International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 16 (2018) pp. 12631-12637
© Research India Publications. http://www.ripublication.com

Design of MSW Collection Systems through Peak Generation Coefficients: a Methodological Proposal for Developing Countries

Carlos Zafra[1,*], Álvaro Gutiérrez[1,], Juan Alarcón[***]**

[1]Environmental Engineering Research Group (GIIAUD), Faculty of Environment and Natural Resources, Universidad Distrital Francisco José de Caldas, Avda. Circunvalar Venado de Oro, E-111711 Bogotá D.C., Colombia.

Abstract

This paper shows a methodological proposal for developing countries to design pre-collection (containers) and collection (collection trucks) systems of municipal solid waste (MSW) considering the temporal variation in quantities generated and collected from waste. This temporal variation has been included using three peak coefficients of MSW generation: weekly peak generation coefficient, daily peak generation coefficient, and daily peak coefficient of heterogeneous distribution in MSW generation (Dpch). The MSW amount collected varies in relation to the collection frequency and distribution of this throughout the week. Thus, Dpch coefficient increases as the MSW collection frequency decreases during the week. Its increase is because the containers will stay longer without being emptied at the MSW presentation points. This consideration in the temporal variation of MSW generation allows reasonable designs to be adjusted to the maximum collection rates, so that no waste is left outside the MSW presentation points. Expressions that include peak generation coefficients for calculating MSW generation can only be used to design pre-collection and collection systems. These design expressions do not represent an estimate of the average daily generation of MSW in a locality. Finally, the methodological proposal can be used for selection of the MSW management equipment in developing countries.

Keywords: Urban dirt, Solid waste, Waste collection, Peak generation.

INTRODUCTION

Municipal solid waste (MSW) forms part of the daily reality. In recent times, the MSW volume has reached such levels of generation, that its collection and final disposal constitute one of the main problems facing the municipalities of developing countries [1]. The 'MSW management' is the term applied to activities associated with the management of various waste streams within a community, and its goal is to administer them in a manner compatible with the environment and public health [2]. Therefore, it is necessary to develop methodologies to guide engineers during the estimation of containers and waste-collection trucks needed in a locality. These methodologies are fundamental for designing materials recovery facilities, waste transfer stations, and final disposition sites. Additionally, MSW collection costs continue to be the largest budget items in municipalities compared to final disposition costs [3].

The 'MSW pre-collection' includes the activities of handling, processing, and storage until they are deposited at presentation points (containers) [4]. The 'MSW collection' is defined as the waste collection by personnel and equipment available for it (collection trucks), with the purpose of being transferred to the place of treatment or elimination, or to a previous transfer station [5]. In the fixed-box collection systems, the containers used for waste storage remain at the MSW presentation points. This MSW collection system varies depending on the number of generating points, and type and quantity of waste to be collected. There are mainly two types of MSW collection systems: manual and mechanized [6].

The most successful methodology for designing MSW management systems will be the one that probably considers temporal variations in quantities generated and collected from these [7]. The maximum MSW generation rates should be considered with the inclusion of peak generation coefficients. In the case of information for MSW generation, the peak coefficients are estimated by relationship between the maximum and average generation values from the locality under study. Otherwise, a temporal variation criterion should be developed for the MSW quantities generated, which considers the peak generation and collection frequency, among other factors.

The main objective of this paper is to present a methodological proposal to design and evaluate pre-collection (containers) and collection (collecting trucks) systems of MSW in developing countries, when there is or not information about the MSW generation rates in a locality. This study will deepen the knowledge about design criteria that should be considered in relation to the temporal variation of quantities generated and collected in MSW management systems.

METHODOLOGICAL PROPOSAL

Population projection

The knowledge of the current and future population is constituted in importance information for the MSW management, since the generation and collection of these are related to the inhabitants' number, and with the size and growth of localities [8]. It is established that this population must correspond to that projected according to the design period defined [9]. Depending on the community socioeconomic level, methods of calculation are proposed to estimate the future population in developing countries (Table 1).

Table 1. Methods of population projection proposed according to gross national income (GNI) [9].

Method	GNI [a]		
	Low	Lower middle	Upper middle
Arithmetic, geometric or exponential	X	X	
Arithmetic, geometric, exponential, and additional methods			X
Method of multiregional components (sex and age)			X
To detail locally by areas and population densities			X

[a] GNI for 2017. Low-income, $1005 or less USD; lower middle-income, between $1006 - $3955 USD; upper middle-income, between $3956 - $12235 USD.

2.2. Average daily MSW generation

Per capita generation (PCG) is defined as the waste amount produced by one inhabitant per day (kg/inhabitant*d). The methods used to estimate PCG in developing countries (number of loads, weight-volume, and mass balance) consider the MSW amount generated per day and inhabitants' number of the area under study (Table 2). To estimate the future PCG it is recommended to use annual growth rates between 0.5% - 1.0%, so that populations with a low GNI have a low growth rate (0.5%) and populations of upper-middle GNI tend to 1% [10]. In addition to the amounts generated of MSW is necessary to know its physical composition. In other words, we must determine the individual components that constitute the MSW flow and its relative distribution normally given as a percentage by weight (Table 3). A classification of the MSW components is by their organic and inorganic origin [11].

Table 2. Typical PCG values according to GNI [9].

GNI	Minimum value	Maximum value	Average value
Low	0.30[a]	0.75	0.45
Lower middle	0.30	0.95	0.45
Upper middle	0.37	1.05	0.71

[a] PCG in kg/inhabitant*day.

Table 3. Physical composition of MSW (%) according to GNI [12].

Component	Low-income countries	Middle-income countries
Organic		
Food waste	40-85	20-65
Paper and cardboard	1-10	8-30
Plastics and rubber	1-5	1-6
Textiles	1-5	2-10
Leather	1-5	1-4
Wood	1-5	1-10
Inorganic		
Glass	1-10	1-10
Metals	1-5	1-5
Dirt, ashes, etc.	1-40	1-30

In this way, the average daily MSW generation (current and future) is calculated with the following expression:

$$Adg = PCG * Population \quad (1)$$

Where *Adg* is the average daily MSW generation (kg/d), *PCG* is the per capita MSW generation (kg/inhabitant*d), and *Population* is the inhabitants' number (current or future) of the locality under study.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 16 (2018) pp. 12631-12637

Peak generation coefficients

The peak generation coefficients used to consider temporal variations in the generation and collection rates of MSW are as follows.

Weekly peak generation coefficient (Wpc): This peak coefficient allows including the maximum weekly variation for a year in MSW generation. If there are annual MSW generation information in one locality, then *Wpc* is obtained through the following expression:

$$Wpc = \frac{Mwg}{Adg} \quad (2)$$

Where *Wpc* is the weekly peak generation coefficient (dimensionless), *Mwg* is the maximum weekly MSW generation for one year (ton/d), and *Adg* is the average daily MSW generation for the same year (ton/d).

Figure 1 shows the weekly variation during a year in MSW generation for a Spanish population of 250000 inhabitants, which generates annually 11160200 tons of MSW with an average daily rate of 30.5 ton/d (PCG = 1.22 kg/inhabitant*d). Therefore, *Wpc* will be equal to the ratio between maximum weekly MSW generation (week 33) and average daily MSW generation during that year (*Wpc* = 46.5/30.5 = 1.52).

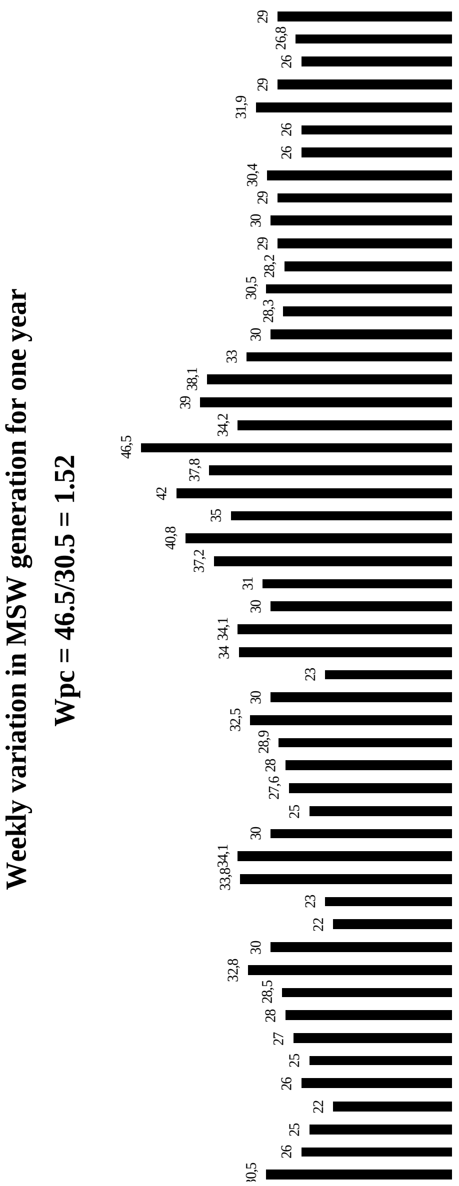

Figure 1. Weekly variation in MSW generation during one year for a Spanish population of 250000 inhabitants [13].

The typical values for *Wpc* in developing countries range from 1.5 to 1.9, so that populations with low GNI are closer to 1.9 due to the homogeneity in habits, and populations of upper middle GNI tend to 1.5 by the heterogeneity in habits [14]. Tchobanoglous et al. [15] reported typical values for *Wpc* between 1.25 and 2.0.

Daily peak generation coefficient (Dpc). This peak coefficient allows including the maximum daily variation in MSW generation for one year. If there is annual generation information in one locality, then *Dpc* is obtained through the following expression:

$$Dpc = \frac{Mdg}{Adg} \quad (3)$$

Where *Dpc* is the daily peak generation coefficient (dimensionless), *Mdg* is the maximum daily MSW generation for one year (ton/d), and *Adg* is the average daily MSW generation for the same year (ton/d).

Figure 2 shows the maximum daily MSW generation for a Spanish population of 250000 inhabitants, which generates annually 11160200 tons of MSW with an average daily rate of 30.5 ton/d (PCG = 1.22 kg/inhabitant*d). Therefore, *Dpc* will be equal to the ratio between maximum daily MSW generation (Thursdays) and average daily MSW generation during that year (*Dpc* = 37.2/30.5 = 1.22). Tchobanoglous et al. [15] and Tejero et al. [14] report typical values for *Dpc* between 1.5 and 2.5. Populations with low GNI are closer to 2.5 due to the homogeneity in habits, and populations of upper middle GNI tend to 1.5 by the heterogeneity in habits. *Dpc* will not be considered in this methodological proposal because it can lead to overestimations in quantities generated from MSW. Otherwise, we would be assuming that peaks of MSW generation are being presented every day, which is unlikely in practice.

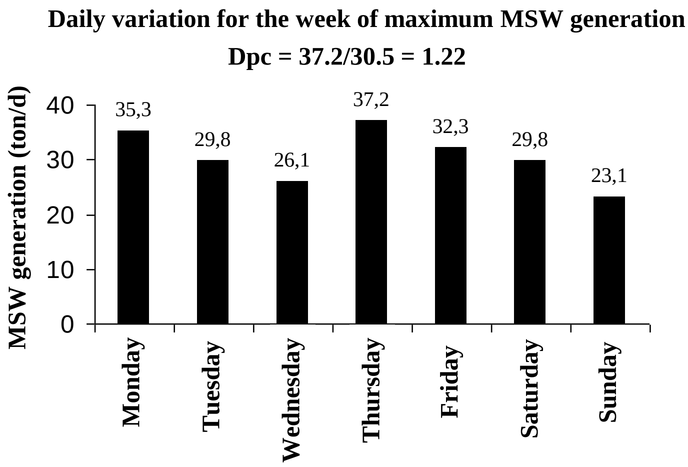

Figure 2. Daily variation for the week of maximum MSW generation in a Spanish population of 250000 inhabitants [13].

Daily peak coefficient of heterogeneous distribution in MSW generation (Dpch). If the MSW collection is not done every day, then *Dpch* must be added. The MSW amount generated varies in relation to the frequency and distribution of collection throughout the week. The following interval can be used for calculating *Dpch* [14]:

$$Dpch = \left[\frac{7}{n}; 1 + \frac{7}{n}\right] \quad (4)$$

Where *n* is the number of days per week in which the MSW collection operations are carried out (collection frequency). The proposed interval considers two extremes in quantities generated or collected from MSW. Lower limit of the proposed interval (7/n) considers that the amount collected from MSW is distributed uniformly throughout the week in relation to the collection frequency. Integer part of the upper limit considers the MSW amount generated during the maximum number of days without collection service in relation to its collection frequency. As noted, *Dpch* magnitude depends on the MSW collection frequency established in the study locality. For example, Figure 3 shows the distribution of MSW collection for two days per week (n = 2). According to the lower limit for calculating of *Dpch* (7/2 = 3.5; see Eq. 4), for a uniform MSW generation during the week it is necessary to collect them every 3.5 days (Figure 3a). Integer part of the upper limit (1+7/2 = 4.5) shows that the maximum number of days without collection service is four (Figure 3b).

Design generation for MSW collection systems

The following expression is used to calculate the design generation in pre-collection (containers) and collection (collection trucks) systems of MSW:

$$Dg = PCG * Population * Wpc * Dpch \quad (5)$$

Where *Dg* is the design generation for pre-collection and collection systems of MSW (kg/d), *PCG* is the per capita generation of MSW (kg/inhabitant*d), *Population* is the inhabitants' number (current or future) of the locality under study, and *Wpc* and *Dpch* are the peak coefficients weekly and daily of heterogeneous distribution, respectively (dimensionless).

Systems design for MSW pre-collection

To design pre-collection systems, it is necessary to predefine the container capacity to be used. The volumetric capacities and types of containers to be installed depend on the MSW characteristics to be collected, type of collection system used, collection frequency, and space available for container location. The commercial volumetric capacities are usually the following: 90, 120, 140, 240, 360, 700, 800, 1000, 1100, 2400, and 3200 L [16]. The average density of MSW should also be defined inside the container. Typical values are reported between 120-300 kg/m^3 [17, 18]. In this way, the number of containers required for MSW pre-collection is calculated with the following expression:

$$NC = \frac{Dg}{\rho * V} \quad (6)$$

Where *NC* is the total number of containers for MSW pre-collection systems, *Dg* is the design generation for pre-collection systems (kg/d), ρ is the MSW density inside the container (kg/m^3), and *V* is the volume of selected container (m^3).

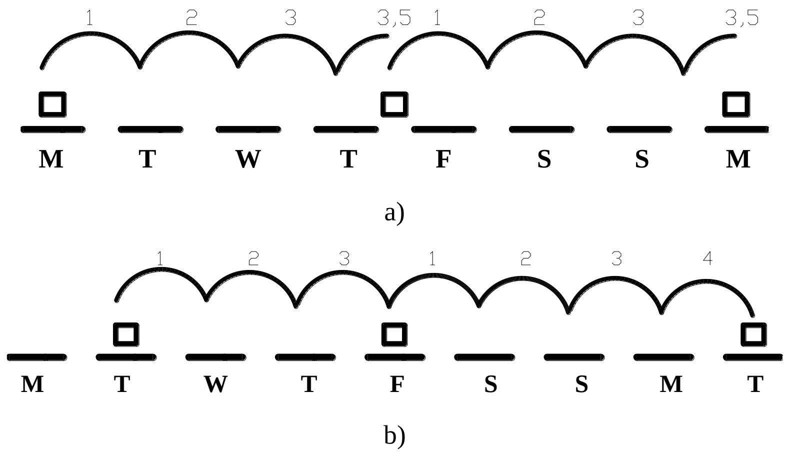

Figure 3. MSW collection scheme for a frequency of two days per week. a) Lower limit and b) upper limit for the proposed interval. M = Monday, T = Tuesday, W = Wednesday, T = Thursday, F = Friday, S = Saturday, and S = Sunday.

Systems design for MSW collection

To design MSW collection systems, it is necessary to predefine the type of collection truck to be used. Technical specifications such as the box capacity and compaction density are very important to determine the duration of MSW collection itinerary. The general technical characteristics of rear-loading trucks manufactured by industries in developing countries are as follows: Box capacity between 6.1 m^3 (8 yd^3) and 18.3 m^3 (24 yd^3), and compaction density ranges between 450-750 kg/m^3 [19, 20].

Number of MSW presentation points attended by collection truck

The number of MSW presentation points attended by collection truck is determined using the following expression:

$$Ppt = \frac{Vc * \rho c}{V * \rho} \quad (7)$$

Where *Ppt* is the total number of presentation points attended by collection truck, *Vc* and *V* are the volumetric capacities of collection trucks and containers (m^3), respectively; and ρc and ρ are the MSW densities inside collection trucks and containers (kg/m^3), respectively.

Itinerary of MSW collection by truck

The collection itinerary consists of the following times: container-taking time, transport time between MSW presentation points, transport time to and from the treatment or final disposal site, discharge time at the final disposal site, and downtime (e.g., start-up time and rest time).

a) Container-taking time: This is the time required to load a container, which depends mainly on the container placement and driver skill. Typical times for side-loading container systems range from 65-70 seconds. For four-wheel container and manual rear-loading systems, the times oscillate between 35-37 seconds [13].

b) Transport time between MSW presentation points: This is the time required to move between the MSW presentation points, and depends fundamentally on the distance between points, container location, timetable, and road characteristics. In general terms, the average transport speed between MSW presentation points increases as the distance between points also increases. For example, for a Spanish city of 250000 inhabitants two expressions were developed to estimate the transport time between MSW presentation points (in seconds). The first expression corresponds to places without road congestion and easy access to the MSW presentation points (t = 3.7+0.168*X). The second expression developed corresponds to places with road congestion and difficult access to the MSW presentation points (t = 9.9+0.197*X). These expressions depend only on the average distance (X in meters) between MSW presentation points [13].

c) *Transport time to and from the treatment or final disposal site*: This is the time between filling the truck at the last MSW presentation point and transportation to the final disposal site, including its return to the first MSW presentation point. This time depends fundamentally on the timetable and road characteristics [9].

d) *Discharge time at the final disposal site*: This is the time elapsed between the arrival and departure of collection truck at the final disposal site. The estimation of this time is related to the road surface type, ease of vehicle movement, vehicle size, weighing processes, and time required to compact the MSW [9].

e) *Downtime*: This itinerary time considers the trip time from the vehicle garage to the start of collection route. Trip times should also be considered from the final disposition site to the parking site and times inherent to the collection crew such as lunches, fatigues that affect the collection efficiency, dispatch of vehicles, accidents, etc. [9]. Typical values for downtime range from 5-10% in relation to the sum of all previous truck itinerary times [14].

Therefore, the total time of collection itinerary per truck is calculated with the following expression:

$$TI = [n * Cti + (n-1) * Ttp + Ttd + Dtf] * \left[1 + \frac{Dt}{100}\right] \quad (8)$$

Where *TI* is the total time of collection itinerary by truck (hours), *n* is the number of MSW presentation points attended by collection truck; *Cti*, *Ttp*, *Ttd*, and *Dtf* are the times of container taking, transport between MSW presentation points, transport to and from the final disposal site, and discharge at the final disposal site (hours), respectively; and *Dt* is the downtime percentage.

Number of itineraries required per day

The total number of itineraries required to collect the daily MSW generation in a locality is calculated with the following expression:

$$NI = \frac{Dg}{Vc * \rho c} \quad (9)$$

Where *NI* is the total number of itineraries required to collect the total MSW generation in the study locality, *Dg* is the design generation for pre-collection and collection systems (kg/d), and *Vc* and *ρc* are the volumetric capacity of collection truck (m^3) and MSW density inside the collection truck (kg/m^3), respectively.

Number of itineraries per workday

The total number of MSW collection itineraries per workday is calculated with the following expression:

$$NIW = \frac{WD}{TI} \quad (10)$$

Where *NIW* is the total number of itineraries per workday that can make a collection truck, *WD* is the established workday for MSW collection (hours), and *TI* is the total time of collection itinerary by truck (hours).

2.6.5. Total number of collection trucks

The total number of trucks required to collect the MSW in a locality is calculated with the following expression:

$$NT = \frac{NI}{NIW} \quad (11)$$

Where *NT* is the total number of trucks required to collect the total MSW generation in the study locality, *NI* is the number of itineraries required to collect the total MSW generation, and *NIW* is the total number of itineraries per workday that can make a collection truck.

CONCLUSIONS

The design of MSW collection systems using peak-generation coefficients allows considering the temporal variation in quantities collected from waste in a locality. This temporal consideration allows making designs that conform to the maximum rates of MSW generation, in such a way that no day there are MSW outside of the presentation points (containers).

Since MSW collection is not normally done every day, then we propose a daily peak coefficient of heterogeneous distribution in MSW generation (Dpch). This peak coefficient considers the collection frequency and its distribution throughout the week. Dpch increases as the collection frequency of MSW decreases. This increase is because the containers stay longer without being emptied at the MSW presentation points. For a good MSW collection design is not enough with the inclusion of peak generation coefficients. The design should consider political factors such as the reduction in origin, existing legislation, and public attitudes. Geographic factors such as demographic growth and climate should be considered, and lifestyle-related factors such as the development level (gross national income), seasonal variations, and vacation periods also should be considered.

Expressions that include peak-generation coefficients for calculating MSW generation can only be used to design MSW collection systems. These expressions do not represent an estimate of the average daily MSW generation in a locality. To do this, we must use the basic expression that includes only the per capita generation (PCG) and population.

Finally, it is necessary to develop research in developing countries that aim at estimating fundamental parameters to design MSW pre-collection and collection systems. For these designs it is essential to obtain estimates about PCG, physical composition, evolution over time, temporal variation in generation rates (daily, weekly, and monthly), average density within containers and collection trucks, and times of collection itinerary depending on the system used. In this way, it will be possible to develop more reliable designs that are tailored to the reality of developing countries. The methodology proposed here can be used as a guide during the equipment selection to manage the MSW.

ACKNOWLEDGMENT

The authors thank the Environmental Engineering Research Group (GIIAUD) of the Universidad Distrital Francisco José de Caldas (Colombia).

REFERENCES

[1] Botello, J.E., Rivas, P., Fausto, L., Estrada, A., Gomez, R. (2018). Informal collection, recycling and export of valuable waste as transcendent factor in the municipal solid waste management: A Latin-American reality, *Journal of Cleaner Production*, 182(5):485-495.

[2] Ministerio del Medio Ambiente, *Política para la Gestión de Residuos*, Bogotá D.C., Departamento de Planeación Nacional, Colombia, 1998.

[3] Ronen R., Kellerman A., Lapidot, M. (1983). Improvement of a Solid Waste Collection System: The Case of Givatayim, Israel, *Applied Geography*, 3(2):133-144.

[4] Ferrer, J., Gallardo, A., Vidal, M., Belles, M., Ramos, J. *Metodología para la Generación de Alternativas a la Gestión de Residuos Sólidos Urbanos. Aplicación a la Ciudad de Castellón*, Castellón, Fundación Dávalos-Fletcher, 2002.

[5] Hontoria, E., Zamorano, M. (2000). *Fundamento del Manejo de los Residuos Urbanos*, Madrid, Colegio de Ingenieros de Caminos, Canales y Puertos, Colección Senior 24, pp.23-268.

[6] Shuster, K.A., Schur, D.A. *Heuristic Routing for Solid Waste Collection Vehicles*, Washington D.C., Publication SW-113, U.S. EPA, 1974.

[7] Sufian, M., Bala, B. (2007). Modeling of Urban Solid Waste Management System: The Case of Dhaka City, *Waste Management*, 27(7):858-868.

[8] Jaramillo, J. *Gestión Integral de Residuos Sólidos Municipales-GIRSM.*, Medellín, Seminario Internacional: Gestión Integral de Residuos Sólidos y Peligrosos Siglo XXI, 1999.

[9] Ministerio de Vivienda, Ciudad y Territorio, *Resolución 0330 de 2017*, *Reglamento Técnico para el Sector de Agua Potable y Saneamiento Básico*, Colombia, 2017.

[10] Collazos, H. (2005). *Diseño y Operación de Rellenos Sanitarios*, Bogotá D.C., Editorial Escuela Colombiana de Ingeniería, pp.23-49.

[11] American Society for Testing and Materials, *Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste*. *D 5231-92*, Philadelphia, American Book of Standard, 1992.

[12] Cointreau, S., Gunnerson, G., Huls, J., Seldman, N. *Recycling from Municipal Refuse: A State-of-the-Art Review and Annotated Bibliography*, Washington D.C., Integrated Resource Recovery, World Bank, Technical Paper No. 30, United Nations Development Program, 1985.

[13] Grupo de Ingeniería Ambiental UC-GIA, *Diseño de Programas de Gestión de los Residuos Sólidos en Cantabria*, Convenio de colaboración entre la Universidad de Cantabria y la Diputación Regional de Cantabria, Santander, España, 1998.

[14] Tejero, I., Suárez, J., Jacóme, A. Temprano, J. (2001). *Introducción a la Ingeniería Sanitaria y Ambiental*, Santander, Universidad de Cantabria-Universidade da Coruña, España, pp.T4/1-T6/13.

[15] Tchobanoglous, G., Theisen, H., Vigil, S. (1994). *Gestión Integral de Residuos Sólidos*, Madrid, McGraw-Hill, pp.143-278.

[16] Contenur, *Catálogo de Productos: Contenedores*, Madrid, España, 2017.

[17] Pineda, S. (1998). *Manejo y Disposición de Residuos Sólidos Urbanos*, Bogotá D.C., Acodal, pp.55-73.

[18] U.S. EPA. *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 1998*, Washington D.C., EPA 530-F-00-024, 2000.

[19] Industrias Búfalo LTDA. *Catálogo de Productos: Compactadores de Basura*, Bogotá D.C., Colombia, 2017.

[20] Fanalca S.A. *Catálogo de Productos: Cajas Compactadoras,* Cali, División Ambiental, Colombia, 2017.