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TECHNOLOGICAL ASPECTS OF ELECTRIC POWER GENERATION FROM MUNICIPAL SOLID WASTE

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Abstract. *To analyze the technological aspects of the generation of electric energy from the Municipal Solid Waste (MSW) generated in Belo Horizonte (BH), the main technologies applied were selected aiming the production of fuel or heat. The composition of the MSW and its thermophysical properties were investigated. Using GE GateCycle™ software to model the thermodynamic cycles, it was found that with 675,728 t/y of MSW it's possible to generate, using the Brayton cycle, 22.0 – 34.4 MW or 59.6 – 82.8 MW of electrical power, while the Air-Standard Dual cycle can generate 27.6 – 43.2 MW or 62.5 – 86.7 MW using landfill's gas or gasifiers' gas, respectively. In a Rankine cycle, with the MSW being the fuel of the boiler, it is possible to generate 15.47 MW of electricity. In terms of generation costs, landfills (0.051 R$/kWh) were the most feasible for deployment in the taxes market trading of electricity in Minas Gerais (MG).*

Keywords: *MSW, Sustainable Development, Alternative Energy Sources*.

1. INTRODUCTION

A research conducted by the *Agência Brasileira de Empresas de Limpeza Pública e Resíduos Especiais* – ABRELPE (2014) showed that the MSW's generation in Brazil in 2014 was approximately 78.6 million tons, representing an increase of 2.9% when compared to the previous year.

Based on informations from the *Pesquisa Nacional de Saneamento Básico* from IBGE (2008) it estimates that approximately 58.3% of all MSW ends in landfills, followed by 19.4% in controlled landfills and 19.8% in open dumps, only 1.4% goes to recycling and 0.8% to composting, the other values are insignificant.

Almost nothing of energy currently distributed is generated from organic compounds, been these resources few explored in Brazil. Although Brazil has not tradition of reuse MSW, awareness has increased and, consequently, discussions and proposals on the subject have been taking place.

2. LITERATURE REVIEW

Researches conducted in Brazil indicates that the annual generation of MSW increased by 6.8% in 2009 compared to 2010, representing a per capita increase of 378.4 kg/y.

Manaf, *et al.*, 2008 researched the MSW's management issue in Malaysia, they noticed some difficulties of the Government to deal with the use of MSW, among them, 50% of the MSW's management budget is for collection of MSW and, according to Yunus and Kadir (2003), only landfills (the majority open) are used to eliminate it, posing a serious environmental and social threat.

Tsai and Kuo (2010) analyzed the potential of electric power production using Taiwan's MSW incineration plants. There are 24 incineration stations, which use heat recovery, equipped with a steam turbine system (cogeneration) that has a capacity of generating of 622.5 MW and treatment of 24 thousand tons of MSW per day. The incineration capacity raised from 2,660 tons in 2000 to 6,110 tons in 2008 and the electricity production from 1,117 GWh to 2,967

GWh at the same period. There economic benefit from the sale of energy was almost US$ 150 million and CO_2 emissions decreased by 1.9 million tons, mitigating environmental pollution.

Lee, *et al.*, 2013 studied the potential of generation energy from MSW in Ghana, where the MSW's annual generation is around 4.5 million tons. In this study, three methods of thermochemical conversion were proposed: 1) by incineration/combustion, the MSW (with a minimum LHV of 7,000 kJ/kg) are burned, releasing high pressure steam that pivot a turbine connected to an electric generator and approximately 544 kWh/t of MSW are produced, 2) by gasification, the MSW undergo partial combustion in two stages and generate CO and H_2. In this process, the gasifier is coupled to a turbine for energy generation, and 3) by pyrolysis (thermal decomposition without oxygen), this process produces charcoal and oil, the gas produced from the oil can generate 571 kWh/t of MSW. This study revealed that 2 GWh of electricity per year can be generated using controlled incineration and 1.0 – 1.5 GWh of electricity per year if landfills were used.

3. METHODOLOGY

The present work has as objective study and assess the technological aspects of electric power generation from MSW generated on the city of BH. This study has been based on the propositions mentioned below:

- Were selected the main applied technologies, aiming at environmental impacts and production capacity of fuel or heat, to turn them into electrical energy, was defined then Landfills, Gasification and Incineration;
- Was considered the use of microturbines, internal combustion engines and boilers for energy recovery;
- Was established that BH produces 675,728 t/y of MSW, according to *Prefeitura de Belo Horizonte* (2016), the energy recovery plants operate 8,030 h/y and the inert compounds were removed.

3.1 Biogas' generation

In accordance with Oliveira and Oliveira (2012), landfills generate 160 – 250 m³/t of MSW of biogas, while Lora and Venturini (2012) estimate that gasifiers generate 1,800 – 2,500 Nm³/t of MSW. Some gases' properties can be found in Tab. 1 and Tab. 2.

Table 1. Chemical composition of gases – data from Oliveira and Oliveira (2012) and Lora and Venturini (2012).

	CH_4 (%)	CO_2 (%)	H_2 (%)	CO (%)	N_2 (%)
Landfill	55	44	1	-	-
Gasifier	7	20	9	14	50

Table 2. Density of gases – data from Gama Gases (2007a), Gama Gases (2007b) and Varejão (2012).

	CH_4	CO_2	H_2	CO	N_2
Density (kg/m³)[(1)]	0.72	1.97	0.09	1.25	1.15

[(1)] At 101.325 kPa and 20ºC.

Employing GE GateCycle™ software, a Brayton cycle (Fig.1a) and an Air-Standard Dual cycle (Fig.1b) were modeled for each fuel gas under the conditions shown in Tab. 3 and using the equipment data shown in Tab. 4.

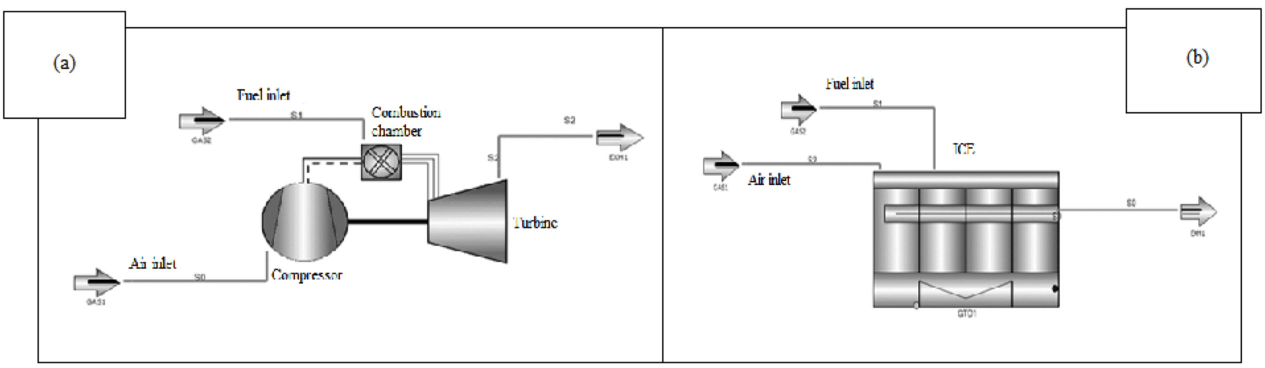

Figure 1. GateCycle modeling – (a) Brayton; (b) Air-Standard Dual.

Table 3. Cycles' parameters.

	Ambient air	Fuel gas
Temperature	15°C	20°C
Pressure	101.32 kPa	1114.32 kPa
Humidity	60%	-

Table 4. Equipment – engine's data provided by Cummins Engine Company (2001).

Cycle	Brayton	Air-Standard Dual
Equipment	Turbine Allied – Signal ASE40	Engine Cummins KTA50 – G3

3.2 Burning MSW

Only 20% – 25% of the heat from the burning is converted into electrical energy, according to *Ministério de Minas e Energia* (2007). Knowing the data from Tab. 5 and Tab. 6, the MSW's Lower Heating Value (LHV) was calculated, resulting in 1,913.75 kJ/kg. A simple Rankine cycle (Fig.2) was modeled with steam at 400°C leaving the boiler.

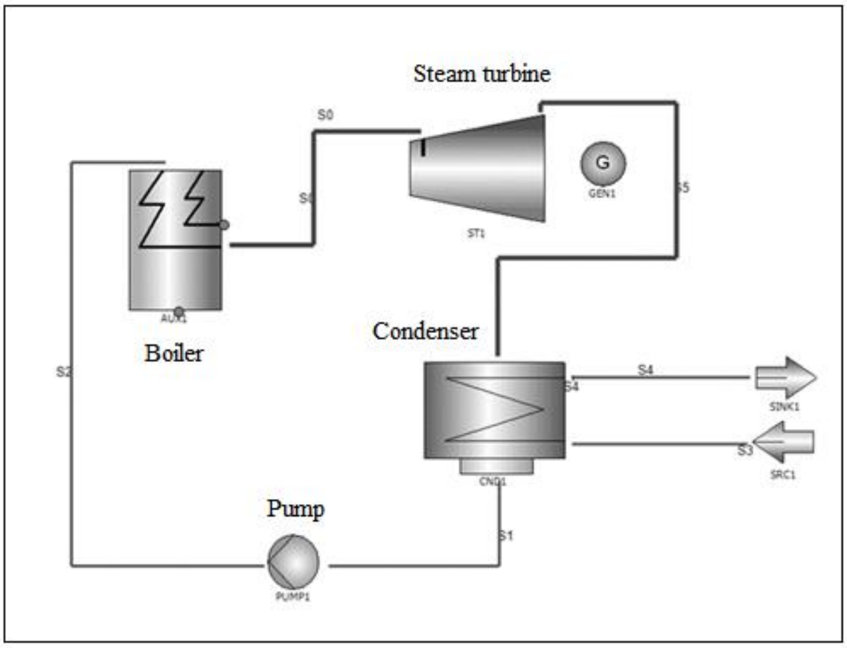

Figure 2. GateCycle modeling (Rankine).

Table 5. Composition of MSW – data from *Ministério do Meio Ambiente* (2012).

	Metal	Paper	Plastic	Glass	Organic Matter	Others
Quantity (%)	2.9	13.1	13.5	2.4	51.4	16.7

Table 6. Properties of MSW's components – data from *Fundação Estadual do Meio Ambiente* (2012).

MSW	LHV – dry (kJ/kg)	Humidity (%)	LHV – wet (kJ/kg)
Organic Matter	18,000	66	2,980
Papper	15,900	21	11,420
Textile	17,570	36	8,040
Wood	15,480	25	10,420
Plastic	43,095	17	34,280
Rubber	40,585	5	36,120

3.3 Costs

The cost of generating electricity can be obtained through Eq. (1), in accordance with Ulrich and Vasudevan (2004).

$$C_{ger} = C_{inv} \times \frac{FA}{C \times H_o} + \frac{C_{O\&M}}{C \times H_o} \tag{1}$$

Where:

$$FA = \frac{i \times (1+i)^n}{(1+i)^n - 1} \tag{2}$$

Where: C_{ger} – cost of generation electricity [R$/kWh]; C_{inv} – investment cost [R$]; FA – amortization factor; H_o – operation time [h]; $C_{O\&M}$ - maintenance cost [R$]; C – energy production capacity [kW]; i – annual interest rate; n – operation time [years].

C_{inv} e $C_{O\&M}$ were determined by Eq. (3), according to Ulrich and Vasudevan (2004), and using the information in Tab. 7.

$$\not{C}_y = \not{C}_{ref} \times \left(\frac{c_y}{c_{ref}}\right)^{0,6} \tag{3}$$

Where: $\not{C}_y$ – Overall cost for capacity under study [R$]; $\not{C}_{ref}$ – Overall cost for reference capacity [R$]; c_y – Capacity of the study plant [t/day]; c_{ref} – Capacity of reference plant [t/day].

Table 7. Costs' References

Deposition	C_{ref} [t/day]	C_{inv} [Millions R$]	$C_{O\&M}$ [Millions R$/year]	Source
Gasifier	3,800	1,300.00	42.30	Governo do Estado de Minas Gerais (2012)
Incinerator	3,800	1,15800	39.53	Governo do Estado de Minas Gerais (2012)
Incinerator	1,300	650.00	40.33	BNDES (2012)
Landfill + Energy Recovery	3,800	383.00	24.97	Governo do Estado de Minas Gerais (2012)
Landfill + Energy Recovery	1,000	3.11	14.13	BNDES (2012)
Energy Recovery in Landfill	3,800	33.00	2.77	Governo do Estado de Minas Gerais (2012)

Some supplementary data are shown in Tab. 8.

Table 8. Data collected – Interest rate provided by BNDES (2016).

Interest rate (i)	7.5% (annually)	
Operating time (n , Ho)	20 years	8030 hours
Amortization factor (FA)	0.098	

4. RESULTS AND DISCUSSION

Table 9 shows the potential of energy generation with the different technologies considered.

The gasifiers presented greater potential of electricity generation, surpassing the landfills because of the difference in the mass flow rates.

Table 10 presents the power generation costs for the different technologies studied.

Considering CEMIG's average tariff of R$0.55/kWh, according to CEMIG (2016), only incinerators are not viable for electricity generation and landfills are the most viable.

Table 9. Results' Comparison

Deposition	Product	Technology	Thermodynamic Cycle	Equipment quantity	Total Energy [MW]
Landfill	136,960 – 214,000t [gas]	Microturbine	Brayton	6 – 9	22 – 34.4
		Internal Combustion Engine (ICE)	Air-Standard Dual	20 – 32	27.6 – 43.2
Gasifier	1,174,845,433 – 1,631,729,768t [gas]	Microturbine	Brayton	10 – 14	59.6 – 82.8
		ICE	Air-Standard Dual	43 – 63	62.5 – 86.7
Incineration	$1.22x10^{12}$ [kJ]	Boiler + Steam Turbine	Rankine	2	15.47

Table 10. Costs' Comparison

Deposition	Gasifier	Incineration	Landfill + Energy Recovery	Energy Recovery in Landfills
C [MW]	70	15	30	30
C_{inv}/C [R$/kW]	12,063.20	50,283.69	3,267.89	1,691.02
$C_{O\&M}$/C.Ho [R$/kWh]	0.049	0.304	0.061	0.030
C_{ger} [R$/kWh]	0.196	0.918	0.101	0.051

5. CONCLUSIONS

Gasifier's gas has a higher available mass flow rate than landfill's gas, 41.2 – 57.2 kg/s versus 4.8 – 7.5 kg/s, consequently also has a higher power generation potential, 59.6 – 82.8 MW and 62.5 – 86.7 MW against 22 – 34.4 MW and 27.6 – 43.2 MW, using microturbines and ICE's, respectively. Compensating its smaller PCI, 4.2 MJ/kg versus 15.7 MJ/kg of landfill gas.

The incinerators presented lower potential for electric power generation, being 15.47 MW and were not competitive at current tariffs in the electricity market of MG, costing R$0.9185/kWh while the average tariff of CEMIG is R$0.55/kWh. The landfills proved to be feasible for deployment at a cost of R$0.101/kWh.

6. ACKNOWLEDGEMENTS

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