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Surface Methane Emission in a Former Dumpsite in Tijuana, Mexico

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ABSTRACT: Dumpsites can produce serious pollution problems in soil, water and air, and are the most frequent method of solid waste disposal in many developing countries. One of the pollution concerns at dumpsites is the emission of methane, which has been identified as a green house gas. In order to determine the surface emission of methane at an informal settlement built on a former dumpsite, six sampling events were conducted using the enclosed chamber method. The results showed that the surface emission of methane in the study area is high, with a maximum mean value of 2441.8 $g/m^2/h$; this surface emission is between one to four orders of magnitude higher than the maximum values found in other published studies. The total mass of methane emitted at the site is also two orders of magnitude higher compared to studies within a similar area. But it is 177 and 3.5 times lower than in other studies conducted in South Korea and India, respectively. High variation in the surface emission of methane may be a result of the changing conditions in this urban environment.

Key words: Dumpsite, Landfill, Surface emission, Methane, Irregular settlements,Tijuana

INTRODUCTION

In many developing countries municipal solid waste is usually disposed of in dumpsites or non-regulated landfills which lack facilities to collect the leachate and the gas which is generated (Abduli *et al.,* 2007; Nasrabadi *et al.,* 2008). The municipal solid waste disposed of in landfills produces methane and carbon dioxide (60%/40%), as well as traces of organic compounds, due to the anaerobic degradation of organic matter in the refuse (Christophersen and Kjeldsen, 2001). Methanogenesis can occur when the pH of the organic portion of the municipal solid waste is between 6.8 and 7.4, and is enhanced mainly by the moisture content (Gurijala *et al.,* 1997). The presence of water (40% or more) increases gas generation due mainly to an increase in bacterial growth. Landfill gas generation is dependent on the time at which the waste is buried or dumped; research by several authors indicates that major gas generation takes place between 5 and 7 years after waste is buried, and decreases only slowly in periods spanning more than 50 years (U.S. EPA, 1993). In addition to moisture and pH, landfill gas generation is also influenced by other environmental variables such as temperature, nutrients, barometric pressure, as well as the characteristics of the waste (age and composition).

Temperature also has a great impact on landfill methane generation because it directly affects bacterial activity. Gas generation decreases at temperatures lower than 10^{o}C, although a covered landfill maintains a stable temperature because of heat-generating bacterial activity. The temperature in a landfill can be between 25 and 45 ^{o}C (ASTDR, 2001).

Landfills are considered one of the main anthropogenic sources of greenhouse gases. According to some estimation the total emission of methane in the world is 600 Tg/year and landfills contribute with 40 Tg/year (Lelieveld *et al.,* 1998). Other estimations calculated methane emissions between 19 and 40 Tg/year (Bogner and Matthews, 2003). Methane can hold infrared radiation 20 times better than carbon dioxide (Abichou *et al.,* 2006). Moreover, methane at concentrations of 5 to 15% is explosive, but given that oxygen concentrations are usually low inside landfills and dumpsites, the risk of explosion is low. However, a mixture of methane in the explosive range can be formed if the landfill gas migrates outside of the landfill (Tchobanoglous *et al.,* 1993).

A review of fieldwork studies done worldwide, using mainly the chamber technique, indicates that the range of methane emissions from landfills is six fold in magnitude ranging from 0,003 to 3000 g/m^2 day (Bogner and Scott, 1995).

The emission and migration of landfill gas can have negative impacts on the surroundings of the landfills such as explosion and fire hazard, health risk,

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damage to vegetation, undesirable odors, groundwater pollution and global climate effects (Kjeldsen, 1996). Several factors influence the migration process of landfill gas. These processes are diffusion, advection, dilution, distribution of the gas in water, sorption in soil particles and methane oxidation (Kjeldsen, 1996). Other factors are meteorological conditions (atmospheric pressure, rainfall, temperature and wind); soil conditions (fissures, permeability, porosity, diffusivity, water and organic matter contents), landfill conditions and the type of waste confined (Kjeldsen, 1996).

The city of Tijuana is located in the northwest part of Mexico (Fig. 1) and has a Mediterranean-type climate with average temperatures between 18 and 22.4^{O}C. The main rainy season is between November and April when 91% of the annual precipitation occurs and the average annual precipitation is 268 mm (CNA, 2008).

The study site is located in the southwest part of the city of Tijuana, inside an area that was classified by the municipality as a “high risk zone” (PDUCPT, 2002) and includes steep slope areas and a former dumpsite. This study site is located in a canyon which was filled with municipal solid waste, and then covered with a layer of soil, however, soon afterwards, the site became an irregular settlement. The area of the former dumpsite is approximately 25,700 m^2 and the depth of the buried solid waste varies from 10 to 20 meters (Fig. 2). The soil texture of the study area is predominantly sandy loam with a sand content ranging from 64.2 to 93.5% and clay from 0.2 to 17.8%.

In many developing countries, authorities have found that the removal of informal settlements, such as the one at this study site, is politically difficult when these shanty towns become “consolidated” and particularly since the government has failed to offer other feasible alternatives (Ferguson, 1996). The study site began a “consolidation” process, meaning that the settlers constructed more permanent structures instead of previous temporary dwellings made with recycled materials such as plastic or wood. The leaders of the squatters also negotiate and lobby politicians and city managers to obtain improvements from the government such as electricity, piped water, sewerage and paved roads. These improvements lead to the settlements becoming more permanent.

Urban conditions in this type of settlement are characterized by frequent changes, leading to sampling conditions that can produce highly variable results; these conditions include changes in surface cover in the settlement due to the construction of paved roads;

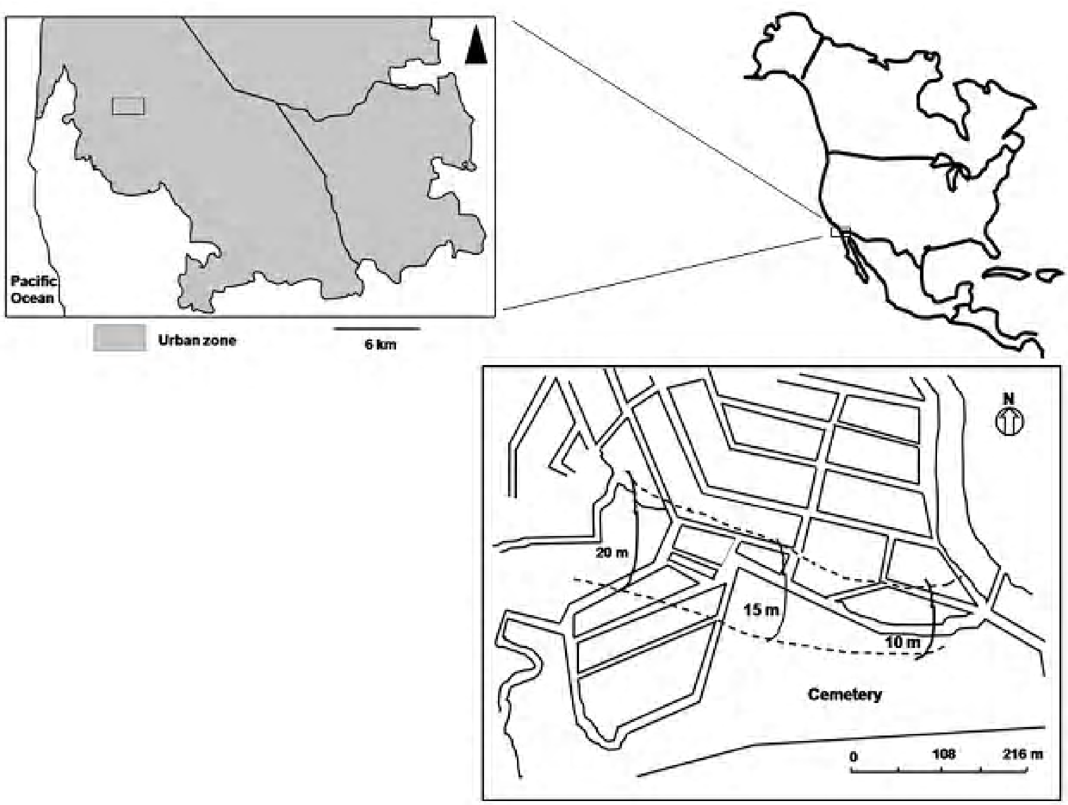

Fig. 1. Location of the study site showing the approximate waste depth and the former area of the canyon

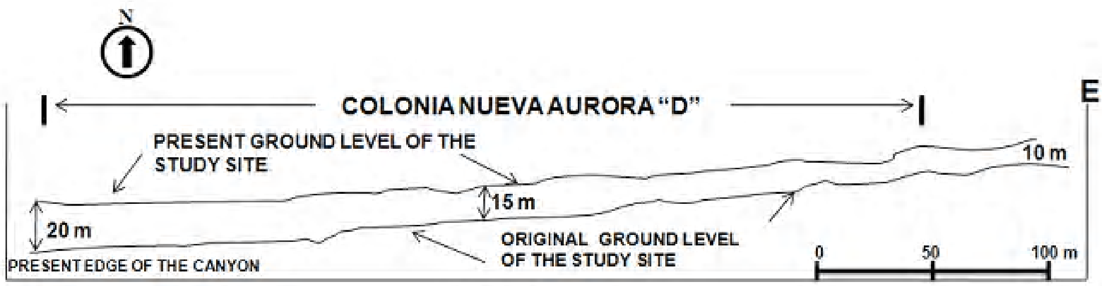

Fig. 2. Longitudinal view showing the waste depth profile of the site (modified from Mendoza Garcilazo *et al.*, 2004)

an increase of impermeable area in the dwellings; different soil permeability produced by soil compaction; different soil cover thicknesses due to the periodical addition of soil in streets and patios; and different percolation of water in the dumpsite due to the provision of sewerage or use of septic tanks or latrines in the settlement.

Table 1 shows the average percentages of the different components of the municipal solid waste for Tijuana, Mexico and other countries. The percentage of processed material in developed countries is higher than that observed in developing countries, with developed countries having a lower proportion of organic waste than developing countries.The percentage of organic waste in the municipal solid waste in India and Mexico is between 40-60%. For example, Table 1 shows that the percentage of organic waste in the US is two times lower than the amount generated in Mexico.

The main objective of the present study was to quantify the surface emission of methane at an informal settlement built on a former dumpsite in the city of Tijuana, Mexico. The surface emission of methane data may help to assess the hazard and health risk of this emission on the inhabitants of this area. This information may be a tool for decision makers to implement remediation measures.

MATERIALS & METHODS

Six sampling events were conducted during February 2006 and June 2007. In each sampling event eight sites were sampled using the enclosed chamber method. Polyethylene containers (35 cm in diameter and 60 cm in length) equipped with an internal fan were placed approximately 10 cm deep. The fan was then turned on and the sample was taken after a five minute period to ensure mixing of gases in the interior of the container. Sampling was conducted using a pump fixed at a flow of 1 L/min and the sample was collected in a 1 L Tedlar bag. After two hours the procedure was repeated to collect the second sample. The samples were protected from sunlight until the analysis was conducted in the following 24 hrs. Table 2 shows the meteorological conditions during the sampling events as well as the methane emission ranges and total mass of methane.The samples were analyzed by gas chromatography with a flame ionization detector. The chromatograph used was a HP 6890 with a split injection port, an HP 5MS column (5% Phenyl Methyl Siloxane), 60 m x 0.32 mm (internal diameter) x 1 µm (stationary phase). The furnace temperature program selected was: 35°C during 3 min with increments of 5°C/min to reach the temperature of 80°C. The calculation for surface methane emissions was carried out using the following equation (Hedge *et al.*, 2003):

$$f = \frac{V\Delta C}{A\Delta t}$$

Table 1. Composition of municipal solid waste in Tijuana and other countries

Subproducto	E.U.A[1]	India[2]	Taiwán[3]	México[4]	Tijuana[5]
Paper and cardbox(%)	36	9.05	30	14	20
Plastics (%)	10	7.23	20	6	13
Metals (%)	8	-	4	3	4
Textiles (%)	-	-	5	1	-
Glass (%)	6	0.53	6	7	5
Organic waste (%)	25	46.37	27	42	45
Other-Inerts (%)	10	32.20	8	27	13

[1]Savage and Eggerth, 1999; [2] Kumar *et al.*, 2004; [3]Hegde *et al.*, 2003; [4]SEISA, 2005; [5]DOSPMT, 1996

Table 2. Average methane surface emission flow and the meteorological data during the sampling events

Sampling date	Temp. range ^{o}C	% Relative humidity range	Pressure at sea level range HPa	Emission range $g/m^2/h$	Average surface emission $g/m^2/h$
01/18/06	14.4-16.1	27-52	1023.0-1022.5	0.00 - 11.25	2.81
08/09/06	23.3-26.7	68-58	1013.2-1012.5	0.05 - 1.70	0.39
10/16/06	16.7-18.9	78-59	1010.6-1010.4	2.28 - 4127.55	920.61
03/08/07	15.6-21.7	64-32	1019.2-1018.5	25.12 -16107.72	2441.81
04/30/07	15.6-18.9	80-68	1016.0-1015.4	0.00 - 1.39	0.17
06/21/07	17.8-22.2	80-61	1016.1-1015.8	4.33 - 4030.31	56.02

where f is the emission rate of methane in mg/m^2 h, V the chamber volume of the soil (m^3), A the area of the chamber in m^2 and t the time, ΔC is the difference between the initial and final concentration, mg/m^3 and Δt is the time between the samplings.

RESULTS & DISCUSSION

The surface emission of methane varied in the sampling period from 0 to 16,107.72 $g/m^2/h$ (Table 2). The highest average methane surface emission (2441.81 $g/m^2/h$) was obtained on the March 8th, 2007 sampling, and the lowest on the April 30th sampling (0.174 $g/m^2/h$) of the same year (Table 2). The samplings were conducted during different periods of the year (one in spring, two in summer, one in autumn and two in winter). There is one order of magnitude variation between the summer (0.39 to 560.15 $g/m^2/h$) and winter samplings (2.81 to 2441.81 $g/m^2/h$). A probable cause for these variations in surface emission of methane is the presence of fissures in the terrain (the authors observed the presence of fissures in the study area, and in other non-sampled areas), or zones with different soil permeability produced by compaction due to public works to provide sewerage and piped water to the area. In addition to fissures, residents of the zone are aware of the methane emission and have installed pipes to try to induce preferential methane flow to the atmosphere.

Another possible factor may be the infiltration of water to the buried waste due to the perennial runoff of wastewater from the streets and septic tanks utilized at the study site. A general practice of the inhabitants was to discharge grey water to the streets; this practice was gradually changed because of the introduction of sewerage during 2006, after which only small streams of wastewater remained in secondary streets.The percentage of moisture is important in the generation of landfill gas. Forty percent of moisture or higher increases the generation of landfill gas due to an increase in bacterial growth. Water acts to transport nutrients to the buried waste (U.S. EPA, 1993) and wastewater has a high nitrogen and phosphorus content.

Another factor that can influence the variability of methane surface emissions may be the age of the waste buried at the site. The solid waste buried at this site was deposited from east to west, therefore the solid waste buried on the west side is more recent (the waste on the west side was buried five to eight years later than that buried on the east side) (Velazquez personal communication). Generally, the highest methane emission flows were measured in the sampling points located in the west part of the study site (Fig. 3). All of the factors mentioned previously could have affected the sampling results, so that at the same sampling points, the surface emissions values have a high variability (non-detected to 325.46 $mg/m^2/h$) in a period of two months.

Table 3 shows the comparison of the surface emission of methane and the total methane mass emitted in different studies. The results show that the mean surface emission of methane in Tijuana is higher than in other studies conducted in Taiwan and India, but is lower than the surface emission measured by Hedge *et al.,* (2003) in a landfill in South Korea. However, because the total area of the study site is less than the other studies, the total mass of methane of the surface emission in this study is 177 and 3.5 times lower than that measured in the South Korea and India studies, respectively. However, the total mass of methane in the study area is approximately 300 times higher than the studies conducted in Japan and Taiwan (Table 3). Other factors in the difference of surface emissions may be the time of the site closedown; the percentage of organic waste and the control facilities for gas emission. The difference of surface emission concentrations between this study and the Indian study may be the time of closedown: whereas in this study the site has been closed for approximately 18 years, the landfills monitored in India are still in operation, and it is estimated that landfill gas emissions reach their maximum approximately seven years after closedown of the landfill (Crawford and Smith 1985). The organic waste content could be the main reason for the difference in the results of surface emission of methane in the case of the Taiwan study. The percentage of solid waste in Tijuana is almost double that in Taiwan. The percentage of organic waste in the

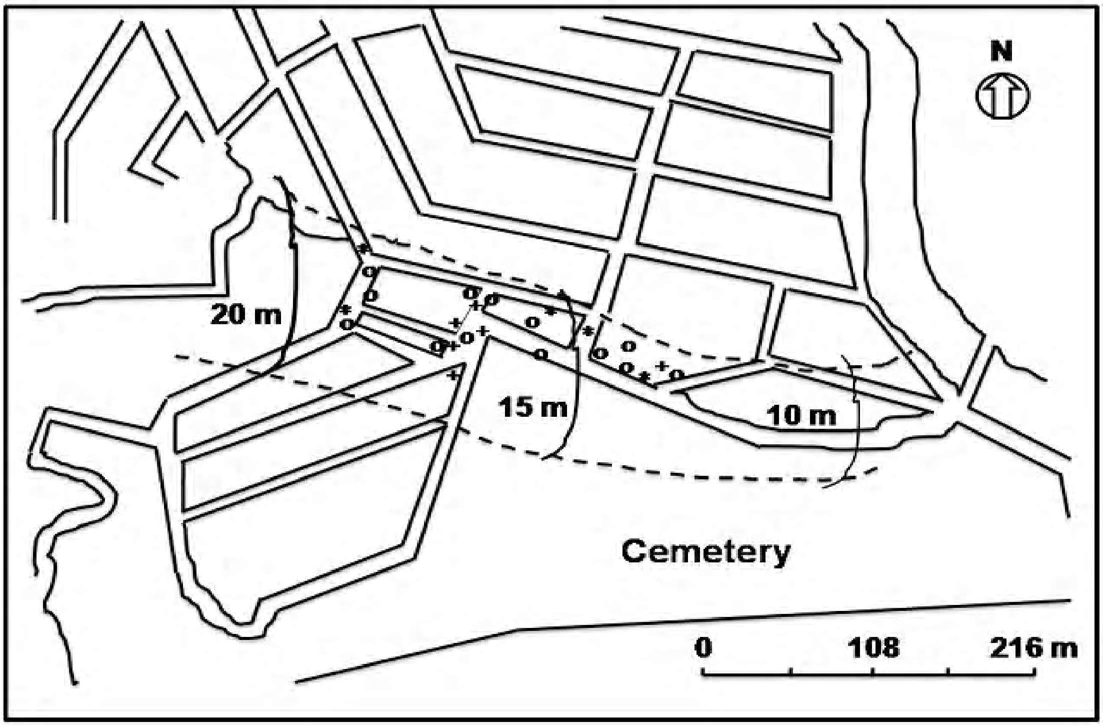

Fig. 3. Location of sampling points showing the surface emission range of methane (* = 0- 10^3 mg/m^2/h; o = 10^3 – 10^6 mg/m^2/h; + > 10^6 mg/m^2/h)

Table 3. Comparison of flow and total mass of the methane surface emission from different studies

Site	Time of closedown (years)	Methane emmision range g/m^2 h	Mean surface emission g/m^2 h	Area m^2	Tg/y
Taiwan[1]	1 - 5	1x10^{-4} - 0.16	0.06	300000	1.6x10^{-4}
India[2]	In operation	0.15 - 0.45	0.27	87500000	0.21
South Korea[3]	6	10.65 - 578.01	295.69	4088832	10.60
Japan[4]	5	1.7x10^{-4} - 16.00	0.57	37000	1.9x10^{-4}
Tijuana[5]	18	0.0 - 9812.80	269.03	25000	0.060

[1] Hegde *et al.,* (2003); [3]Rawat *et al.,* (2008); [3]Park and Shin, (2001), [4]Ishigaki *et al.,* (2005). [5] This study;

waste buried at the study site may be higher since most of the recyclable materials (metals, plastic and cardboard) would have been recovered by garbage dump scavengers before the solid waste was dumped at the site. The study site at the former dumpsite does not have any equipment to extract the landfill gas that the site in Taiwan probably has, which may also lead to high concentrations of methane at the study site.

CONCLUSION

The results have shown that methane is emitted from this former dumpsite and that this emission is high with a maximum average value of 2441.81 g m^{-2} h^{-1}; this surface emission is four orders of magnitude higher than in other studies. However, the total mass of methane emitted is 177 and 3.5 times lower than in other studies conducted in South Korea and India, respectively, and approximately 300 times higher than studies conducted in Taiwan and Japan.

A high variability in the measured emissions of methane was observed; this variability may be the result of continuous changes in soil conditions due mainly to the urban and social characteristics of the study site.

The results presented in this paper will be helpful in evaluating the health risks for the inhabitants of this area and may provide a decision tool for implementing restoration measures to improve the environmental conditions of the site and achieve a better quality of life for its inhabitants.

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REFERENCES

Abduli, M. A., Nabi Bidhendi, G. R., Nasrabadi, T. and Hoveidi, H. (2007). Municipal Solid Waste Management on the South Coastline of the Caspian Sea (Golestan, Mazandaran, and Guilan Provinces of Iran), Journal of Environmental Health, **70 (5)**, 34-37

Abichou, T., Chanton, J., Powelson, D., Figler, J., Escoriaza, S. and Stern, J. (2006). Characterization of Methane Flux and Oxidation at a Solid Waste Landfill. J. Environ. Eng., **132 (2)**, 220-228.

ASTDR, (2001). Landfill gas an overview for environmental health professionals. Retreived April 5, 2010, from http://www.atsdr.cdc.gov/HAC/landfill/PDFs/Landfill_2001_ch2mod.pdf

Bogner, J. and Matthews, E. (2003). Global methane emissions from landfills: new methodology and annual estimates 1980–1996. Glob. Biogeochem. Cycles, **17 (2)**, 341-347.

Bogner, J., and Scott, P. (1995). Landfill CH_4- emissions: guidances for field measurements, International Energy Agency (IEA). Expert working group on landfill gas, preprint, 20 pp.

Christophersen, M. and Kjeldsen, P. (2001). Lateral gas transport in soil adjacent to an old landfill: Factors governing gas migration, Waste Manage. Res., v.19, pp. 579-594.

CNA , (2008). Comisión Nacional del Agua, Datos inéditos de precipitación pluvial de la presa Abelardo L. Rodríguez (unpublished data of annual rainfall of the Abelardo L. Rodríguez Dam). CNA, Tijuana. México.

Crawford, J. F. and Smith, P. G. (1985). Landfill technology. (London:Butterworths).

DOSPM, (1996). Departamento de obras y servicios pulblicos del municipio de Tijuana, Estudio de caracterización de la basura del relleno sanitario. Tijuana. (Characterization study of the garbage in the landfill, Tijuana). DOSPM, Tijuana, Mexico.

Ferguson, B. (1996). The environmental impacts and public costs of unguided settlement; the case of Montego Bay, Environ. urban, **8 (2)**, 171-193.

Gurijala, K. R., Sa, P. and Robinson, J. A. (1997). Statistical modeling of methane production from landfill samples. Appl. Environ. Microbiol., **63 (10)**, 3797-3803.

Hegde, U., Chang, T. and Yang, S., (2003). Methane and carbon dioxide emissions from Shan Chu Ku landfill site in northern Taiwan. Chemosphere, **52**, 1275-1285.

Ishigaki, T., Yamada, M., Nagamori, M., Ono, Y. and Inoue, Y. (2005). Estimation of methane emission from whole waste landfill site using correlation between flux and ground temperature. Environ. Geol., **48**, 845-853.

Kjeldsen, P. (1996). Landfill gas migration in soil (in T.H. Cristensen, R. Cossu, and R. Stegmann,(Eds). Landfilling of waste: biogas (pp. 87-132). London: E and FN spon)

Kumar, S., Gaikwad, S. A., Shekdar, A. V., Kshirsagar, P. S. and Singh, R. N. (2004) Estimation method for national methane emission from solid waste landfills. Atmos. Environ., **38**, 3481-3487.

Lelieveld, J., Crutzen, P. and Dentener, F. (1998). Changing concentration, lifetime and climate forcing of atmospheric methane. Tellus, Series B: Chem. and Phys. Meteorol., **50**, 128-150.

Mendoza Garcilazo, L. H., Vázquez Hernández, S., Rocha Guerrero, E. and Reyes Serrano, R. (2004). Actualización de los límites de las zonas de riesgo asociadas a los depósitos de residuos ubicados en terrenos de las Colonias Nueva Aurora "B", Nueva Aurora "D", Fausto González y Cañón de las Carretas (Updating of the limits of the risk zones associated to the waste deposits located in the Colonias Nueva Aurora "B", Nueva Aurora "D", Fausto González y Cañón de las Carretas). Tecnical report PA: 17682. CICESE - Implan pp. 1-52.

Nasrabadi, T., Nabi Bidhendi, G. R., Yavari, A. R. and Mohammadnejad, S. (2008). Evaluating Citizen Attitudes and Participation in Solid Waste Management in Tehran, Iran, Journal of Environmental Health, **71 (5)**, 30-33.

PDCUCPT, (2002). Programa de desarrollo urbano del centro de población de Tijuana, B.C. (Program of urban development of Tijuana, B.C.). Periódico Oficial del Estado de Baja California, Mexicali, Baja California.

Park, J. W. and Shin, H. C. (2001) Surface emission of landfill gas from solid waste landfill, Atmos. Environ., **35**, 3445-3451.

Rawat, M., Singh, M. K ., Mishra, A. K. and Subramanian, V. (2007). Methane emission and heavy metals quantification from selected landfill areas in India. Environ. Monit. Assess., **137**, 67-74.

Savage, G. M. and Eggerth, L. L. (1999) Status of the solid waste management in the United States. Seminario internacional de gestion de residuos solidos y peligrosos, siglo XXI, Medellin Colombia, Noviembre 9, 1999, retrieved March 29, 2009 from http://www.bvsde.paho.org/bvsacd/acodal/i.pdf

SEISA, (2005). Aprovechamiento de los desechos sólidos para la generación de energía eléctrica. Competitividad, ahorro y energía limpia para la frontera.

Tchobanoglous, G., Theisen, H. and Vigil, S. (1993). Integrated solid waste management. Engineering principles and management issues. (New York: McGraw-Hill).

U.S.EPA, (United States Environmental Protection Agency) (1993). Solid waste disposal facility criteria—technical manual. EPA 530-R-93-017. November 1993.