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APLICACIONES INDUSTRIALES

Analysis of Waste Biogas (Landfills) applied to Power Generation

Análisis de biogás de residuos (vertederos) aplicados a la Generación de Energia

Anderson José Rangel de Oliveira[1]
Lucas Novaes Barreto[1]
Márcio Zamboti Fortes[1]
Filipe Marques Paes da Costa[1]
Luiz dos Santos Moreira[1]
Bruno Soares Moreira Cesar Borba[1]

[1] Fluminense Federal University, Niterói, Rio de Janeiro, Brazil.

ABSTRACT/RESUMEN

In Brazil, despite the high share of renewable energy sources in the energy mix compared to the world average, the use of gas generated by landfills for power generation is still incipient. There are landfills recently implanted with the purpose to produce electricity from biogas, but the oldest installations do not have this structure. Since the oil industry is energy intensive, the article proposes the evaluation of waste gas use in the steam generation system of a typical refinery in Brazil to generate electricity and feed the refinery process units and considering the economic impact. In this sense, it presents an analysis based on real data to contextualize and quantify the waste biogas potential in a specific landfill in Brazil. The study considers a landfill at the end of life (17 years), and the reuse of the residual gas generated until the full depletion of gases considering a case study with real data obtained from an existing landfill.

Keywords: Biogas; Waste Gas; Municipal Solid Waste; Electricity; Landfill; Steam Generation.

En Brasil, a pesar del alto porcentaje de las energías renovables en el mix energético en comparación con el promedio mundial, el uso de gas generado por los vertederos para la generación de energía es aún incipiente. Hay vertederos desplegadas recientemente con el objetivo de producir electricidad a partir de biogás, pero las plantas más viejas, no tienen esta estructura. Dado que la industria petrolera es de alto consumo energético, este artículo propone la evaluación de la utilización de los gases residuales en el sistema de generación de vapor de una refinería típica en Brasil para generar electricidad y alimentar las unidades de proceso de la refinería. En este sentido, se presenta un análisis basado en datos reales para contextualizar y cuantificar el potencial de biogás de residuos en Brasil. Este estudio considera un relleno al final de la vida (17 años), y la reutilización del gas residual generado hasta el agotamiento completo de gases, teniendo en cuenta un estudio de casos con datos reales de un vertedero existente.

Palabras clave: Biogás; Gas Residual; Residuos Sólidos Municipales; Electricidad; Vertedero; Generacion de vapor.

INTRODUCTION

Every year, Brazil has an energy demand growth; a level of 296.2 Mtep was reached in 2013, representing a growth rate of 4.5% over the previous year. Although globally act or encouragement to reduce the use of fossil fuels, the natural gas and oil persist as major sources of primary energy in the country; in fact, its consumption increased by 7% in 2014, compared to the year 2012.

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It is noteworthy, however, that the use of products from sugar cane and hydropower to generate electricity provide a high level of Brazil's share of renewable sources in the energy mix, having reached 41% in 2013.

Another form of renewable energy production is from waste gas recovery, whose technology presents slow exploration in Brazil. Indeed, the generation of municipal solid waste inherent in the continued growth of the population, which currently claims 201,900,000 inhabitants, reached the level of 62,730 tonnes per year, of which 90% was collected. Thus, the average daily per capita waste generation in the country reached 1.05 kg in 2012, and in developed countries, each person produces an average 1.50 kg of solid waste per day. A research evaluating the potential of electricity production from municipal solid waste in the biggest cities in Brazil is presented in [1].

In the past, the incineration of municipal waste was the technology used to reduce the volume and destroy harmful substances in order to avoid risks to human health. Currently, landfills are the main form of management for virtually all types of municipal solid waste. In Brazil, the disposal of municipal solid waste is distributed: 58% to landfills, 24% to controlled landfills, and 18% to open dumps. In Brazil, the need to protecting the environment and combating the pollution and sanitation supply is guaranteed in the Constitution, which gives municipalities the burden of management of the municipal solid waste [2]. Despite having one of the highest tax burdens in the world, the country does not have a well-defined fiscal policy of encouraging the reuse of waste.

Properly handling the garbage generated in cities can bring many benefits to society. For example, Florida, USA, which has 19 million inhabitants and was the fourth most populous US state in 2010, deposited 40% of its solid waste in 16 landfills, and the gases generated by them are harnessed to generate energy. In [3] is reported the United Kingdom experience with different scenarios assessment. Other concerns must also be considered as the mitigation of greenhouse gases and climate change as outlined in [4] and [5]. Thus, this paper aims to conduct a technical and economic evaluation of the use of waste gas from a landfill as a supply for power generation in steam boilers of a nearby typical oil refinery in Brazil.

WASTE BIOGAS TECHNOLOGY

Garbage disposal via landfills is one of the oldest techniques used by man to dispose of waste. Nowadays, a work of engineering aims to accommodate the waste ground in the smallest possible practical space that is compact, so that it has the smallest volume and involves a smaller available area, using the concept of layers. A review about waste management is presented in [6].

Proper waste management in landfills and its subsequent reuse is an environmentally sustainable alternative, as there is the opportunity of renewable energy generation, as well as the reduction of the emission of greenhouse gases, thereby allowing the generation of carbon credits within the Clean Development Mechanism (CDM). Techniques for use of these gases are studied for more than 20 years and the research of Porteous [7] presented the state of the art technology at this time. Recently, some research present a similar research but focuses on information and communication technology (ICT) to facilitate planning and design of sustainable new systems [8]. Wanichpongpan and Gheewala [9] address this context discussing the Life Cycle Assessment (LCA) concept to evaluate the environmental consequences of landfills.

There are several studies/experiments related to management and technology application for solid waste and waste gas generation, in this paper the authors relate some among many other researches in development. The authors highlight the researches: Methods for solid waste management [10], Olive industry waste [11], food waste [12], agro-industrial residues [13], thermal properties of municipal solid waste [14], landfill mining [15], prediction model [16] and methane data comparison [17].

The treatment of municipal solid waste landfills is based on anaerobic digestion (absence of free oxygen). Thus, the biogas generated from the deposition of waste in landfills is the result of biochemical decomposition. In the presence of atmospheric air, the layer organic components in contact with air are oxidized, generating carbon dioxide and water vapor. The main phase of the reaction cycle occurs in three stages. First, fermenting bacteria hydrolyze soluble complex organic molecules. Then, these molecules are converted to organic acids, carbon dioxide, and hydrogen. Finally, methane is formed by methanogen bacteria, which breaks both organic acids into methane and carbon dioxide, but also reduces the carbon dioxide with hydrogen. The simplified procedure is shown in equation (1).

$$C_6H_{10}O_4 + 1.5\,H_2O = 3.25\,CH_4 + 2.75\,CO_2 \tag{1}$$

According to [18] and [19], the generated biogas is typically comprised of methane (CH_4 - from 55 to 65%), carbon dioxide (CO_2 - 35 to 45%), nitrogen (N_2 - 0 to 1%), hydrogen (H_2 - 0 to 1%), and hydrogen sulfide (H_2S - 0 to 1%).

In their study, Themelis and Ulloa [20], show several applications for biogas waste as: industrial heaters and heat exchangers in industries, micro turbines and fuel cells for electric power generation and others.

However, the Brazilian reality in 2010 was that only two landfills performed the use of biogas for power generation. The most common practice was to direct the emission of biogas into the atmosphere through the exit of the collectors drains. According to [21], there are methodological differences to estimate the potential for energy generation in landfills due to the difficulty of this process modeling, i.e., gas capture and effective power generation.

In recent years, several mathematical models of zero decay, first and second order were developed, and the first-order model has been widely used by industry and government agencies. The two main parameters of the kinetic equation of the first order are the maximum potential methane generation and the constant first-order decay, as shown in equation (2).

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k\, L_0 \left[\frac{M_i}{10} \right] e^{-kt_{i,j}} \qquad (2)$$

Where: QCH_4, which is the annual rate of biogas generation (m^3/year), *k* is the rate of methane generation (year -1), L_0 is the maximum potential methane generation (m^3/t), M_i is the mass of solid waste deposited in the year *i*; and $t_{i,j}$ is the age of the residue deposited in the year *i*. On average, it is considered that the biogas production capacity in landfills is approximately 83 Nm^3, or 0.12 tons of methane per tonne of waste. The projection is that landfills around the world produce about 20 to 60 million metric tons of methane per year. An example is the Gramacho landfill in Rio de Janeiro, which produces about 42,000 tons of methane per year. Among others, there is in the literature a document presented by [22], studying the use of biogas in the region of Baja California, Mexico and other with a optimization use of waste gas application in Latvia [23].Conventional technologies for biogas energy conversion are compared in [18]. Silva [18], states that, for power generation with a small or medium capacity, internal combustion engines are best suited. Only for high capacity, gas turbines operate with efficiency and, the plant can further be optimized when using them in combined cycles.

METHODS

This work aims to provide a technical and economic evaluation of the use of waste gas from a landfill as a supply for power generation in steam boilers of water at a nearby oil refinery. For this analysis, it is assumed that the electricity consumption of the oil refinery to feed their process units is 40 MWh. This energy is generated from two generators, driven by steam turbines that require 325 tons of steam each. Figure 1, is a schematic model proposed for the generation of steam through natural and waste gas.

Technical Analysis

To generate steam, two boilers are considered, each with a 340 t/h production capacity. The boilers use refinery gas as an energy source, and the nominal name plate are: operating pressure (main steam) of 100 kgf/cm^2, operating temperature (main steam) of 515 °C, design pressure of 115 kgf/cm^2, supply water temperature of 150 °C, dry bulb ambient air temperature of 24 °C, energy efficiency premise of 0.95, front burning combustion system and forced exhaustion system. With from the boiler, we are able to determine the amount of fuel needed to generate 340 t/h of superheated steam to the operation pressure of 100 kgf/cm², considering an energy efficiency of 95%. For this, calculation is made considering primarily as fuel gas from the refinery. The typical refinergy gas composition considered is: Methane (86.2 %Vol), Ethane (6.9 %Vol), Hydrogen (2.5 %Vol), Propane (1.8 %Vol), Nitrogen (1.3 %Vol), Carbon Dioxide (0.7 %Vol), Oxygen (0.2 %Vol), H_2O (0,2 %Vol), Butane (0.1 %Vol), Pentane (0.1 %Vol) and, Ethylene, Cyclopropane, 1-Butene, 2-trans-butene, 2-cis-butene and Hexane with 0% Vol.

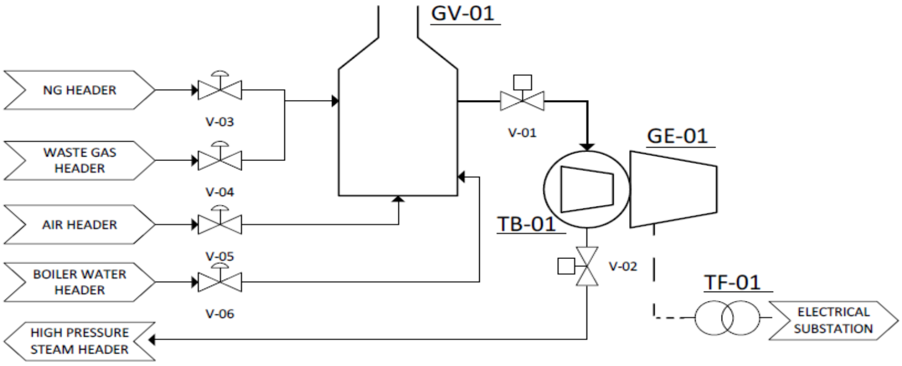

Fig. 1. Schematic of the Steam Generation System

To calculate the amount of energy required to generate super-saturated steam in the boiler must determine the enthalpy (H) of the liquid input and steam output to conditions presented (PERRY E SMITH, VAN NESS, ABBOTT – 1996). The HHV of refinery gas is 12,552 kcal/kg. The calculus to obtain the HHV of waste gas uses the methodology based on the Combustion Heats of its components. Thus, once known mass or composition of substance in an amount (volume or moles) of fuel in question, there is the amount of heat released in the combustion of each of the components. The sum of these released energies will be the estimated of the calorific value.

H (150ºC) = 632,2 kJ/kg ou 632,2 / 4,1868 = 151,0 kcal/kg;

H^v (P=100 Kgf/cm² e T=515ºC) = 3414,1 kJ/kg ou 815,4 kcal/kg;

ΔH = 815,4 – 151,0 = 664,4 kcal/kg;

$$Q = \frac{m\left[\frac{Kg}{h}\right] * \Delta H\left[\frac{Kcal}{Kg}\right]}{n\,[\%]}$$

$$Q = \frac{340.000,0\left[\frac{Kg}{h}\right] * 664,4\left[\frac{Kcal}{Kg}\right]}{0,95\,[\%]}$$

Q = 237.785.263,2 kcal/h ou 995.559.339,97 kJ/h

To find out the PCS of the waste gas, a methodology of PCS determination is used through the Combustion Heat of its components. Where the mass or quantity of matter (volume or moles) of the fuel in question is known, the amount of heat released in the combustion of each component is checked. The sum of these energies released will be the estimated value of the calorific value. (SMITH, VAN NESS, ABBOTT - 1996). In order to validate the method that calculate the density and calorific superior (HHV) for refinery gas and so it is possible to calculate the waste gas, compared to the HHV and density values calculated with typical operating data. The Table 1, presents these data. For error calculations, the following methodology (equation (3), was used:

Example HHV:

$$\frac{HHV\,(OD) - HHV\,(calculated)}{HHV\,(OD)}.100 \qquad (3)$$

The errors revealed a minimum of 0.31% for density and 0.18% for HHV. Therefore, the calculation method has been validated. Similarly, the calculations were performed to HHV and density of the waste gas. The Table 2, shows the results and the error of 7.26% for HHV.

Table 1. Calculation Worksheet Superior Calorific Value of refinery gas.

Refinery Gas Composition			Heat of combustion (kcal/mol)	Molecular Weight (g/mol)	Heat of combustion (kcal/kg)	Quantity (l)	Quantity of material (mol)	Quantity of mass (g)	Calorific Power (kcal)
Hidrogen – H_2	%Vol	2.5	-68.32	2.02	-33,888,89	25	1.12	2.25	-76.2
Oxigen – O_2	%Vol	0.2	0	32	0	2	0.09	2.86	0
Nitrogen – N_2	%Vol	1.3	0	28.01	0	13	0.58	16.25	0
Carbon	%Vol	0.7	0	44.01	0	7	0.31	13.74	0
Methane –	%Vol	86.2	-212.8	16.04	-13,265,18	862	38.46	616.94	-
Ethane – C_2H_6	%Vol	6.9	-372.82	30.07	-12,399.23	69	3.08	92.56	-1,147,7
Ethylene -	%Vol	0	-337.23	28.05	-12,021,6	0	0	0	0
Propane –	%Vol	1.8	-530.6	44.09	-12,033,38	18	0.8	35.41	-426,11
Cyclopropane	%Vol	0	-491.98	42.08	-11,692,1	0	0	0	0
Butane –	%Vol	0.1	-687.98	58.12	-11,837,23	1	0.04	2.59	-30,69
Pentane –	%Vol	0.1	-845,16	74.16	-11,396,13	1	0.04	3.31	-37,71
Hexane –	%Vol	0	0	86.17	0	0	0	0	0
H_2O	%Vol	0.2	0	18.02	0	2	0.09	1.61	0
TOTAL		**100**				1,000	44.61	787.52	-9,902,3

Table 2. Assumptions for the Calculation (Waste Gas).

Waste Gas Composition			Heat of combustion (kcal/mol)	Molecular Weight (g/mol)	Heat of combustion (kcal/kg)	Quant. (l)	Quant. of material (mol)	Quant. of mass (g)	Calorific Power (kcal)
O_2	%Vol	0.21	0	32	0	2.14	0.1	3.05	0
N_2	%Vol	6.08	0	28.01	0	60.83	2.71	76.03	0
CO_2	%Vol	0.02	0	44.01	0	0.22	0.01	0.42	0
CH_4	%Vol	93.62	-212.8	16.04	-13,265,18	936.81	41.8	670.49	-8,894.18
TOTAL		**100**				1,000	44.61	750	-8,894.18

Obs: Data of waste gas volume are of the purified gas purchased.

With the data obtained, we can calculate the quantity of fuel required to generate 340 t / h on a supersaturated steam boiler (See Table 3). Table 4, shows the quantity of fuel required for the boiler with different percentage mixtures.

Table 3. Data calculation of energy quantity needed to supply the boiler and HHV waste and refinery gas.

Quantity of energy required to generate 340 t/h for a supersaturated steam boiler (kcal/h).	-237,785,263.2	
HHV		
Fuel	Unit	Value
Refinery Gas	kcal/t	-12,552,000
Waste Gas	kcal/t	-11,858,966.12

Table 4. Quantity of fuel needed to supply the boiler.

Fuel Quantity (%)		**Mass Quantity of fuel (t/h)**		**Total mass quantity of the fuel (t/h)**
Refinery Gas	*Waste Gas*	*Refinery Gas*	*Waste Gas*	*Fuels combined*
100	0	18.94	0	18.94
80	20	15.16	4.01	19.17
60	40	11.37	8.02	19.39
40	60	7.58	12.03	19.61
20	80	3.79	16.04	19.83
0	100	0	20.05	20.05

Biogas Recovery Capacity

Considering the example of a landfill, which initiates the operation in Year 1 and functions for 17 years, the methane recovery potential is shown in Table 5. As the methane corresponds to 93.68% of waste gas volume, dividing the amount of methane (m^3/h) by this value (93.68%) will determine the amount of waste gas (m^3/h). The values in t/h of methane and waste gas were found by multiplying the values found in m^3/h by their respective densities: Gas methane density: 0.000716 t/m^3 (temp. 25ºC) and Waste gas density: 0.00074999 t/m^3 (temp. 25ºC). However, there are always losses in the recovery of methane; that loss is considered to be approximately 20%. The recoveries of methane and biogas are shown in Table 6. The potential assessment has deemed that the landfill waste depreciation stage ends in Year 17 and that the gases generated in the final cycle can still be used.

Source: Comlurb, 2010, citado por Viana y Fonseca, 2011.[1]

Cost

With data obtained for consumer fuels, we can do an economic analysis to verify the expenses of using the waste gas and the possible savings from the sale of carbon credits.

Considering the quotation of 6.65 US$/ t de C_{eq} (day quote on 06/22/2015), waste gas cost of 463.37 US$/t and refinery gas cost of 373.98 US$/t, the Table 7, shows the gas cost in accordance with the consumption and composition (i.e., waste gas and more refinery gas) and the fuel consumption costs for a boiler.

To calculate the savings from the sale of carbon credits, it is necessary to determine the amount of waste gas (t/h) available for each boiler and, consequently, determine the amount of methane (t/h) present in the waste gas. As the quantity of waste gas supplied decreases over the years, an analysis will be necessary to verify that the quantity of waste gas from Year 1 to Year 32 will be available to meet each boiler.

Tables 8 and 9, present combinations of gases to be used for the boiler and the cost of the fuels.

[1] Viana de Abreu, F y Fonseca Costa Filho, M. A. Technical and economical feasibility analysis of energy generation through the biogas from waste - Gramacho, Caieiras and Santo Andre landfills. En: Proceedings of COBEM 2011

Table 5. Methane (CH4) and garbage recovery potential from the landfill gas.

Year	Deposition Rate [t/ano]	Retained Waste [t]	Methane recovery potential		Potential Waste Gas Recovery	
			m³/h	t/h	m³/h	t/h
1	1,646,374.00	1,646,374.00	0.00	0.00	0.00	0.00
3	1,800,209.00	5,116,026.00	9,399.00	6.73	10,032.93	7.52
5	2,414,508.00	9,855,695.00	16,535.00	11.84	17,650.23	13.24
7	2,403,311.00	14,649,027.00	22,833.00	16.35	24,373.01	18.28
9	2,417,409.00	19,520,999.00	26,970.00	19.31	28,789.04	21.59
11	2,359,715.00	24,354,632.00	29,793.00	21.33	31,802.44	23.85
13	2,400,000.00	29,154,632.00	31,401.00	22.48	33,518.89	25.14
15	2,747,760.00	34,470,392.00	32,212.00	23.06	34,384.59	25.79
17	1,460,000.00	38,850,392.00	33,053.00	23.67	35,282.32	26.46
18	0.00	38,850,392.00	31,958.00	22.88	34,113.46	25.58
20	0.00	38,850,392.00	23,404.00	16.76	24,982.52	18.74
22	0.00	38,850,392.00	17,045.00	12.20	18,194.63	13.65
24	0.00	38,850,392.00	12,414.00	8.89	13,251.28	9.94
26	0.00	38,850,392.00	9,041.00	6.47	9,650.79	7.24
28	0.00	38,850,392.00	6,585.00	4.71	7,029.14	5.27
30	0.00	38,850,392.00	4,796.00	3.43	5,119.47	3.84
32	0.00	38,850,392.00	3,493.00	2.50	3,728.59	2.80

Source: (Adapted, Silva 2015)

Table 6. Methane and waste gas recovery, considering a 20% loss in the recovery process.

Year	Deposition Rate	Retained Waste [t]	Methane recovery		Biogas recovery	
			m³/h	t/h	m³/h	t/h
1	1,646,374.00	1,646,374.00	0.00	0.00	0.00	0.00
3	1,800,209.00	5,116,026.00	7,519.20	5.38	8,026.35	6.02
5	2,414,508.00	9,855,695.00	13,228.00	9.47	14,120.19	10.59
7	2,403,311.00	14,649,027.00	18,266.40	13.08	19,498.41	14.62
9	2,417,409.00	19,520,999.00	21,576.00	15.45	23,031.23	17.27
11	2,359,715.00	24,354,632.00	23,834.40	17.07	25,441.95	19.08
13	2,400,000.00	29,154,632.00	25,120.80	17.99	26,815.12	20.11
15	2,747,760.00	34,470,392.00	25,769.60	18.45	27,507.68	20.63
17	1,460,000.00	38,850,392.00	26,442.40	18.93	28,225.85	21.17
18	0.00	38,850,392.00	25,566.40	18.31	27,290.77	20.47
20	0.00	38,850,392.00	18,723.20	13.41	19,986.02	14.99
22	0.00	38,850,392.00	13,636.00	9,76	14,555.70	10.92
24	0.00	38,850,392.00	9,931.20	7,11	10,601.03	7.95
26	0.00	38,850,392.00	7,232.80	5,18	7,720.63	5.79
28	0.00	38,850,392.00	5,268.00	3,77	5,623.31	4.22
30	0.00	38,850,392.00	3,836.80	2,75	4,095.58	3.07
32	0.00	38,850,392.00	2,794.40	2,00	2,982.87	2.24

Table 7. Fuel consumption costs for each boiler.

Quantity Percentage of Fuel		Quantity of Fuel [t/h]		Total Quantity of Fuels [t/h]	Fuels Costs [US$/h]		
Refinery Gas (%)	*Waste Gas (%)*	*Refinery Gas*	*Waste Gas*	*Fuels Combined*	Refinery Gas ($)	Waste Gas ($)	Total Cost ($)
100	0	18.94	0.00	18.94	7,084.71	0.00	7,084.71
80	20	15.16	4.01	19.17	5,667.77	1,858.20	7,525.97
60	40	11.37	8.02	19.39	4,250.83	3,716.41	7,967.23
40	60	7.58	12.03	19.61	2,833.88	5,574.61	8,408.49
20	80	3.79	16.04	19.83	1,416.94	7,432.81	8,849.75
0	100	0.00	20.05	20.05	0.00	9,291.01	9,291.01

However, with the sale of carbon credits, it is possible to get an income that can be reduce in the final cost with fuel. The calculation of carbon credits is calculated using the following assumptions:

- 1 t/h of methane (CH_4 (g)) is 21 t/h carbon dioxide (CO_2 (g)), and the quantity of available methane recovered was multiplied by 21, obtaining the flow of carbon equivalent; To determine the amount of the carbon credits [US$/h] with this amount of carbon equivalent, multiply the flow Ceq by the carbon credit value [$ 6.65/t Ceq]; and using the value of the carbon credits [US$/h] to obtain the savings achieved by using the combined fuel for 100% utilization of refinery gas makes up the difference between carbon credits [US$/h] and the fuel costs mentioned above.

Table 8. Quantities of waste gas available to supply a boiler and the tonne/hour obtained from each fuel.

Year	Fuel Quantity [t/h]		Percentage of Fuel		Total mass quantity
	Waste Gas Quantity available to supply the boiler [t/h]	Refinery Gas [t/h]	Waste Gas (%)	Refinery Gas (%)	*Fuels Combined*
23	4.66	14.54	23.23	76.77	19.20
24	3.98	15.19	19.83	80.17	19.16
25	3.39	15.74	16.92	83.08	19.13
26	2.90	16.21	14.44	85.56	19.10
27	2.47	16.61	12.32	87.68	19.08
28	2.11	16.95	10.52	89.48	19.06
29	1.80	17.24	8.97	91.03	19.04
30	1.54	17.49	7.66	92.34	19.03
31	1.31	17.71	6.54	93.46	19.02
32	1.12	17.89	5.58	94.42	19.01

In the Table 9, (first column) shows the possible carbon credits when using the waste gas for each boiler .

Table 9. Cost of each fuel.

Year	Savings (US$/h)	Fuel Cost [US$/h]				
		Waste Gas ($)	Refinery Gas ($)	Total Cost (Combined Cost) ($)	Total Cost (100% Refinery Gas) ($)	Cost Difference Fuel ($)
23	69.65	2,158.41	5,438.85	7,597.26	7,084.71	512.55
24	59.45	1,842.05	5,680.08	7,522.14	7,084.71	437.43
25	50.73	1,571.99	5,886.01	7,458.01	7,084.71	373.30
26	43.29	1,341.55	6,061.73	7,403.28	7,084.71	318.57
27	36.95	1,144.94	6,211.66	7,356.60	7,084.71	271.88
28	31.53	977.12	6,339.63	7,316.74	7,084.71	232.03
29	26.91	833.78	6,448.93	7,282.71	7,084.71	197.99
30	22.97	711.66	6,542.05	7,253.71	7,084.71	168.99
31	19.6	607.34	6,621.59	7,228.93	7,084.71	144.22
32	16.73	518.31	6,689.48	7,207.79	7,084.71	123.08

RESULTS AND DISCUSSION

Waste Gas Quality

The biogas that reaches the refinery has a very good quality in terms of its energy, compared to the quality of waste gases and other landfills. It was found that this HHV is calculated to be around 8,894.18 kcal/m³, whereas studies show that the average HHV of other biogases is around 4,900 kcal/m³. This is explained by the fact that landfill waste gas goes through a purification process to increase the concentration of CH_4. Furthermore, the control leakage in the gas pipes must be very intense; therefore, the concentration of nitrogen in the gas is too low, it is assumed that no false air intake through pipes. One can also observe that the waste gas HHV (11,858.97 kcal/kg) was very close to the refinery gas (12,573.98 kcal/kg) currently used for the power supply of boilers, i.e., a difference of only 5.7%. This is another fact that proves the quality of waste gas.

Waste Gas Recovery

Figure 2, shows the waste gas recovery capability of a particular landfill. According to the graph, peak biogas generation occurred at the end of the landfill operation. With the waste deposition stop the same, the potential of waste gas generation will fall exponentially as it goes occurring anaerobic decomposition of organic matter there deposited. The biogas recovery is less than their generation potential, as in the recovery process generally occurs gas loss to the surface.

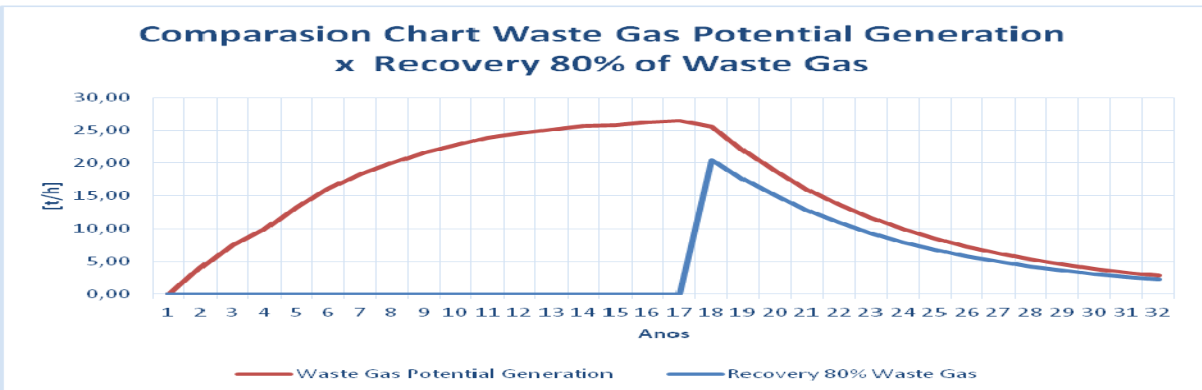

Fig. 2. Waste Gas Generation potential x Recovery 80% of waste gas comparison chart.

Source: Adaptado DA SILVA, 2015

Cost Comparison

The cost of the waste gas going into the oil refinery is greater than the cost of the refinery gas used for feeding the boilers. This should occur, as refinery gas is a cleaner fuel with a calorific value, higher than that obtained by the waste gas. Figure 3, shows the waste gas costs, with and without carbon credit, considering the use of methane from Year 23. The graph illustrates that the use of waste gas, besides being a more sustainable process, also allows for a cost reduction, compared with the use of 100% refinery gas. However, the landfill does not provide enough biogas to supply 100% of the power demand from the two boilers. The graph in figure 4, shows the fuel cost savings potential if we increased the percentage of utilization of waste gas in each boiler. Note that the cost reduction potential using 100% waste gas could reach US$ 299.83 / h.

CONCLUSIONS

The use of waste gas to meet the energy demand of each of the boilers in the refinery fully meets the triple bottom line (environmental, social, and economic).

Regarding the environmental issue, by using waste gas for boilers, the project provides a reduction in the emission of methane gas (a very harmful gas that contributes to the greenhouse effect) by using it sustainably, as an alternative fuel, on average, methane recovery for the guidance years is around 40.000 t/year. . In addition to respect for the environment, the use of waste gas allows for a reduction in the consumption of non-renewable fuels, such as refinery gas. Regarding social issues, the project can generate more jobs and provide an increased quality of life on the planet by reducing the emission of methane gas.

Economic developments in the project provide a reduction in the fuel consumption costs of each boiler. It is estimated that approximately 6.6 million dollars can be saved over 10 years of use of a waste gas landfill during a period of 23 to 32 years for this case study. In addiction, if you condider to use an one hundred percent of a landfill gas, you can save 2.6 million dollars per year. This waste gas recycling policy should be part of every energy plan. Specific assessments of the implementation of pipelines or interconnection to existing networks should be part of the bidding process infrastructure for power generation.

Sees up this energy as required in energy development matrices considering that public policies at the federal, state and municipal levels are in stage settings and deployment to end the cycles of so-called "dumps (lixões in Portuguese)" in Brazil.

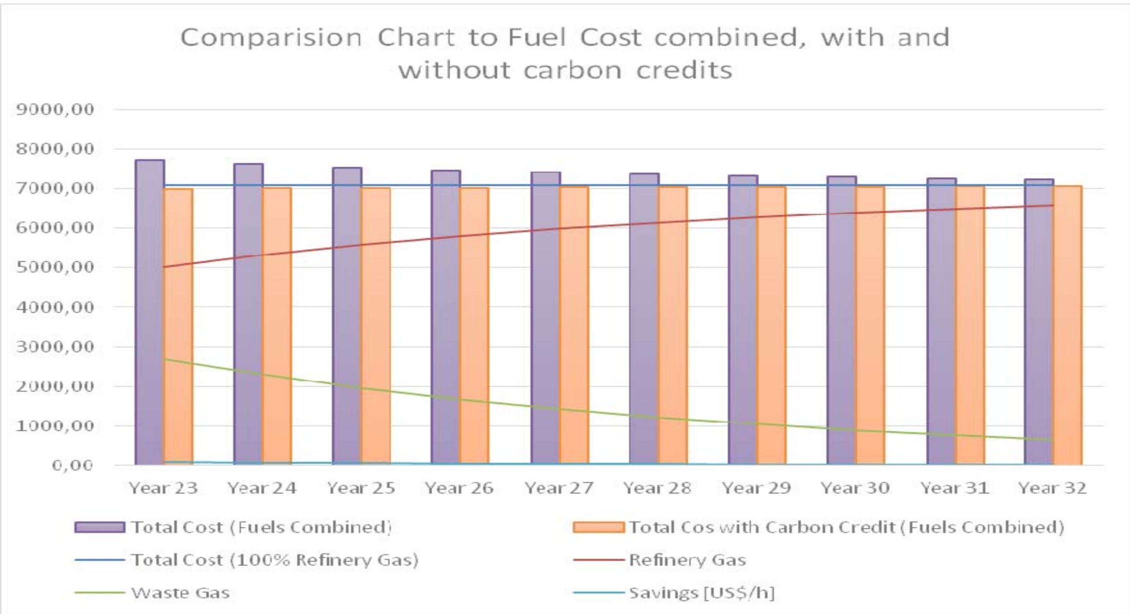

Fig. 3. Fuel Cost combined with and without carbon credits to a boiler.

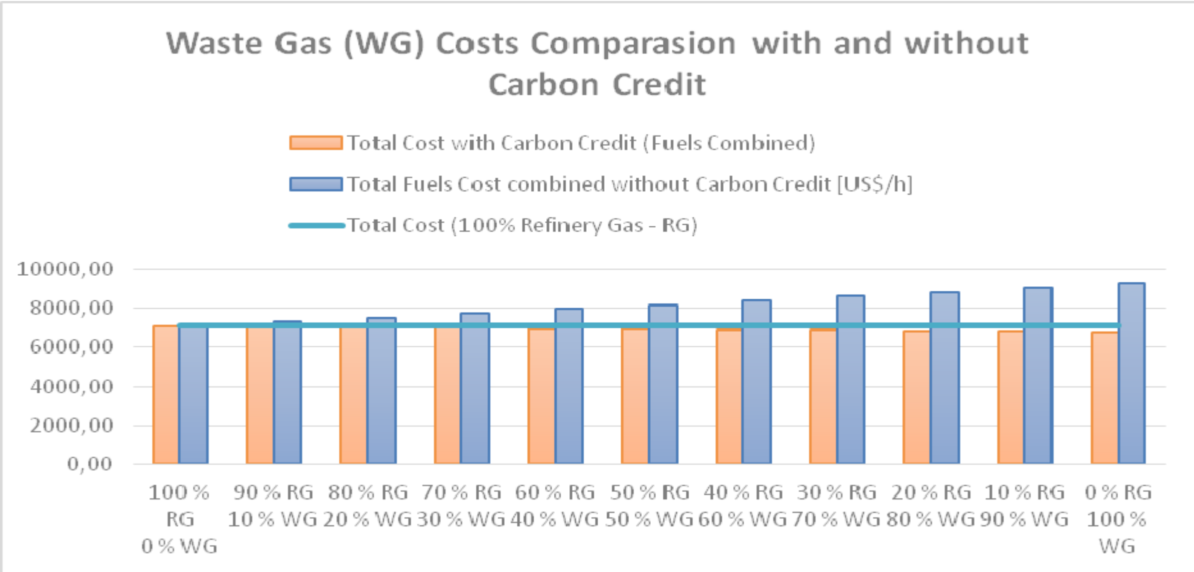

Fig. 4. Cost comparison, varying the percentage utilization of each of the fuels, with and without carbon credits.

RG = Refinery Gas

WG = Waste Gas

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AUTHORS

Anderson José Rangel de Oliveira
He and Electrical Industrial Engineer , Automation Specialist by SENAI/RJ (2008), MBA Project Management by FGV(2012). Maintenance Technical in PETROBRAS. Actually he is concluding the Master Degree in Fluminense Federal University(UFF).
andersonrangel7@gmail.com

Filipe Marques Paes da Costa
He is Brazilian and Chemical Engineer by UFF (2013), Operation Engineer in Essencis Soluções Ambientais. Actually he is concluding the Master Degree in Fluminense Federal University (UFF).
fpepaes@gmail.com

Lucas Novaes Barreto
He is Brazilian and Chemical Engineer by UFF (2013), Planning Engineer White Martins. Actually he is concluding the Master Degree in Fluminense Federal University (UFF).
lucasnbarreto@hotmail.com

Luiz dos Santos Moreira
He is Brazilian and Mechanical Engineer by Souza Marques University (2007), MBA Project Management by FGV(2012). He is a HVAC Specialist and research in Fluminense Federal University (UFF).
luizroux@ yahoo.com.br

Marcio Zamboti Fortes
He is Brazilian and Electrical Engineer by ENVA (1991), Master in Energy Engineering by UNIFEI (2000), Doctorate in Electrical Engineering by USP (2007). He is Adjunct Professor in Fluminense Federal University.
mzf@vm.uff.br

Bruno Soares Moreira Cesar Borba
He is Brazilian and Electrical Engineer by UFRJ (2005), Master and Doctor degree in Energy Planning by UFRJ (2008/2012). He is Adjunct Professor in Fluminense Federal University.
bborba@id.uff.br