Ambiental Valoration and Energy Generation with System Subproduct of Urban Solid Waste for Pirolysys

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Abstract

The biosphere's capacity to absorb the waste generated by society has been long overcharged. Every year it is generated around 1.8 billion tons of urban solid waste (USW) in the world. Brazil produces 7.5 million tons and disposes 58.3% in landfills, and the rest is deposited in controlled landfills and open dumpsites. The appropriate USW management problem has showed to be a challenge, as factors such as quantity, volume, variety and complexity of waste entail risks for human health and the environment. Regulations implanted in Brazil in 2010 encourage the adoption of new alternatives for waste treatment and the development of clean technologies as a way to minimize environmental impacts, as well as technologies that aim to the urban solid waste's energy recovery. In this sense, this study uses the emergy synthesis to evaluate a pioneer USW treatment system in Brazil – the Natureza Limpa Project – installed in the municipality of Unaí in Minas Gerais state, where the slow pyrolysis treatment for urban solid waste is applied. The indicators justify that the system is capable of performing gains in joules of energy (J) and emergy (sej) and presents great potential not only for waste treatment in Brazil, but also as a promising energy source, which is capable to assist on the energy demand by means of the exceeding production of 2.3 tons of charred urban waste, which is capable of producing 3.25×10^3 joules of energy per gram of treated waste.

Keywords: *Emergy, USW treatment, pyrolysis, Natureza Limpa Project*

1. Introduction

The biosphere's capacity to absorb the waste generated by society has been long overcharged. Every year it is generated around 1.8 billion tons of urban solid waste (USW) in the world, and the exploitation of resources goes on in an accelerated pace, mainly due to the 800% increase in the use of resources in relation to the past century (KRAUSMANN et al., 2009)

The use of resources, encouraged by the population growth and the power of buying leads an European individual to consume an average of 50 ton in resources every year, two times the amount for a citizen in an emerging country (BLEISCHWITZ, 2009).

Brazil produces 7.6 million tons of MSW per year (1.04 kg / inhab.). Of this amount, 58.3% is sentto landfill, while the rest is deposited in controlled landfills or dumps (ABRELPE, 2013).

The bias of appropriate urban solid waste management has turned into a great challenge due to factors such as quantity, volume, variety and complexity of waste, which lead to risks for human health and the environment.

However, for Marchettini et al. (2006) the waste must not be considered something to be eliminated, but as a potential resource, as it may generate economic value, but it is an integrated management plan that uses all the available technologies is necessary.

Regarding this, the Solid Waste National Policy – PNRS (BRASIL, 2010) accounts new alternatives for waste treatment, such as the adoption, development and enhancement of clean technologies as a way to minimize environmental impacts, as well as the use of technologies aiming to the energy recovery of urban solid waste.

Taking this scenario as a basis, this study uses the emergy synthesis methodology (ODUM, 1996) to assess a pioneer alternative in Brazil for urban solid waste treatment, the Natureza Limpa Project, located in the municipality of Unaí-MG, where pyrolysis is used for producing of charred urban waste (CUW).

2. State of the art

According to Wiggers (2003), charring the waste offers environmental advantages, since the waste are heated in an oxygen-poor environment where the increase in heat due to the heating of the external walls of the pyrolytic reactor fractionates the molecular structure of the waste product, yielding products with lower molecular weight, such as WDF (Waste Derivate Fuel).

In compliance with Matsuzawa et al. (2007), the thermal efficiency of the coal from USW may reach 50% of the thermal efficiency of the charcoal (ou vegetable coal). But Pereira (2006), in a study performed with different temperatures in solid waste coming from a biomass refinery, states that for obtaining the greatest coal production – and meeting the regulations for coal with energy purposes – the ideal temperature for waste charring is 300°C.

Islam and Beg (2004) compared the liquid residue produced in the pyrolysis process for USW treatment with petroleum-derivate products. The authors concluded that the liquid residue may become a promising fuel source based on hydrocarbons.

In a study in a small pyrolysis plant, Phan et al. (2008) state that the charred product represents from 38% to 55% of the energy content of the original residues, as the liquid product represents 20% to 30% and 33% of the waste corresponds to aqueous fraction. The author concludes that the charred product has become richer in carbon and higher on calorific value, whereas the liquid product shows to have greater calorific value (HCS), from 10 to 12MJ.kg^{-1}.

Tôrres Filho (2014) uses a pyrolysis plant for USW treatment to meet the demand for energy cogeneration in two scenarios: the Rankine Organic Cycle (ROC) from the heat exchange of the thermal fluid with the organic fluidof the ROC module, for the self-supplying of electric power, and a thermoelectric unit. For the first case the system supplies 34% of the electric power demand, as for the second case the charred solid waste (CSW) shower its calorific value to be under 24.7MJ.kg^{-1}and capable to supply the demandof a thermoelectric unit with capacity installed of 111MW.

Marquettini et al. (2006) assess three different types of USW treatment in Italy: landfill, composting and incineration. The indicators point out that the compound has the lowest resource use per gram of waste in comparison to the incineration and the disposal in landfill, whereas the incineration and composting are more efficient on the USW emergy recovery.

Other authors have adopted this methodology to assess alternate waste treatment systems (BJÖRKLUND et al., 2001; BROWN E BURANAKARN, 2003; NICCOLUCCI et al, 2002.; BASTIANONI et al., 2002).

3. Methods

3.1 System Description

The Natureza Limpa Project received a license to start its activities in 2014 and takes 18,000m^2 for operating. The Project can treat 72 tons of USW per day, operating 16 hours per day, 365 days per year and uses coal (CUW) from USW burning in pyrolysis to feed the pyrolytic reactor and maybe selling the exceeding production.

3.2 Methodology

The emergy synthesis is a methodology created by H.T. Odum in the early 1980's. The emergy (spelled with m) is defined as the available energy that is consumed in direct and indirect transformations needed to make a product or service, and it is expressed in sej (solar emergy joules).

Every input used for implementing and operation the system are called energy flows, and they are converted for a common basis, named solar emergy joules (sej).

To convert every flow in the system in a common basis (sej) the transformity is used (sej/J) – when flows come from energy sources – as well as the Unit Emergy Value (UEV) when flows come from measurement units. This conversion allows every flow to influence the total accounting of the system in a distinct manner, as all the anthropogenic or nature's labor for obtaining every energy flow is considered. The transformity and/or UEV may be considered a indicator as well, as a high value indicates that the system has performed a great effort to obtain an input, which may be restrictive for the process.

The energy diagram (Fig. 2) shows the interaction of every energy flow of the Natureza Limpa Project, as well as the interactions on the process and with the environment.

The emergy synthesis methodology (ODUM, 1996) is developed in four stages :

- Construction of emergy diagram;
- Construction of emergy table;
- Calculating the emergy indicators;
- Interpreting results for the indicators.

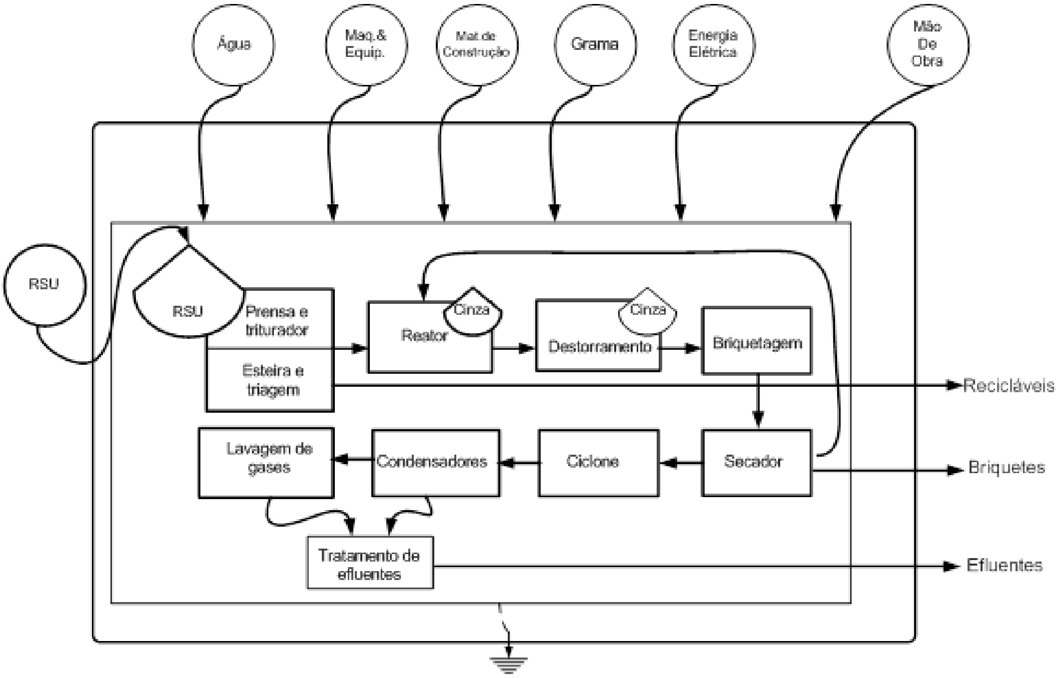

Fig.2. Energy Diagrams of Natureza Limpa Project USW treatment system

Each line with a number on Table 1 indicates the energy flows (inputs) used either on the implementation phase of the operation of the system. These flows were individually divided by the life cycle period to obtain a yearly value. The methodology classifies the flows due to their nature: renewable (R), non-renewable (N) and purchased from economy (F).

The methodology indicators are used to assess the system (EYR, ELR, EIR and ESI).

EYR is the Emergy Yeld Ratio, which is the ratio between the emergy of the system (Y) and the resources purchased from economy (F) and indicates the capacity of the process to explore the local resources coming from the nature and the minimum value is the unit.

ELR is the Environment Load Ratio (ELR = (N + F) / R) and provides additional data for EYR, expressing the use of renewable resources on the system and assesses the stress imposed by the environment and the lower is the value, the lower the stress.

ESY in the Emergy Sustainability Index (ESI = EYR / ELR) and is the measure for sustainability of a productive process (ULGIATI and BROWN, 1998). Higher values mean sustainability on a longer term. A long-term sustainable system needs low Environmental Load Ratio and high Emergy Yield Ratio.

Based on the study of Marchettini et al. (2006), other indicators were used to evaluate the system, as follows:

- Recovered energy (material) (energy of the product (J)/Treated USW mass (g)). It is an indicator of the system's efficiency, capable of providing the quantity of recovered joules per gram of USW.

- Recovered emergy (recovered energy or material ((sej/g) x transformity). The multiplication allows estimating the quantity of emergy that the system can recover from 1g of treated USW.

- Net Emergy (recovered emergy (sej/g) – emergy per gram os USW (sej/g)). It is a non-dimensional measure and indicates how much the system recovers in emergy. The higher the index, the better for the system.

- Finally, the ratio between recovered emergy and the emergy used for treating one USW's gram. This is a cost-benefit indicator, as it measures the percent of profitability or emergy advantage that the system can obtain in relation to all the emergy used (spent) per gram of USW in the process. The higher the indicator, the greater will be the emergy profit for the system.

Table 1. Emergy Table for slow pyrolysis USW Treatment System.

Note	Description	Unit	Class	Value (un/yr)	Emergy per unit (sej/un)	Correction factor	Emergy (sej/yr)	% (sej/sej)
	Treated USW	g		$1.75x10^{10}$				
	Implementation Phase							
1	Soil	J	N	$1.41x10^{12}$	$2.21x10^{4}$	1.00	$3.12x10^{16}$	1,34%
2	Labor	J	F	$9.88x10^{8}$	$4.30x10^{6}$	1.00	$4.25x10^{15}$	<1%
3	Cement (Artefact)	g	F	$4.86x10^{5}$	$1.20x10^{9}$	1.00	$5.83x10^{14}$	<1%
4	Brick	g	F	$1.02x10^{7}$	$1.35x10^{9}$	1.68	$2.31x10^{16}$	1%
5	Concrete	g	F	$1.82x10^{7}$	$1.54x10^{9}$	1.68	$4.71x10^{16}$	2.03%
6	Asphalt	g	F	$2.00x10^{7}$	$4.74x10^{8}$	1.68	$1.59x10^{16}$	<1%
7	Galv. Steel (tiles)	g	F	$3.26x10^{6}$	$1.81x10^{9}$	1.00	$5.90x10^{15}$	<1%
8	Structural Steel	g	F	$3.31x10^{6}$	$2.77x10^{9}$	1.00	$9.17x10^{15}$	<1%
9	Steel (Mach. & Eq)	g	F	$1.64x10^{7}$	$3.00x10^{9}$	1.00	$4.92x10^{16}$	2.12%
10	Cement (mass)	g	F	$3.69x10^{6}$	$3.31x10^{9}$	1.00	$1.22x10^{16}$	<1%
	OperationPhase							
11	Electric Power	J	F	$2.68x10^{12}$	$2.69x10^{5}$	1.68	$1.21x10^{18}$	52.20%
12	Labor	J	F	$1.70x10^{11}$	$4.30x10^{6}$	1.00	$7.31x10^{17}$	31.47%
13	Water	m^3	F	$2.33x10^{5}$	$7.75x10^{11}$	1.00	$1.81x10^{17}$	7.77%
	Total Emergy						$2.32x10^{18}$	100%

4. Results

From the energy diagram (Fig. 2) it may be observed all the interactions of the energy flows within the system on the implementation, operation phases and the relationships between the system and the environment.

According to the emergy table (Table 1), every flow has its origin on the economy (F), except for the Soil (N). The most significant flows for the operation are the electric power consumption (52.20%), the labor (31.47%) and the water consumption (7.77%), showing that the system applies 91.44% of the emergy budget on the operation phase.

Line 11 on Table 1 shows the yearly consumption of electric power of the system, ((2.69E+12 joules). However, the real value for this item is $1.3x10^{6}$ KWh, but it was subtracted $5.84x10^{5}$ KWh (energy consumed by the reactor).

The system is able to produce, with the charred waste (CUW), 2.16x10^7 kWh (7.79x10^{13} J)generating thus an yearly excedent of 1.58x10^6 kWh or 5.69x10^{13} joules.

The indicators of the methodology adopted – emergy synthesis – are shown on Table 2.

Table 2. Result of emergy synthesis indicators.

Emergy Indicators			
EYR	EIR	ELR	ESI
1.0	73.5	-	-

The Emergy Yield Ratio (EYR) of the system is low, the lowest value acknowledged for this indicator. The result points that there is no gain in emergy for the system due to the inefficiency of the system to use the local renewable and non-renewable resources.

The Emergy Investment Ratio (EIR) shows that the system is exclusively depending on the resources (F), the ratio between the emergy of the system and the quantity of treated USW shows that the system uses 1.32x10^8 sej to treat one gram of waste.

As it may be verified, there were no values for the ELR and ESI values. Since the renewable resources (R) represent a null value for the denominator of the ELR ((F+N)/R) calculations, so will the ELR have a null denominator for the ESI calculation, as the system used no renewable resources (R).

The transformity and the units of emergy values (UEVs) of the coal briquettes (or CUW) exceeding from the process (product) were determined (Table 3) and they express an efficiency factor for the system, Either the transformity or the UEV of a product indicate how much emergy was necessary to make one joule, MWh or gram of the product.

Table 3. Transformity values and UEVs for CUW

Transformity (sej/J)	*Unit of Emergy Value (UEV)* (sej/kWh)	(sej/g)
4.08x10^4	1.42x10^{12}	1.01x10^{12}

Table 4 shows the transformities for several energy sources. The lower the magnitude (exponent), the higher the efficiency of the system. This efficiency may be inferred on the quantity of emergy (sej) used in the system to produce one joule of energy.

Table 4. Transformities of energy generation for diverse sources.

Transformity (sej/J)	*CUW*	*Wind**	*Geothermal**	*Hydroelectric**	*Oil**	*Coal**
Electric Power	*4.08x10^4*	*9.90x10^4*	*2.39x10^5*	*9.86x10^4*	*3.14x10^5*	*2.62x10^5*

*Almeida et al, 2011

It is noteworthy that the charred urban solid waste (CUW) production is 2.4 better when compared to the production systems of wind and electric power and about 6 times more efficient that the coal and geothermal energy production. For the oil production it is about 8 times greater (7.7).

On Table 5 the results of indicators for this study are shown and compared to those from landill and pyrolysis studies developed by Marchettini et al. (2006). An example is the quantity of joules that the product (CUW and electric power) that the systems produce, as well as the recovered emergy and energy.

Table 5. Comparison with data from Marchettini et al (2006).

Plant	*Product* *(J_{el})*	*Recovered Energy (J/g)*	*Transformity* *(sej/J)*	*Recovered Emergy* *(sej/J)*
Pirolysis	*$5.69x10^{13}$*	*$3.25x10^{3}$*	*$4.25x10^{5}$*	*$1.47x10^{9}$*
*Landfill**	*$1.16x10^{14}$*	*$6.81x10^{2}$*	*$1.48x10^{5}$*	*$1.01x10^{8}$*
*Incineration **	*$9.58x10^{13}$*	*$8.87x10^{2}$*	*$1.48x10^{5}$*	*$5.59x10^{8}$*

** Marchettini et al, 2006*

It may be verified that, in quantity of joules produced by the system due to the exceeding CUW, that the pyrolysis is less efficient when compared to the energy produced by the landfill and the incineration systems.

However, you can recover 5 times more energy than the landfill to produce electricity and 4 times more than the incineration plant. the recovered energy (Joule) per gram of treated waste.

The recovered emergy – that comprehends how many joules of solar emergy (sej) were recovered for each joule of produced energy – indicates that the slow pyrolysis system recovers 14.5 times more than the landfill and 2.6 more than the incineration plant.

In other words, the amount of energy generated on the pyrolysis process is smaller, but the system reaches more efficiency on the production of energy joules per gram of treated waste, and thus can recover more emergy per gram of treated waste.

On Table 6 the net emergy and the EYR_1 for this study are also compared to the landfill and the incineration plant from Marchettini et al. (2006).

Table 6. Net emergy indicators and EYR_1 of the USW treatment systems

Indicators			
		Pirolys us Landfill	*Incineração*
NET EMERGY	*$1,34x10^{9}$*	*$-4.21x10^{8}$*	*$3.84x10^{8}$*
PROD.'S RECOV. EMERGY *EMERGY PER GRAM OF RSU*	*$1.11x10^{1}$*	*$1.90x10^{-1}$*	*$3.20x10^{0}$*

The ratio between the product's recovered emergy and the emergy per gram of USW shows how much emegy the product recovers in relation to the invested emergy to treat one gram of USW. In this context, the pyrolysis treatment system can recover 58% of what has been invested in emergy in relation to the landfill and about 4% in relation to the incineration plant.

In general, if on one hand the slow pyrolysis USW treatment is not so eco-friendly for using more resources from the economy, on the other hand the methodology doesn't comprehend the benefits that technology provides to the environment if the waste was disposed in a common landfill or in open dumpsites. Hazards include soil, water table and surface water contamination caused by the percolated liquid (slurry), greenhouse gases (GHG) emission, the varmint attracted by the waste and also hazard to the population living on the surroundings of these systems.

However, by using the same methodology of this study, the system has proved to be capable of performing gains in solar emergy and energy joules.

Thus, from the efficiency indexes obtained for the treatment system, it is shown that the technology used by Natureza Limpa Project has a great potential not only for becoming a feasible USW treatment system in Brazil, but also a promising source of energy for other systems due to the charred urban waste.

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