CARBON FLOW IN A SANITARY LANDFILL IN MALAYSIA

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EXECUTIVE SUMMARY

Jeram Sanitary Landfill (JSL) received 766,500 tonnes of municipal solid waste in 2010, from Kuala Lumpur and Selangor Municipality. Domestic waste, bulky waste, garden waste and domestic sewage sludge are generic classification of waste landfilled in JSL. Waste biomass, in JSL for example, paper, food and garden waste, wood and textiles, constitute 62 % of the MSW. We have attempted to quantify the C flow in a dynamic system i.e sanitary landfill in Malaysia via waste input- output analysis, C element flow and the total Substance Flow Analysis (SFA) of C. Mass balance of C was attempted using STAN software. In one-year of landfilling, 29% of the input of the organic C left the landfill via landfill gas pathway, while, less than 1% escaped via leachate pathway. In the same year, more than 70% of the organic C was still in the landfill as sink. Some biomass materials do not fully decompose and the C compound sequestered inside the landfill body and is not released into the atmosphere.

INTRODUCTION

Material Flow Analysis (MFA) or Substance Flow Analysis (SFA) was originally developed back in the 1950's (Baccini and Brunner 1991) and elemental analysis of specific interest were studied in various aspects using MFA as a tool. The carbon flow was studied possibly because it is associated with global warming. Organic C is the main component of biogenous goods, a main carrier of chemical energy and a basic element of toxic substances (CO and CN). It is both a vital substance for growth, as well as, energy via conversion by microorganisms, and in different compounds. Carbon is an essential element of the biosphere and is found in all living things.

Typical refuse contains, (by weight) 25.2 % water, 25.5% C, 3.4% H, 20.3% O; 0.5% N; 0.2% S; 0.5% Cl and 24.4% other inorganics (Senior and Balba 1987). C flow has been determined for various scenarios. However, most estimations were for static systems. This study is an attempt to elucidate the C flow in a dynamic system such as landfill. Hence, the aim of this study is to establish the inter-relationship of C cycle within MFA framework in a sanitary landfill. Previous studies on C flow from temperate countries are available from developed country such as Austria and Japan. Study of MFA is rare in a transitory country especially on C flow in landfill. This paper quantified C flows in sanitary landfill system in Malaysia via waste input-output analysis, mass balancing of C flow, C element flow in temporal and spatial system boundary and the total Substance Flow Analysis (SFA) of C.

METHODOLOGY

Field site and system boundaries

Field study was carried out from January 2010 until December 2010 at Jeram Sanitary Landfill (JSL). A material balance was prepared for the period of 2010. The system boundaries does not include the collection and transportation of waste to and from landfill. Waste segregation and waste sampling was done to determine quantity and quality of waste composition deposited at the landfill sites. Elemental analysis was for Total Organic Carbon (APHA 5310 B) and Inorganic Carbon (ASTM E 949).

Mass Balance

Material flow analysis (MFA) and substance flow analysis (SFA) were performed by means of the mass-balance model STAN which performs MFA according to the Austrian standard ÖNorm 2096 S (MFA – Application in Waste Management) (Cencic and Rechberger, 2008) . In STAN, the waste system or any other system of interest can be built and graphically displayed as Sankey diagrams by adding known mass flows, concentrations and transfer coefficients. Simulations were performed by STAN to reconcile uncertain data and/or to compute parameters (e.g by Monte Carlo Simulations). SFA was performed for C. The uncertainty of concentrations in the waste input was calculated based on data from Boldrin (2009) (as percentage of dry matter in the input mass); C = ±2.0 % unless stated otherwise. The initial uncertainties of concentrations in the outputs were assumed to be 10% for C (Andersen *et al* 2010). The loss of materials and compounds to the atmosphere during the landfilling process was estimated by STAN for C.

RESULTS AND DISCUSSION

Composition of biomass in Jeram MSW

Waste biomass materials, i.e. paper, food and garden waste, wood and textiles, constitute 62 % of the MSW (Table 1). The rest were inorganic materials such as metals, glass, gypsum/asbestos from construction and demolition industry and other minerals. The result shows that the largest portion of the waste disposed in JSL was organic waste, particularly kitchen waste (32%). This is typically similar to other developing countries, as accounted by World Bank (1999). High organic content also indicates that sanitary landfills are conducive for anaerobic decomposition and economic recovery of methane gas. Also sanitary waste (disposable diapers etc) deposited at JSL could possibly be current disposal trend by societies in most developed countries.

Mass Balance and Element Flow

The C cycle need to be framed-out and familiarized to achieve the purpose of cosntructing material balance of large spatial system such as a typical landfill. The system boundary of the studied system is shown in Figure 1 which shows Mass Flow Analysis (in tonne/year) of Jeram Sanitary Landfill in 2010. This system analysis consists of landfill surface, landfill body, landfill gas collection and leachate treatment including the actual landfilling process. The system does not include the collection and transportation of waste to landfill.

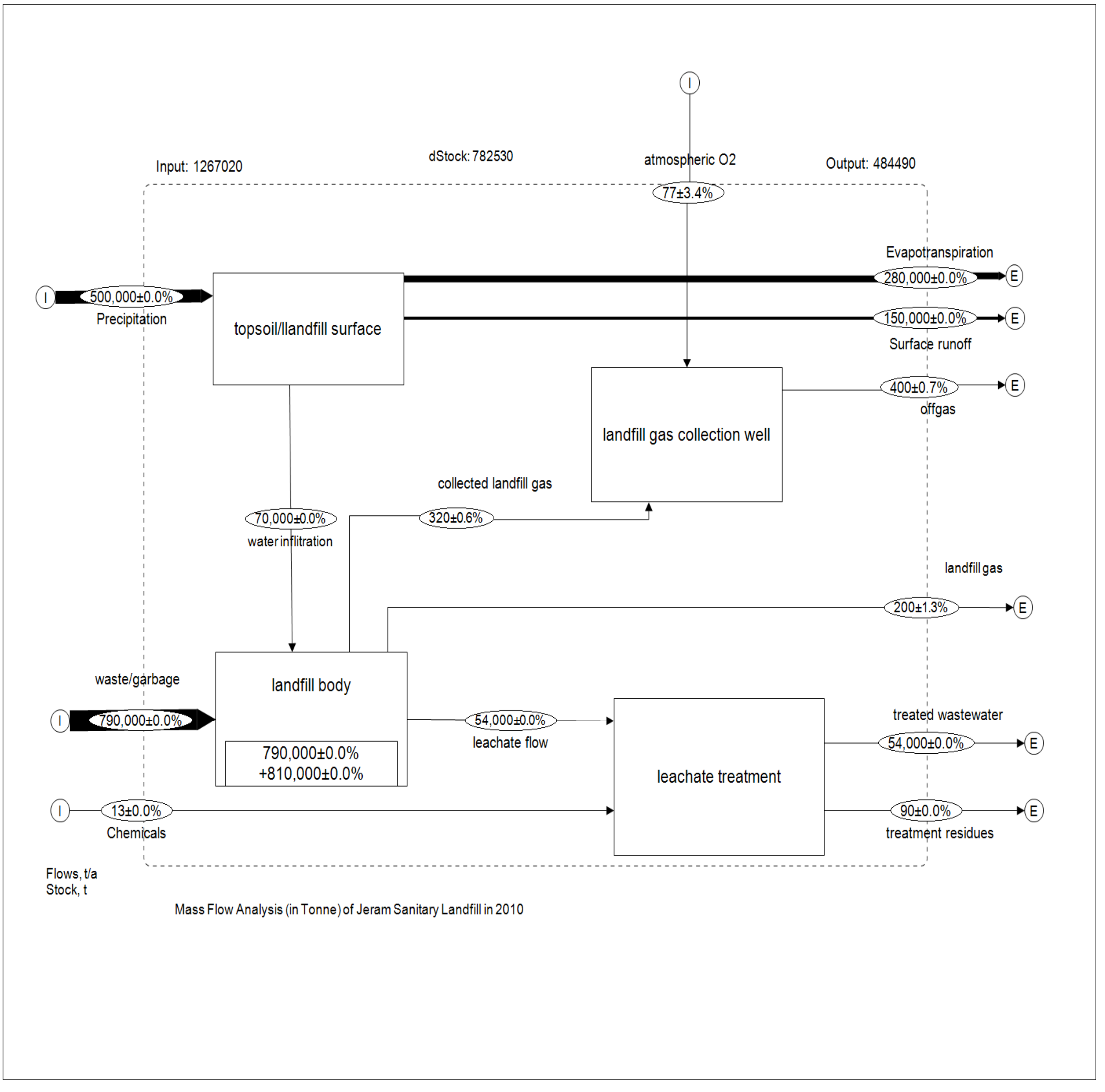

Figure 1 : Mass Flow (in tonne/year) of Jeram Sanitary Landfill in 2010 (System model modified from Spaun, 1995)

The JSL has a flat topography and tropical climate, resulting in high amount of precipitation with a maximum 3000 mm per year and ambient temperature between 37^o C and 40^o C which made the JSL landfill hot and humid. Despite heavy seasonal rainfall volume, the evapotranspiration rate was high with average air humidity above 80% (Manaf *et al* 2009). Rainwater in JSL was acidic with pH value ranging from 4.48 to 6.82. The quantity of leachate generated depends principally on rainfall and the state of the landfill. Currently, an average of 150 m^3 of leachate per day goes to sequential batch reactor facility.
The considerably young, 4-year old JSL site with topsoil depth between 150 to 300 mm as daily cover, allow the rain to percolate vertically and collect as leachate (> 14 %) with some loss in evapotranspiration (> 56 %) or surface runoff (> 30%) (Figure 1) based on water balance component principles (Agamuthu *et.al.* , 2010). Currently, an average of 150 m^3 of leachate per day goes to leachate treatment and during rainy season, the volume increased to 210 m^3 per day. Figure 3 shows the basic material flow schematics of JSL, involving inputs such as precipitations and solid waste and outputs leachate generation and evapotranspirations. The quantification of inputs and outputs in a dynamic system such as landfill are in balance state considering the substance stock in landfill body, substance emissions and the substance concentration. This is shown in Figure 1 where input was quantified at 1,267,020 tonnes while the change in landfill stock was at 782,530 tonnes.

There are potentially large losses of C via landfill gas from landfill body. Most waste were not found in its natural pure compound state. Some waste have other additives added to suite the product need, as to either be attractive or be more durable. Alumnium can and aerosol cointeners, for instance have labels to differentiate products. The label quantifies the carbon value in alumnium tins as shown in Table 1. The highest organic C was found in rubber mat. However, this product is not common in JSL. The high organic C quantified and yet common in JSL is garden waste and plastic containers with percentage at 2.12 and 1.24, respectively. These products, which constitutes a signifcant input of organic C holds as main contributor to GHGs. This is due to its biodegradability and ability to be easily degraded by other existing compounds found in waste. These products of high C value should be seen as the main culprit in generating methane (Göran *et. al.* 2000).

Substance Flow Analysis

Table 1: C in domestic waste, bulky waste and garden waste in JSL.

Sample marking	TOC (%)	Inorganic -C (%)	Sample marking	TOC (%)	Inorganic -C (%)
Electronics	0.15	0.06	Rubber mat	3.15	ND(<0.05%)
Wood	0.27-0.71	ND(<0.05%)	Plastic Container	1.24	ND(<0.05%)
Aerosol Container	0.08	ND(<0.05%)	Shoe	0.78	ND(<0.05%)
Hard paper	0.22	ND(<0.05%)	Rubber hose	0.56	ND(<0.05%)

Alumnium Can	0.10	ND(<0.05%)	Tin/Alloy	0.07-0.09	ND(<0.05%)
Steel	0.16	ND(<0.05%)	AA Battery	0.95	ND(<0.05%)
Polystyrene	ND(<0.05%)	ND(<0.05%)	Wire	ND(<0.05 %)	0.25
Coloured paper	ND(<0.05%)	ND(<0.05%)	Packaging paper	ND(<0.05 %)	ND(<0.05%)
Garden waste	2.12	ND(<0.05%)	Mineral Bottle	ND(<0.05 %)	ND(<0.05%)
Kitchen waste	0.80	0.07	Plastic	ND(<0.05 %)	ND(<0.05%)
Tiles	0.04	0.12	Cloth	ND(<0.05 %)	ND(<0.05%)
Foam (superlon)	0.15	ND(<0.05%)			

Carbon flow

Mass-balance from field studies have indicated that only 1 % (by weight) of the organic C will outflow via leachate, mainly as fatty acids and 99 % via the landfill gas as CH_4 and CO_2 (Baccini *et al* 1987). The organic C concentration inside JSL pond leachate was less than 10% which represents the overall outflow from JSL as only 1%. The ratio of BOD/COD varies during the lifetime of the landfill. The BOD_5 during leachate sampling ranged from 1290 to 2270, while COD was between 3200 to 65400. The analysis show that leachate collected from compactor valve has high BOD and COD compared to those taken from leachate lagoon. Data show high leachate concentrations of all components in the early acid phase due to strong decomposition and leaching. The results of BOD and COD were higher in leachate from the compactors due to the chemical characteristics and nature of leachate relating to factor such as climatic condition or dilution factor due to high rainfall.
The landfill gas contains mainly CH_4 and CO_2 . Other gases are CO, H_2S and O_2. Different organic materials gave different ratios between CH_4 and CO_2. The collection yields have often been very low in JSL and gas flow rate fluctuates over time. The quantity and quality of methane gas are recorded for future electric generation.The non-recovered gas will migrate through the topsoil cover, and methane-oxidising micro-organisms will oxidise a part of the methane to carbon dioxide. *Ex-situ* analysis of topsoil taken from landfill new cell indicated total organic carbon (TOC) was 36% (w/w) while inorganic carbon were less than 0.01% (w/w). The question appears how a higher material output is possible with a lower discharge. The answer lays in the inhomogeneity of the deposited MSW and possible inhomegenous water flow characteristics (Huber, *et. al.,* 2004). Increasing the amount of water flowing through the landfill body for example via rainfall percolation does not necessarily increase the substance output.
Figure 2 shows the SFA for MSW for C in JSL for 2010. The GHG emission from landfilling was estimated, with respect to C : CH_4-C : 50.7±13.5 %, CO_2-C : 35.6±9.6% and CO-C : 4.4± 2.1%. Low uncertainty of C in the atmosphere (Figure 2) indirectly show there are adequate gas venting system on-site to minimize emissions of C to atmosphere. Also uncertainties in the SFAs were quite low for all compound except for C in aluminium, for which the uncertainty was high (129.1%). For some

material its potential for degradation is not clear. For instance, plastic and aluminium, it is uncertain how and when they can be degraded after being landfilled. Biogenic carbon compound for example garden waste and plastic, contain high calorific value, may be economical for energy-harvesting (except for kitchen waste and food waste with significantly high water content). With regards to sustainable waste management, these waste material are suitable for incineration or high-temperature combustion rather than landfilling.

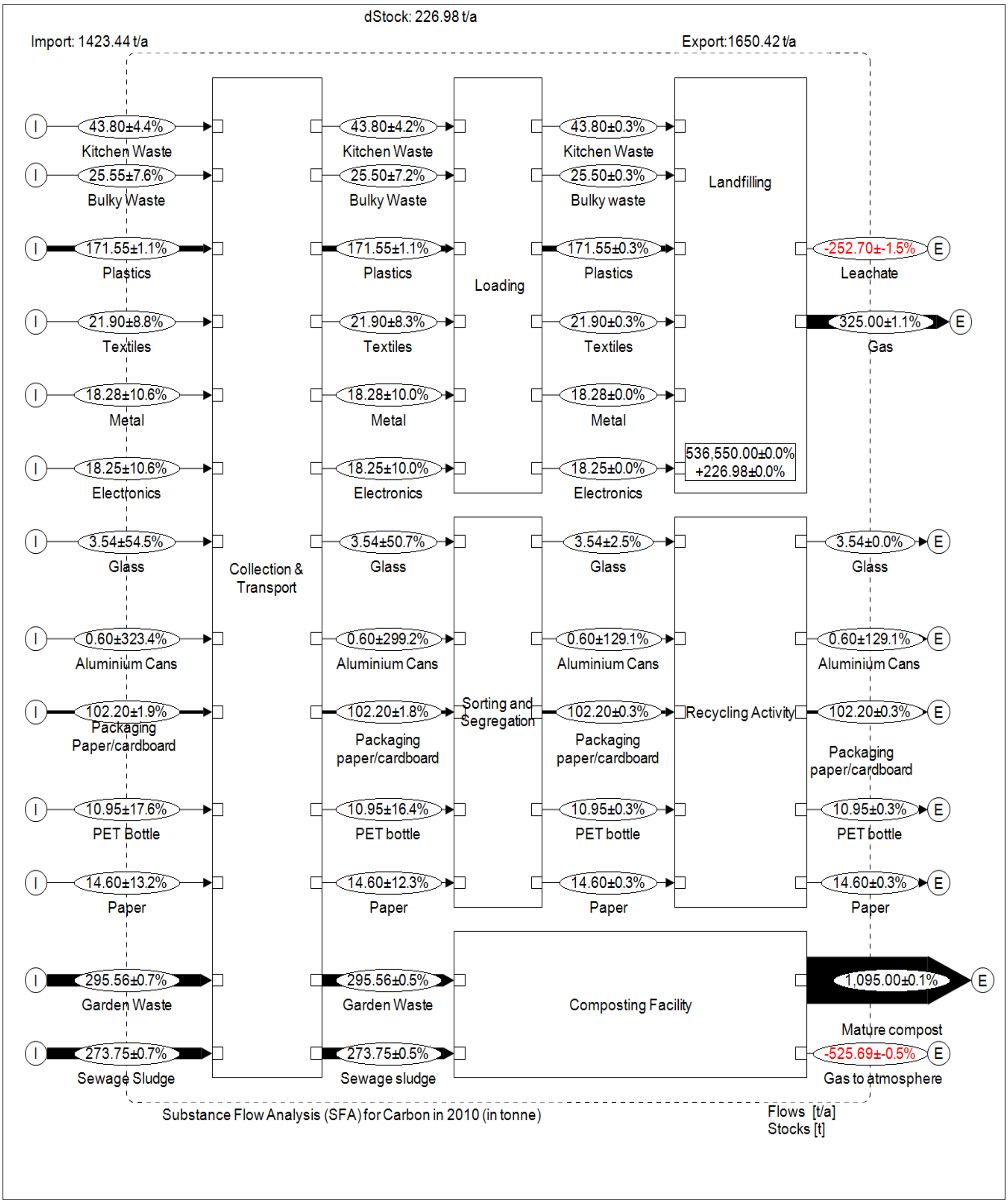

Figure 2 : Substance Flow Analysis for C in JSL, 2010 (tonnes)

SFA study by Huber *et al* (2004) showed 85% C_{org} available was still inside landfill body after 15-years of landfilling. Substance balance results from 4-year old sanitary landfill showed that in one-year of landfilling, 29% of the input of the C_{org} left the landfill via gas pathway and less than 1% via leachate pathway, while 70% of C remained in the landfill body. The landfill age could play an important role to eventually quantify substance/material balance in a sanitary landfill.

CONCLUSION

This study quantified the C flow in JSL system. The main results are:
Kitchen waste and garden waste contribute significantly to the mass flow in landfill. During refuse degradation stage, C is dominantly exported in landfill gas and leachate form. The sampling by waste composition did give a good understanding of the physical and chemical properties. Material flow determination for C showed that in one-year of landfilling, 29% of the input of the organic C left the landfill via landfill gas pathway while, less than 1% escaped via leachate pathway. After one year of study, more than 70% of the organic C was still in landfill sink. The landfill gas emissions are made up from this: CH_4 = 50.7 ± 13,5%, CO_2 = 35.6 ± 9.6% and CO = 4.4 ± 2.1 %. By means of MFA and SFA, flows of material and various C compounds were tracked during landfilling and composting.

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