International Conference on Renewable Energies and Power Quality (ICREPQ'18)
Salamanca (Spain), 21th to 23th March, 2018
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.16 April 2018

Thermoeconomic Analysis of Biomethane Large Scale Production for Cities from Landfill and Sewage Biogas

Nilma R. Barsallo[1], Álvaro I. Ochoa[1], Lesmes A. Corredor[1], Maira A. Sierra[1] and Iván Ochoa[1]

[1] Department of Mechanical Engineering
Universidad del Norte
Km 5 Vía Puerto Colombia, Barranquilla (Colombia)
Phone number: +57 5 3509509, e-mail: nbarsallo@uninorte.edu.co, aiochoa@uninorte.edu.co,
lcorredo@uninorte.edu.co, amaira@uninorte.edu.co , ochoai@uninorte.edu.co

Abstract.

Cities have several sources of biogas, i,e, landfills and sewages treatment plants, which are potential sources for producing pure methane. However, methane opportunity cost depends strongly of international oil and local gasoline and Diesel prices, when methane is oriented to substitute liquid fuels. A thermoeconomic model is required to evaluate the energy and economic feasibility to utilize in cities pure methane obtained from biogas of landfill and sewage sources. Authors have developed a biogas purification thermoeconomic model using ASPEN HYSYS® and exergy analysis to take into account variable chemical composition and distances of each biogas sources to the pure methane production plant. Three alternatives are presented, depending on the biogas rate production and the optimum use of the source. The first one considers crude biogas compression and transportation to pure methane production plant, the Second one considers electrical generation and the last one considers in situ biogas burning similar to fireplaces. Projects like this succeed in countries like Panama because lack of fossil energy reservoirs, and the obsolete Diesel technology in urban transportation, enough reasons for validating the simulation for the Panama City's anthropogenic methane large sources. Economic analysis includes forecast of the total initial investment, investment recuperation, maintenance and operational costs of the plant in order to set the pure methane generated in the plant as a competitive fuel in the national market.

Key words

Thermoeconomics, Biogas, Alternative fuel, Exergy analysis.

1. Introduction

Biogas Technology offers a very smart route to utilize certain categories of biomass for meeting partial energy needs. Proper functioning of biogas systems can provide multiple benefits to the users and the community resulting in resource conservation and environmental protection. But what makes biogas distinct from other renewable energies is its capability of controlling and collecting organic waste material. Unlike other forms of renewable energy, biogas neither has geographical limitations nor is required technology for producing energy and it either complex or monopolistic. [1] In cities there are several sources of biogas, landfills and sewages treatment plants, possibly in different areas of the city and with different gas composition. The composition of the biogas, depending on the feed material and the method of digestion, usually lies within the following range: 50-70% methane, 25-50% CO_2 and notable H_2S and other minor impurities. H_2S provides the biogas its bad odor. So it is necessary to upgrade the biogas of the several sources in order to obtain pure methane, cero H_2S, zero humidity, to apply new environmental methodologies for biogas exploitation in Latin-American.

For example, biogas represents a promising alternative fuel in these countries, especially for diesel engines, by substituting considerable amount of diesel fuels. Diesel engines have higher thermal efficiency compared to other types of engines, but the presence of carbon dioxide in the biogas reduces the burning velocity which ultimately affects the performance of the engine. Studies show that the presence of carbon dioxide in the biogas decreases the power generation. Biogas containing more than 45% CO_2 cause harsh and irregular running of the engine. The carbon dioxide content of biogas can be reduced by several upgrading process. These processes are usually expensive and complicated for developing technology implementations. [2]

Other variables are taking into account in order to implement the adequate upgrading technology, depending on the specific application; the next table summarizes the grade of cleaning for biogas in different applications:

Table 1. Grade of cleaning for de biogas in different applications.

Application	H_2S	CO_2	H2O	Other comp.
Stationary Engine	<1000 ppm	No	No	Yes *
Microturbines	<70 000 ppm	No	Yes	Yes *

Cogeneration	<1000 ppm	No	No condensation	Yes *
Cars	Yes	Yes	Yes	Yes *
Gas Rid	Yes	Yes	Yes	Yes *

*Siloxanes

2. (Upgrading) Absorption Technologies

In order to implement biogas exploitation systems in cities and to obtain useful biogas several upgrading technologies are available, so according their technologic and economic viability some of them are presented below:

Adsorption processes are diverse; however, their main difference lies in the adsorbent material used. Among the technologies implemented in the biogas cleaning beds, the principal types are activated carbon, silica gel and PSA [3].
The process of activated carbon adsorption is widely used in the removal of siloxanes [4]. This technology replaces cooling processes for the removal of siloxanes [5]. To ensure adequate adsorption process, it is necessary to implement pre-drying [6] [4]. The presence of contaminants such as H_2S reduces the life of activated carbon beds, and it is suggested to combine activated carbon beds with solvents [4] [7]. The carbon activated beds are partially regenerable and the regeneration process demands high energy rates, therefore they must be replaced in the long term [4] [7].

Pressure swing adsorption (PSA) combines separation and purification processes in a single step at high pressures and it is considered the most advanced technology in the field [7]. This process is cheaper and requires less energy expenditure compared to other separation processes such as absorption and distillation [8]. Adsorption process depends on the composite adsorbent used, being zeolites the more advanced compounds which have replaced the carbon-based compounds [8]. Natural zeolites, unlike their predecessors, allow the removal of more than one contaminant-by-step, eliminating the deployment of consecutive adsorption towers [8]. The implementation of natural zeolites requires the use of activation methods to improve their adsorptive properties [7] [8], the above implies an extra energy demand on the process. Unlike other processes that involve the regeneration of the stripper element, with the implementation of the activation process, zeolites do not lose their natural zeolite adsorption capacity, even the adsorption capacity increases cycle by cycle for H_2S and it is stable for CO_2 [4] [7] [8]. MolecularGate ™ developed a process to remove CO_2, H_2S and siloxane, allowing one process to convert landfill gas to methane [7].

Other alternative is **absorption process**. Scrubbing with amine solutions has the advantage of absorbing CO_2 and H_2S [9], and the most common Monoetanoamina allows a 98% removal of CO_2 [10]. Scrubbing with alkaline solutions has the advantage of H_2S absorption, eliminating problems of corrosion and foaming, which makes it less expensive, but the anti-foaming agent requires a more complicated operation equipment and high energy consumption for pumping solution and gases [11]. For organic absorption, a common absorbent is Selexol [12]. It has the advantage of being non-toxic, non-corrosive, and a high rate of solubility of CO_2, H_2S and humidity, reducing the size of the plant. [12]. Overall absorption processes have high operating costs.

There are a number of advantages that favor the use of this **membrane separation method** for biogas upgrading, among the most important is safety, ease of operation, easy maintenance and operation free of hazardous chemicals. Alongside this is the possibility that the plant can be operated without personal attention. This is important because in most plants those operators have no special training. [13].

This method has the advantage that separates methane from the H_2S and CO_2 [14] but the separation should be given at different stages and very specific membranes must be used [15]. The single-stage separation can't achieve the separation of CH4 and H_2S due to the property of the membrane mentioned above. On the other side of the flue gas at low pressure contains 12% of CH4 by volume, while the gas produced has an 88% volume CH4. It is recommended the use of multi-stage method is obtained as a purification of 98% by volume CH4 [12]. But the disadvantages are the low efficiency of separation of methane, high operating costs and the need for very high pressures, 4MPa [11] [16]. Compared with other processes of improving the implementation and operation costs are within the average range, this technology is one of the big promises regarding the improvement of biogas. [16]

The **Cryogenic Separation** is an advantageous technology since it can produce large quantities of upgraded high purity gas and does not require the use of chemical processes. [17] The disadvantage of the process is the large amount of equipment required for its implementation, the temperatures needed are about -50 degrees. This increases the costs of technology implementation. [12]

Finally, two of the latest technologies of biogas upgrading are: In Situ Methane enrichment and Ecological lung. The first offers the possibility of obtain a 95% CH_4 gas with no more than 2% of CH_4 losses, it is simple and it does not require a lot of auxiliary equipment the problem is that still limited to small plants [15]. In the other hand, Ecological lung has the possibility of obtain a 99% CH_4 upgrade gas, but at the present the technology is immature and very expensive [15].

In addition to the removal of siloxanes, CO_2 and H_2S, due to the need for further compression of the clean gas used as motor fuel is necessary to ensure that the humidity of gas is zero. From the technologies mentioned above, adsorption processes, if activated carbon is replaced by a bed of silica gel the removal rate of vapor in the mixture of biogas is increased, setting a stage of dehumidification [18]. Also, the membrane separation method can be modified to ensure low moisture levels in the resulting gas, the main advantage of this method is that selecting a specific membrane or configuration (hollow fiber membrane) allows preferential permeability of water vapor during the gas drying. But the drawback of this process is that some amount of feed biogas also passes through the membrane and get lost. In the US Patent 5,259,869 such problem is solved, using a recycling method that produces a negligible amount of biogas. Another method in the US Patent 4,718,921, authors presents a similar methodology to increase the efficiency of the drying gas and reduce operating costs.

A. Technologies Review

Table 2. Technologies review.

Absorption	Physic	Water Scrubbing	CO2
			H2S
			NH3
		Organic Scrubbing	H2S
			CO2
			N_2
			H_20
			O_2
	Chemical	MEA	CO_2
			H_2S
		DEA	CO_2
Adsorption		Activate Carbon	H_20
			CO_2
			Siloxanes
			H_2S
		Silica Gel	Siloxanes
			H_2O
		PSA	H_2O
			CO_2
			H_2S
Membranes		Zeolites	CO_2
			H_2S
Cryogenic		Condensation-solid removal	CO_2
			H_2S
			Siloxanes

Also exists commercial upgrading technologies patented by some companies for example:

Surfside Environmental Inc, licensed a simple and low cost technology for the removal of virtually all the hydrogen sulfide from any natural gas or liquid stream. This method works at ambient temperature and pressure. The device creates a bath of reacted water and the gas flows from the bottom of the device through a catalytic chamber and water bath then out the top of the device. Hydrogen sulfide present in the sour gas gets absorbed by the reacted water and is subsequently converted into elemental Sulphur and iron sulfide. The Sulphur thus generated is removed from the water bath by filtration. The reacted water is again passed through the device and recycled for further cleaning of sour gas.

Other international company dedicated to the gas improvement is Wittemman ™, offering plants depending on the component to remove, either acid or carbon dioxide.
The company Energy Waste Technologies from Spain also proposed solution specially to obtain biogas for automobiles uses from landfill gas.

The process includes, cooling of the biogas stream until 2 ºC to eliminate siloxanes, condensation to reduce humidity, scrubbing to reduce H_2S and NH_3, finally the utilization of activated carbon to eliminate siloxanes and halogens compounds.

3. Process Simulation

As it was discussed in the previous sections, the great difficulty for the implementation of the landfill biogas as fuel is that its composition is variable. To solve this problem, absorption technologies have been implemented, one of them is the absorption and desorption process for CO_2 removal with an aqueous MEA solution which has been simulated in this paper.

The biogas from Cerro Patacon landfill, as well as the nearest sewage, is used as the feed to this model. This biogas is compressed in each source and sends to the refinery, the average biogas flow received is shown in the next figure and was obtained from an EPA simulator.

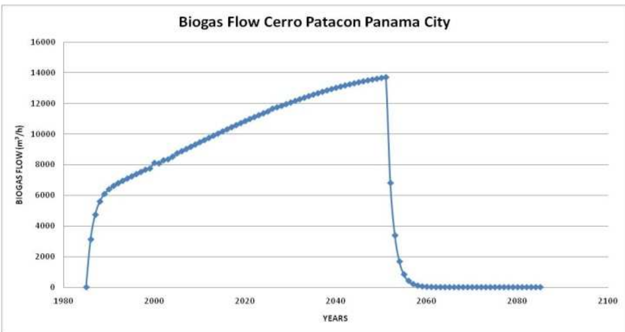

Fig. 1 . Biogas Flow in Cerro Patacon.

After the biogas is received, this is cooled using cooling water and sent to an absorption tower where the H_2S is removed and also is dried as is described in figure 2. This is a purification process to avoid the acid rain if the natural gas is burned within.

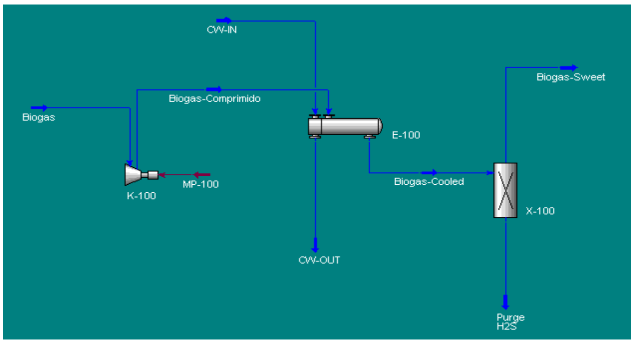

Fig. 2. Compression and adsorption process

In the simulation this stage is considered in a simple way to simplify the overall complex process. To remove the H_2S there are several options, one of them is the technology developed by Surfside Environmental, Inc., that has licensed a simple and low cost technology for the removal of virtually all the hydrogen sulfide from any natural gas or liquid stream. This method works at ambient temperature and pressure. The device creates a bath of reacted water and the gas flows from the bottom of the device through a catalytic chamber and water bath then out the top of the device. Hydrogen sulfide present in the sour gas gets absorbed by the reacted water and is subsequently converted into elemental Sulfur and iron sulfide. The Sulfur thus generated is removed from the water bath by filtration. The reacted water is again passed through the device and recycled for further cleaning of sour gas. The next step is other crucial stage at the refinery, where it is necessary to remove the CO_2 from the biogas as is described in figure 3. At this point the MEA aqueous solution absorption technology is applied; typical MEA concentrations as well as temperatures and pressures are used in the base case simulation. The thermodynamics for this mixture is simulated by an Amines Property Package available in Aspen HYSYS. This particular package is used because in this way it is possible to simulate the CO_2 absorption and desorption stages as happens in the real processes.

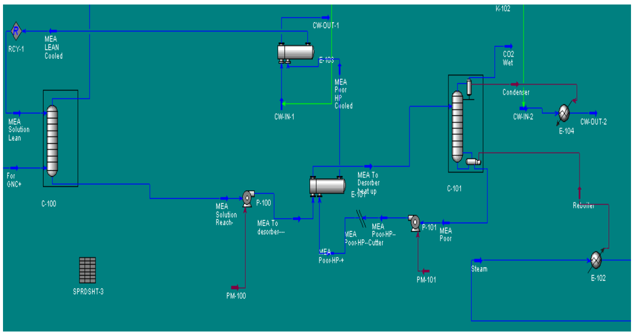

Fig. 3. CO_2 Adsorption and Desorption process

After CO_2 is removed from the main stream, this gas flows through the absorption column where a packed column of molecular sieves dehydrate it. After this process, biomethane is compressed in a two stages compressor with intercooler up to 21 bar and then is pumped to a pipeline network for vehicular, residential or electricity generation use. Residual heat from gas turbine is used for producing steam for biogas cleaning plant. An scheme of this stage is showed in figure 4.

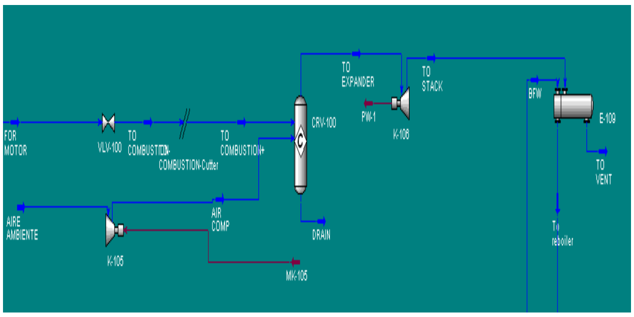

Fig. 4. CO_2 Adsorption and Desorption process

The other stream, the MEA rich is sent to a desorption column where the CO_2 is released to the atmosphere or also could be compressed for industrial application as soft drink bottlenecking. The poor MEA solution is sent back to the CO_2 absorption column.

4. Thermo-Economical Analysis

The variable plant operating cost can be calculated from the simulation results and the major equipment is dimensioned using Aspen HYSYS®. This information is used to calculate the overall investment of the plant using Lang Index Method [19]. The plant was designed for an annual capacity of 36 million Nm^3 natural gas. The results obtained for this project are summarized in Table 3.

Table 3. Total project investment required.

INVESTMENT:	
Currency Conversion Rate	1 USD/U.S. DOLLAR
Total Project Capital Cost	$ 27,440,451 USD
Total Operating Cost	$ 13,034,168 USD/Year
Total Raw Materials Cost	$ 6,266,860 USD/Year
Total Utilities Cost	$ 5,084,814 USD/Year
Total Product Sales	$ 27,467,040 USD/Year
Rate of Return	21.94%/Year
P.O. Period	5.60 Year

It is very important to sell the Certified Emissions Reductions (CERs) obtained for the capture of the methane produced during the organic matter decomposition in the land fill, to get a feasibility project. Methane in the Earth's atmosphere is an important greenhouse gas with a global warming potential of 21 compared to CO_2 over a 100-year period. This means that a methane emission will have 21 times the impact on temperature of a carbon dioxide emission of the same mass over the following 100 years [20].

The project was analyzed taking into account a sell price for the natural gas of US$ 0.5/Sm³ and 8 dollar cents per kW-h. Currently, in Colombia the natural gas cost at city gate US$ 2.4/MMBTU equivalent US$ 0.08/Nm³; however, this natural gas is sold to vehicles gas stations at US$ 0.77/Nm³. According to information reported in table 4, the project is attractive for investors for countries as Panama which do not have natural gas reserves.

5. Conclusions

A simulation model was developed based on the new absorption technologies as well as thermodynamics and heat transfer concepts. Experiments were carried out to improve the simulator and to confirm its accuracy. The program was run for different gas flows and compositions, and the results were used to design a biogas refinery that no matter the inlet composition is able to give a constant output composition for the biogas. The thermo-economic analysis prove that this is a feasible project that can be improved specially in countries without natural gas reserves where it can be implemented as fuel for vehicles or for domestic consume.

References

[1] M. B. &. H. Balat, "Biogas as a Renewable Energy Source—A Review," *Journal Energy Sources, Part A: Recovery, Utilization, and Environmental Effects,* pp. Pages 1280 - 1293, 2009.

[2] S. Bari, "Effect of carbon dioxide on the performance of biogas/diesel duel-fuel engine," *Renewable Energy,* vol. 9, no. 1-4, pp. Pages 1007 - 1010, 1996.

[3] Esteves, Adsorption of natural gas and biogas components on activated carbon, 2008.

[4] M. Ajhar, "Siloxane removal from landfill and digester gas – A technology overview," *Bioresource Technology,* p. 2913–2923, 2010.

[5] Reina, Humedad y siloxanos en el biogas generado en vertederos y depuradoras, 2006.

[6] Schweigkopfler, Removal of siloxanes in biogases, 2000.

[7] M. Tagliabue, "Natural gas treating by selective adsorption: Material science and chemical," *Chemical Engineering Journal 155,* p. 553–566, 2009.

[8] Alonso-Vicario, "Purification and upgrading of biogas by pressure swing adsorption on synthetic," *Microporous and Mesoporous Materials,* p. 100=107, 2010.

[9] Kadpi, Biogas scrubbing, compresion and storage: perspective and prospects in Indian context, 2004.

[10] Tippayawong, Biogas quality upgrade by simultaneous removal of CO2 and H2S in a packed column reactor, 2010.

[11] H. Llaneza, "Estudio de viabilidad de sistemas de purificacion y aporvechamiento de biogas," PSE PROBIOGAS, 2010.

[12] S. E. P. Agency, "Guidance on gas treatment technologies for landfill gas engines," Enviroment Agency, Bristol, 2004.

[13] A. Makaruk, "Membrane biogas upgrading processes for the production of natural gas," *Separation and Purification Technology 74,* pp. 83-92, 2010.

[14] E. Favre, "Biogas, membranes and carbon dioxide capture," *Journal of Membrane Science 328,* p. 11–14, 2009.

[15] B. IEA, "Task 24: Energy from biological conversion of organic waste," IAE Bioenergy, Oxfordshire, 2003.

[16] J. Reijenga, "IFP project Biogas upgrading," Eindhoven, 2008.

[17] A. Petersson, "Biogas upgrading technologies – developments and innovation," IEA Bioenergy, 2009.

[18] Pramuang, "The regeneration of silica gel desiccant by air from a solar heater with a compound parabolic concentrator," 2007.

[19] P. M. a. T. Klaus, Plant Design and Economics for Chemical Engineers 4th edition, Chapter 6..

[20] E. P. A. (EPA), "Inventory of US Green House Emissions and Sinks," 1990-2006..