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Optimal planning for the sustainable utilization of municipal solid waste

José Ezequiel Santibañez-Aguilar [a], José María Ponce-Ortega [a,*], J. Betzabe González-Campos [b], Medardo Serna-González [a], Mahmoud M. El-Halwagi [c,d]

[a] Chemical Engineering Department, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán 58060, Mexico
[b] Institute of Chemical and Biological Researches, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán 58060, Mexico
[c] Chemical Engineering Department, Texas A&M University, College Station, TX 77843, USA
[d] Adjunct Faculty at the Chemical and Materials Engineering Department, Faculty of Engineering, King Abdulaziz University, P.O. Box 80204, Jeddah 21589, Saudi Arabia

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ABSTRACT

The increasing generation of municipal solid waste (MSW) is a major problem particularly for large urban areas with insufficient landfill capacities and inefficient waste management systems. Several options associated to the supply chain for implementing a MSW management system are available, however to determine the optimal solution several technical, economic, environmental and social aspects must be considered. Therefore, this paper proposes a mathematical programming model for the optimal planning of the supply chain associated to the MSW management system to maximize the economic benefit while accounting for technical and environmental issues. The optimization model simultaneously selects the processing technologies and their location, the distribution of wastes from cities as well as the distribution of products to markets. The problem was formulated as a multi-objective mixed-integer linear programing problem to maximize the profit of the supply chain and the amount of recycled wastes, where the results are showed through Pareto curves that tradeoff economic and environmental aspects. The proposed approach is applied to a case study for the west-central part of Mexico to consider the integration of MSW from several cities to yield useful products. The results show that an integrated utilization of MSW can provide economic, environmental and social benefits.

1. Introduction

Waste is defined as any residual material from industrial and human activities that has no residual value (Ortiz et al., 2010). Nowadays, there is much interest in waste production, management and disposal. This is attributed to the observation that waste generation is a side effect of consumption and production and it tends to increase with the economic development of the society (Beolchini et al., 2012). Furthermore, there is an increasing awareness of the environmental, health, economic, and social problems associated with waste disposal. Particular attention should be given to the treatment and management of municipal solid waste because of its abundance and impact on the environment (Vasudevan et al., 2012).

In Malaysia the average amount of municipal solid waste generated is about 0.5 kg/person/day; but it can be up to 1.7 kg/person/day in other cities of the world (Ramayah et al., 2012). This creates problems in some countries because of the lack of sufficient landfills and an adequate MSW management system. For example, in several countries of Central and South American (like the specific case of Mexico), the waste management is not adequate; also, one important problem is that the MSW is mixed (i.e. different types of materials are mixed and they require to be separated for further treatment), which increases the separation costs, makes more difficult and expensive the treatment process and even yields insalubrious conditions. This is very common in Mexico, where most of the people do not separate the solid wastes, which results in a very significant increase of total wastes volume and weight, besides the fact that the facilities are not adequate to store these residues. In these cases the application of proper environmental, institutional, financial, economic and social tools to guarantee a sustainable waste management is required (Ghinea et al., 2012). There are also negative impacts on water, land, and air resulting from inadequate treatment and management of the municipal solid waste (Krüger et al., 2012).

It is important to note that the actions that have been implemented to solve this problem are focused only on one particular type of waste, without taking into account the interaction between the waste composition and distribution, and without considering the entire supply chain optimization as well as the economies of scale. The distribution of wastes, products and the design and selection of the processing facilities are crucial in yielding an adequate solution for the entire problem. Therefore, this paper

* Corresponding author. Tel./fax: +52 443 3273584.
E-mail address: jmponce@umich.mx (J.M. Ponce-Ortega).

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proposes a general methodology for the optimal planning of a distributed system of processing facilities based on municipal solid waste. The proposed methodology is based on a mathematical programming formulation for the optimal planning of the reuse of municipal solid waste to maximize the economic benefits while accounting for social and environmental aspects. The optimization model is capable of selecting the processing technologies, consumers, cities producing wastes, amount of recycled waste, products and location of processing facilities.

1.1. Different types of MSW

Since waste characteristics vary over time and location, there is a need to account for such variability. Plastic materials are extensively used (Passamonti and Sedran, 2012); nonetheless, plastic wastes have a great impact on the environment because they are mostly non-biodegradable and they occupy an enormous volume (see Table 1). Another important waste is paper, which represents 30–40% of the total municipal solid waste. Metals are other important constituents of MSW, which are recyclable materials used to obtain high value products (Plunkert, 2006). Glass is another material that can be readily recycled. For glass recycling, it has to be recovered and separated from other wastes as well as differentiated between the different types of glass (clear, amber and green). A particular advantage for recycling glass is the reduction in energy consumption compared to the use of silica feedstock. In addition, the food and garden wastes are important since they represent around 40% of the wastes generated in Mexico and 27% of the wastes generated in USA (see Table 1); their composition is very diverse depending on the considered city, and the characterization to use this waste for the production of several valuable products is complicated since commonly there is not enough reported information for this purpose. However, these wastes are very important and they have a high potential to be reused; in this paper, these wastes are considered as a mixture, which is obtained after the separation of the recyclable materials as plastics, metals, paper and glass (this is based on the proposed work by Young, 2010).

1.2. Processing routes to treat MSW

Effective methods need to be implemented to recycle the plastic materials (Kalantar et al., 2012). In this context, physical, thermal, and chemical recycling technologies are the most widely used (Hur et al., 2003). Gasification provides a promising alternative to thermal recycling of plastic waste to produce a synthesis gas (syngas). Additionally, the plastic waste can be transformed into carbon nanotubes (Alireza and Gordon, 2012; Wu et al., 2012).

For recycling and utilizing paper wastes, there are several processing routes, including thermal processing and landfilling, which do not typically require sorting, while many other routes entail the separation of paper, for example, paper digestion can be used for papermaking (Hanan et al., 2012) and fermentation to yield bioethanol (Wang et al., 2012), mixed alcohols, acids, ketones, or fuel (Pham et al., 2010).

The biowastes (food and garden wastes) can be used to obtain several bioproducts through composting, anaerobic digestion or another processing technology; or even to obtain biofuels like biogas or bioethanol, however, their composition can be very different and variable and the determination of production factors can be complicated, although these wastes could be included in the model as another type of waste separately if necessary data are available, this type of wastes are taken into account with the mix of the remain waste after the separation of plastics, glasses, paper and metal.

In addition, thermal pathways as incineration, gasification and pyrolysis have been proposed to treat the wastes as a mixture of different wastes (Grieco and Baldi, 2012). Incineration is a combustion process that uses an excess of oxygen to burn the municipal solid waste. Pyrolysis is a thermal decomposition of carbon-based materials in an atmosphere without oxygen using heat to produce syngas, the process is endothermic. For the pyrolysis process there are several variations; for example, there is pyrolysis–gasification, where another reactor is added to gasify the produced liquids from the first step of pyrolysis. On the other hand, conventional gasification is a thermal process, which converts carbonaceous materials in syngas using a limited quantity of oxygen, where steam may be injected to promote CO and hydrogen production. Finally there is another variation of the gasification process which is known as plasma arc gasification, and this processing route is a high temperature pyrolysis process, where organic compounds and solid wastes are converted into syngas and inorganic materials and minerals (Young, 2010).

1.3. Assessment of processing routes to treat MSW

Several papers have addressed the processing technologies to treat the different types of MSW, these evaluations have considered the human, environmental and economic aspects; in this regard, Young (2010) evaluated and compared the economic aspects of five thermal routes to treat the MSW. Ramayah et al. (2012) examined the human behavior for the recycling process. Also, Ghinea et al. (2012) investigated some waste management alternatives in the city of Iasi in Romania from the environmental point of view based on the life cycle assessment. Furthermore, the costs and benefits of waste recycling in Portugal were presented by Cruz et al. (2012), where the analysis included the return of the capital employed and the landfilling activities. On the other hand, Ling and Poon (2012) presented a study to compare the feasibility for using recycled glass. Finally, the assessment to obtain energy from wastes has been studied too, for example Iakovou et al. (2010) concluded that biomass from wastes to energy production

Table 1
Composition of municipal solid waste for several countries.

Type of waste	USA[a] 2010	Mexico[b] 2009	France[b] 2009	Colombia[b] 2009	American[c] Samoa 2009	China[c] 1993
Paper and cardboard	28.5	14.2	35	22	26.4	3.1
Plastic	12.4	5.8	7	5	12.8	4.9
Metals	9	3.1	5	1	7.9	0.7
Textiles	5.3	1.2	5	4	4.2	2.1
Glass	4.6	6.6	12	2	3.4	2.2
Food wastes	13.9	31.6	21	56	3.78	46.9
Yard trimmings	13.4	9.8	–	10	11.30	–
Others	12.9	27.7	15	–	30.22	40.1

[a] Environmental Protection Agency Office of Resource Conservation and Recovery (2011).
[b] Mexican National Institute of Ecology (2012).
[c] Rogoff and Screve (2011).