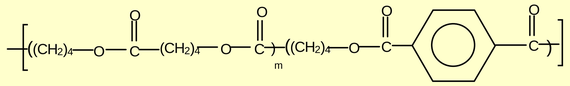
A Polyurethane



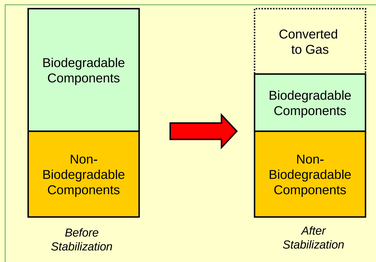
Poly lactic acid



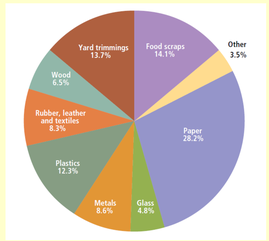
Polybutylene adipate – co- butylene terephthalate



Polytetramethylene adipate -co-terephthalate



Waste stabilization process in a landfill



Total MSW generation in USA (EPA, 2009)

In landfill anaerobic conditions Methane gas is produced based on the following equations.(Yagi et al., 2009)

$$C_aH_bO_c + \left(\frac{4a-b-2c}{4}\right)H_2O \rightarrow \left(\frac{4a+b-2c}{8}\right)CH_4 + \left(\frac{4a-b+2c}{8}\right)CO_2$$

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O \rightarrow \left(\frac{4a+b-2c-3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{8}\right)CO_2 + dNH_3$$

Gas generation Model (USEPA, 2005)

$$G_0 = L_0 M_0$$

G_0 -Total Volume of gas produced by the degradation of compound/ waste (m^3)
M_0 - Mass of the waste (Metric ton)
L_0 - m^3 of methane per metric ton of waste

Sample in a serum bottle after sludge addition (incubating at 35ºC)

Analysis of generated methane using GC-FID

Gas generation and analysis in the laboratory

Objective

To estimate the additional methane amount at waste disposal site with emergence of bio-plastic in waste stream.

Methodology

❖Literature was reviewed related to brand names, quantity, polymer types incorporated and biodegradability (in terms of methane production) of BDPs commonly found in the global market (Year 2007) (PROBIP, 2009).
Study was carried out in 4 steps. Steps regarding estimation of the total methane levels are assumed that, total amount of manufactured BDPs are being landfilled and readily being biodegraded.

Step 1: Theoretical methane production per day was calculated (Table 1).
Following equation gives the total biogas (CH_4 + CO_2) amount released by a particular polymer (Yagi et al., 2009).

Mass of the polymer / Molecular weight x Volume of 1 mole of gas at standard temperature & pressure x # of carbon moles in the molecular structure

Step 2: Methane production per day was calculated using available, published experimental data on methane gas production in simulated landfill conditions (Table 2).

Step 3: Current (year 2007) landfilled BDP contribution to global methane production was estimated.
Methane production was calculated considering the maximum amount of BDPs that will be landfilled under the 90% substitution of petrochemical plastics by BDPs.

Step 4 : Percent contribution of landfilled BDPs to global methane emission was calculated using the total methane emission data obtained from step 3 and step 4.

Results

•Based on 2007 BDP production data, theoretical methane release from landfills is calculated to be 8.3 x 10^8 m^3. Global contribution was estimated as 0.011 % over other anthropogenic methane sources (Table 1).

•Worldwide MSW stream composed of 205 million tons of petrochemical plastics in year 2003 (Gervet and Nordell, 2007). The maximum amount of BDPs that could possibly substitute to petrochemical plastics was calculated to be 184.5 million tons.
At 90% substitution scenario, amount of methane released is calculated to be 1.06 x 10^{11} m^3/year. This was 1.38% of global anthropogenic methane release and was 116% over current total landfill methane generation based on the year 2006 landfill methane emission levels (USEPA, 2006).

•Percentage experimental methane emission was in the range of 56-69% (Table 2) of the theoretical values, when compared the methane emission levels of available experimental data of polylactic acid and polycaprolactone polymers.

Table 1 Maximum theoretical methane amounts released during anaerobic biodegrdation of major polymer types at standard temperature and pressure conditions.

Major polymer type	Polymer	Production capacity (kt/annum)	Theoretical methane production (m^3/kt)	Theoretical methane production (m^3/yr)
Cellulose based	Cellulose acetate	670	6.2 x 10^5	4.1 x 10^8
	Cellulose acetate butyrate	450	4.0 x 10^5	1.8 x 10^8
Starch blends (Mater Bi)	Starch	20	4.1 x 10^5	8.3 x 10^7
	Polycaprolactone	20	7.4 x 10^5	1.5 x 10^7
Poly lactic acid	Poly lactic acid	151	3.73 x 10^5	5.6 x 10^7
Polyhydroxy alkaonates	Poly(3-hydroxybutyrate-co-3-hydroxyvalerate)	20	1.1 x 10^6	2.2 x 10^7
Polyurethane based polyol	Polyurethane	8.8	5.5 x 10^5	1.3 x 10^4
Other	Polyethylene terephthalate	45	6.5 x 10^5	2.9 x 10^7
	Polytetramethylene adipate -co-terephthalate	15	1.5 x10^6	2.2 x 10^7
	Polybutylene adipate -co-butylene terephthalate	14	7.0 x 10^5	9.8 x10^6
Total theoretical Methane production due to C, H, O polymers in year 2007 if assumed all manufactured polymers being landfilled		1411	7.0 x 10^7	8.3 x 10^8

Table 2 Comparison of theoretical and experimental methane emission levels.

Polymer	Experimental Methane volume (m^3/ kt)	Theoretical methane amount (m^3/ kt)	% experimental emission in relation to theoretical emission
Polylactic acid	257,000	373,330	69
Polycaprolactone	659,000	1,178,950	56

Conclusions

Global methane contribution of BDPs was low, compared with the other anthropogenic sources. However, in comparison of the methane emission from BDPs, over other landfill components, BDPs are likely to contribute a considerable amount of methane, with increase of manufacture. Experimental data indicate an overestimation of the theoretical estimates of the methane release from BDPs.

References

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