Biotransformation of Municipal Solid Waste (MSW) to Bioenergy: Prospects and Potentials

Piyush Nanda, Ramkrishna Sen, and Ramalingam Dineshkumar

Abstract The rampant increase in municipal solid waste (MSW) accumulations has largely contributed to the exacerbating scenario of the environment. The lack of efficient waste processing technologies to mitigate accumulation has led to a large influx of waste into environment causing multiple damages to nature. Failure of developing efficient mechanisms to degrade polythene which constitutes a major fraction of the MSW has also been a hindrance. Scientists across the globe are trying to develop efficient methods of converting waste to energy which can help us resolve energy crisis and reduce solid waste accumulations. Although a plethora of technologies are coming up, their potential to intake unsegregated waste is limited and hence their applications are restricted. Polythene being the most stable component of MSW remains practically unaffected for decades. It is well known that polythene on combustion produces CO_2 and other gases which are responsible for air pollution. The prospects of utilizing this released CO_2 in fuel production are being investigated in this research. Microalgae has been considered as a potential candidate for biofuel production owing to their invasiveness, high CO_2 sequestering potential, and high lipid content. In this study, the growth of microalgae using polythene combustion gas as the CO_2 source was investigated.

Bioprocess optimization can enhance the CO_2 sequestration kinetics and hence cause high oil content. The whole system comprises of an aqua-separation unit to segregate MSW, an anaerobic digester for degrading organic waste, a fermentor to process lignocellulosic waste coupled with the polythene decomposition, and a waste gas bioprocess unit. This can serve the process of utilizing almost all the components of MSW for energy production and hence impart a carbon reduction advantage to the system.

Keywords Carbon dioxide sequestration • Microalgae • Municipal solid waste • Polythene combustion gas

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1 Introduction

Development of waste processing technologies is quintessential to a country like India where each day around 1.5 million metric tons of municipal solid waste (MSW) is produced, of which around 0.9 million metric tons is collected and only 0.158 million metric tons is processed and treated (Artuchelvi et al. 2009). Accumulation of such huge quantities of MSW causes the release of thousands of tons of obnoxious gases due to open decomposition in the environment. Approximately an average 0.400 kg per capita per day of MSW is generated, and this goes on increasing at a rate of 1.3 % per annum (Sharma and Ganguly 2014). The actual composition of MSW depends entirely on the source and location, but one of the greatest hindrances faced in developing waste processing technologies is the resistance of plastic wastes to chemical and biological treatments. Plastic waste in particular polythene occupies a considerable portion in MSW. Its inert nature is due to the long hydrocarbon chains and absence of reactive groups. Technologies to process and effectively extract value-added products from other parts of waste have been developed. In the recent past, techniques of degrading polythene using xenobiotic microbes have come to picture, but the major drawback of such a process is the unmanageably slow degradation kinetics and sensitivity of such microbes toward toxins in polythene. This is possibly due to high positive free energy of depolymerization of polythene, and the metabolism of such microbes is not exergonic enough to impart a net negative Gibbs free energy to degradation of polythene. The combustion of polythene is exergonic in contrast to one-step depolymerization of polythene, and it releases CO_2 and other combustion products under appropriate oxygen supply. Controlled combustion of polythene releases mixture of gases with CO_2 predominating in composition and varying with oxygen supply. As the process is exergonic, a very low input of heat energy is required to sustain combustion.

Microalgae are being extensively used for Bio-CSS or bio-carbon sequestration and storage because of the faster growth rate and high substrate to oil conversion ratio (Gross 2013). Microalgae such as *Chlorella minutissima* are being used in photo-bioreactors to sequester CO_2 and generate oil which can be transesterified to biodiesel or processed to bio-butanol. In this study, the growth kinetics of photosynthetic microalgae in laboratory scale photo-bioreactor using waste gas released from market polythene was investigated. Some factors which may retard the growth of microalgae such as the presence of toxins can be eliminated using ligninolytic fungi or appropriate adsorbent.

This can successfully capture the carbon from polythene and metabolize the same to triglycerides which can be transesterified to biodiesel. The mass transfer analysis and maximum theoretical yield were estimated to be 480 mg per 1000 mg of polythene burnt. Experimental analysis is being conducted to see the efficiency of such an approach in industrial scale. Toxin degradation techniques are being developed to minimize inhibitory effects of toxins.

In an attempt to couple the polythene processing unit with anaerobic digestion unit to degrade organic loading in MSW (Sharholy et al. 2007) and lignocellulosic fermentor to produce bioethanol (Mata-Alvarez et al. 2000) from lignocellulosic portion of the waste, an aqua-separation system was proposed. Such a system will separate the components of MSW according to their specific gravities. Organic loading which will mostly settle down due to relatively high density (Schmitta et al. 2011) can be fed to the anaerobic digester to generate biogas which can be further used for sustaining polythene combustion. The lignocellulosic portion can be alkali treated to separate cellulosic filtrate and can be processed to bioethanol.

The whole process can be a one-stop solution for treatment of municipal solid waste and subsequent extraction of value-added products from it. The biofuel produced can be used with gasoline or diesel in appropriate proportions as per need.

2 Materials and Methods

To execute the proposed processing system, the first requirement is polythene separated from the domestic waste, which generally comes as a mixture of polythene wastes, lignocellulosic, cellulosic, and food waste. Segregated waste is easier to process than unsegregated ones both with regard to time and money. To make the process economic with respect to segregation of wastes, this process utilizes aquaseparation method which is new to this kind.

Aqua-separation method utilizes the fact that the density of polythene and in general most of the polymers is relatively quiet less in comparison to that of food waste, cellulosic wastes, etc. (Schmitta et al. 2011). Transferring the entire waste feed, i.e., the waste collected from the localities into water tank, will cause the lighter polythene and a major portion of the lignocellulosic waste to rise up and the heavier food waste and cellulosic wastes to settle down. Hence, we separate the entire waste feed into two layers, one consisting of polythene and lignocellulosic waste and the other of food/kitchen waste and cellulosic waste. The basic advantage of this method is that generally we have soiled polythene from domestic wastes; this method will desoil the polythene waste hence making it suitable for further processes. The top layer is transferred to pretreatment chamber where it is alkaline treated to breakdown the lignin, and then the cellulose extracted is solubilized in water and transferred to fermentation unit. The polythene, which remains as the residue, is taken to the combustion unit. There it is combusted aerobically under controlled flow of air, and the heat of combustion of polythene can be used to generate electricity using steam turbines. The combustion gases having a large composition of CO_2 along with hydrocarbons and CO are first compressed into storage cylinders. The gases are passed through water with fungal inoculums, which aids in decomposition of toxins, i.e., PAH and other organic toxicants. The filtered CO_2 is then mixed with air to have a 20% CO_2 concentration and bubbled through the raceway containing algae with appropriate nutrient medium. The undissolved gases are recycled (Fig. 1).

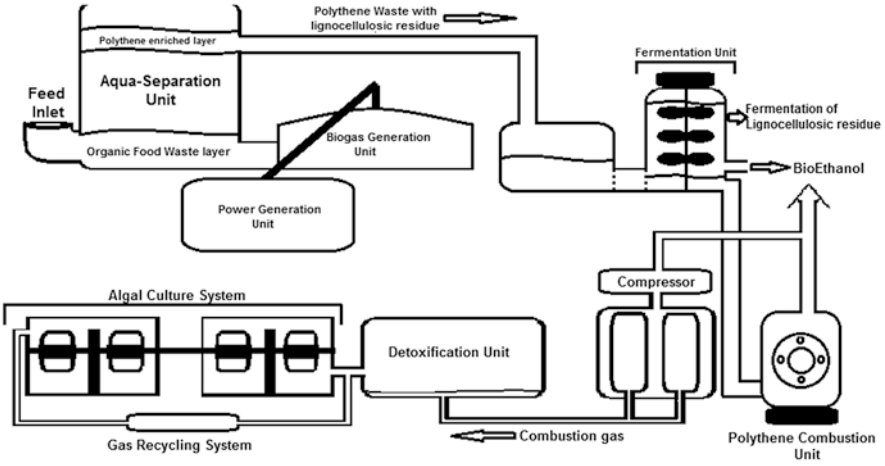

Fig. 1 The prototype design of the processing plant abstracting the whole process

Then the bottom layer of the separation unit that will be consisting of heavier kitchen/food waste and cellulosic waste will be subjected to anaerobic digestion where biogas is extracted which can be used to supply the electricity needs of the entire processing plant. Hence, make the processing system selfsustainable. The water used in separating the wastes can be reused or, in case after optimum usage, can be processed in a sewage treatment unit or using water hyacinth, whichever will be suitable. The bioethanol produced can be used in the transesterification of biooils extracted from the algae, making the system sustainable.

This makes the processing unit selfsustainable in terms of energy and chemical inputs. The further sections describe about the physical analysis of the plant.

3 Calculations and Results

3.1 Theoretical Estimation of Expected Output and Yield from the Algal Culture

It is important to estimate in advance the fuel generation per unit of the supplied waste feed so as to make a rough estimate of feasibility of the project. The entire arc of conversion of polythene to biooil takes place through various physical and biochemical transformations.

The aerobic combustion of polythene (domestically used) or LDPE yields CO_2 gas along with CO and other hydrocarbons. The percentage composition of these in the combustion products depends on oxygen supply rate (OSR), feed purity, and temperature of operation. Table 1 gives the amount of products released

Table 1 Quantity of combustion products released

Air flow, cc/min	100	100	100
Oxygen flow, cc/win	0	40	0
Heating rate, C/min	5	5	50
Carbon dioxide	88.0	1610.0	178.0
Carbon monoxide	312.0	171.0	110.0
Methane	10.0	7.0	17.0
Ethylene	40.0	33.0	70.0
Ethane	5.0	3.0	11.0
Propylene	29.0	14.0	33.0
Propane	5.0	3.0	7.0
1-butene	17.0	8.0	19.0
Butane	4.0	2.0	6.0
Trans-2-butene	6.0	4.0	9.0
Cis-2-butene	0.95	0.50	1.0
1-pentene	9.0	4.30	12.0
Pentane	2.0	1.0	3.0
1,3-pentadiene7	23.0	8.0	32.0
1-rexene	10.0	5.0	15.0
2-hexene	4.0	2.0	6.0
%plastic accounted for	32.0	61.0	34.0

Source: Office of Research and Monitoring, US Environmental Protection Agency
The quantity of each combustion product is reported in milligrams per gram of sample

(in milligram) per gram of polythene in the mentioned conditions. This helps in making a rough assumption about the amount of CO_2 released per gram polythene.

Assuming a yield of 1600 mg/g of polythene, 1.6 g of CO_2 is released when 1 g of polythene is aerobically burnt. The maximum biomass production is observed in the range of 5–10 % concentration of CO_2 (in ppm by volume). This turns around to be 387.5 mgCO_2/L.

At other conditions being optimized, algae is supposed to absorb almost twice the CO_2 its own mass (Gross 2013). Hence, assuming that after repeated recycling of the unused gases, algae absorb almost all CO_2 (theoretical maximum). This results in production of 193.75 mg algae/L of algal biomass when all 387.5 mg/L is used.

As polyculture is used, oil content in different species of algae will be different. An average content of 60–70 % will not affect rough assumptions. This turns out to be 116.25 mg oil/L.

From about 1 g of polythene, a theoretical maximum of 1.6 g of CO_2 is released. Provided this amount of CO_2 is air diluted to 1 L, extrapolating the results, this would result in production of 800 mg algae/L. About 480 mg oil/L can be extracted assuming a conversion efficiency of 60 % to oil.

3.2 Experimental Results

To determine the feasibility of such an approach to use polythene combustion gas to culture algae, a lab scale set was designed, and the growth kinetics of *Chlorella minutissima* was studied.

Locally available polythene was collected and burnt in combustion unit specially designed for collection of combustion gases. The collected gases were stored in cylinders. In the setup, in experimental photo-bioreactor (500 ml) combustion, gas diluted with air was passed, and suitable conditions were maintained for growth of algae. Bold's basal medium (BBM) (Weyer et al. 2009) was used for culture of algae, and appropriate buffer was added to suppress fluctuations in pH due to acidic gases present. The growth of algae was measured relative to a control. The growth was determined in terms of absorbance or optical density of the culture at 750 nm using UV-vis spectrophotometer. Gravimetric analysis was also conducted to quantify the final biomass (Figs. 2 and 3).

Analysis of the data made us conclude that algae was able to sequester the CO_2 present in the polythene combustion gas but presence of toxins which bioaccumulate in algae inhibits their growth. These toxins are produced due to presence of additives in polythene and their incomplete combustion. Oxygen supply can be properly regulated to ensure maximum feed mass to gas conversion and minimal carbonaceous residue production. We are looking forward to use ligninolytic fungi to decompose toxins present in the combustion gas so that algae can properly biosequester the CO_2 in combustion gas.

We are working on process optimization of this proposed model and eliminating carbon loses and inhibition.

Fig. 2 Experimental setup for studying growth kinetics of algae using polythene combustion gas

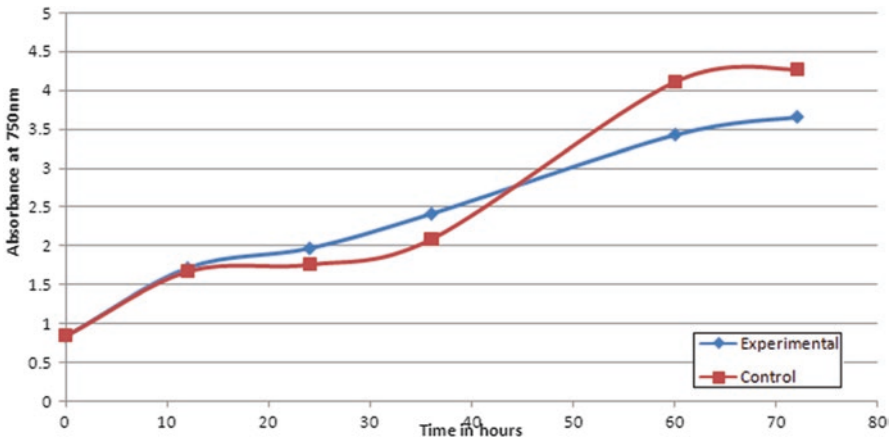

Fig. 3 Growth profile of *Chlorella minutissima* growing in medium sparged with polythene combustion gas

Table 2 Gravimetric analysis of final biomass

Sample	Final algal concentration (500 ml culture)
Control	1.18 g/L
Experimental	1.06 g/L

As it can be observed from the growth profile during mid-log phase of growth, there was a decrease in growth possibly due to the presence of toxins. After the end of the experiment, gravimetric analysis of the centrifuged biomass was conducted (Table 2).

4 Conclusion

This processing plant intakes the unsegregated domestic wastes, sustainably processes them converting them to fuel and energy. The impacts of scaling up this into industrial scale model are enormous.

4.1 Reduction in accumulation of MSW and conversion to value added products:

Around 55 million metric tons of MSW is generated each year in India. Each day around 0.4 Kg/capita of waste is generated/averaged all over the states. Due to lack of efficient and versatile technologies, a major fraction of these wastes are dumped

in landfills which become the epicenter of air pollution. Open burning of wastes in certain anthropological specific region is responsible for the addition of carcinogenic dioxins in the air. There are many present-day technologies dealing with processing of MSW and production of valueadded products from it. But the ability to intake all components of waste and produce energy and fuel from it is rare to its kind.

Conversion of wastes to value-added products: Wastes are a vast reserve of chemical energy that can help us meet our energy need. Introduction of efficient, green, and cheap alternative fuel can remove our dependence on petroleum and coal-based fuel. Our country is expected to undergo acute energy shortage. The need of technologies making it possible for production of fuel and energy from cheap and readily available raw materials is required. This definition of raw materials perfectly matches with that of "waste," which is cheaply and readily available in India. Harnessing the chemical energy by the application of chemistry and biotechnology converting waste into energy is the need of the hour.

4.2 Self-Sustainable and Green Process

The whole process is designed in such way that all the energy needs within the system are met by the energy generated within it. The generation of electricity from biogas from the kitchen waste/organic waste and the energy generated by polythene combustion are thoroughly utilized in meeting the energy needs within the plant, hence making the process selfsustainable. The biochemical and biological feed must be externally supplied that is cheap and selfreplicating.

4.3 Decomposition of Waste Polythene

There are a number of technologies coming up for degradation of polythene including that of pyrolysis of polythene, gasification, and microbial degradation using fungi, waxworms, bacteria, etc. But most of them either require high energy and chemical input which does not give them edge on ecofriendly and sustainable ground or in case of microbial degradation are ecofriendly and sustainable but highly inefficient and slow. So, polythene degradation and extraction of value-added products from it is the need of the hour. Though a large fraction of polythene can be recycled, again this recycling process is carbon positive. Also, we are looking for extraction of bioplastics from the biooils generated from algae.

The growth kinetics of microalgae is being studied using polythene combustion gas as source of carbon dioxide. The process is being optimized for enhanced oil productivity. The enhancement in amount of oil obtained per gram of algae by supplying external stimuli is also being studied.

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