CHEMICAL ENGINEERING TRANSACTIONS

VOL. 65, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Eliseo Ranzi, Mario Costa

ISBN 978-88-95608-62-4; **ISSN** 2283-9216

DOI: 10.3303/CET1865053

Multi-Objective Analysis of a CHP System Using Natural Gas and Biogas on the Prime Mover

Guillermo E. Valencia*[a], Luis G. Obregón[b], Yulineth E. Cardenas[c]

[a] Mechanical Engineering Department, Universidad del Atlántico, km 7 Antigua vía Puerto, Barranquilla, Colombia
[b] Chemical Engineering Department, Universidad del Atlántico, km 7 Antigua vía Puerto, Barranquilla, Colombia
[c] Research group in energy optimization, GIOPEN, College of Engineering, Universidad de la Costa. Barranquilla, Colombia
guillermoevalencia@mail.uniatlantico.edu.co

With the aim of reducing operational costs and gas emissions in a Combined Heat and Power System (CHP), a type of biofuel is proposed as a product of a process using a biomass resource to replace other types of fossil fuels, and to be able to cover the average annual scale of power demand of 24 MWh/day from a metallurgical plant, and a thermal energy demand of 60 MWh/day. This study shows the behavior of gas emissions and economic analysis through the use of HOMER Pro software depending on the type of fuel selected. The proposed system consists of a set of electric generators (2MW in total) and a boiler with a cogenerative system connected to the gas outlet of the electric generators. The results of the simulation showed that the system working with natural gas presents a decrease of 5.66% in the annual operating cost concerning the system that works with biogas. However, the biogas system causes a 19.39% decrease in carbon dioxide production compared to the other systems.

1. Introduction

Biomass is an energy source that that has the potential to play a significant role in the future energy matrix in many countries because it is energy globally available and renewable, unlike fuels such as oil and gas, which are concentrated in restricted geographical areas. Due to its physical characteristics, raw biomass has difficulties competing with fossil fuels in many applications (Batidzirai at al., 2013). IEA Bioenergy, which is an international collaboration on bioenergy under the International Energy Agency (IEA), investigated various renewable energy tasks concentrating on updating the raw biogas for various applications. However, it did not intend to give detailed descriptions of the technical or economic performance of the technologies (Persson, 2006). A Combined Heat and Power (CHP) system can be defined as the sum of individual components such as heat engine, generator, heat recovery system and electrical converter. With the CHP, the system captures the waste heat associated with the power generation that provides the electrical load to jointly supply the thermal load (Zafra at al., 2008). The size of the components of a CHP system with a solar, wind energy and hydrogen storage has been detailed (Lacko at al., 2014). It is important to consider the sizing and placing the CHP systems as distributed generation, due to they tend to improve the overall plant efficiency as it allows the heat recovery in an electricity production process (Benelmir R, 1998). Considering the fuel used in Europe (Basu at al., 2012), CHP development incitation was applied with success in Denmark with the “integrated approach to heat and electricity planning, decreasing the energy consumption and achieving the energy self-sufficiency. Denmark also became the first European user of CHP and a world CHP leader.
With HOMER Pro software which integrates fixed operation strategies, it can be able to simulate the restrictions and considerations of a real environment system to determine the optimal set through economic and greenhouse gas analysis (Jing and Bai, 2012).
Recent investigations using HOMER Pro software has determined that the devices that generate renewable energy are a better option to replace the electrical grid consumption (Barrozo et al., 2017, a, b, c). However, the building of systems to obtain renewable energy obtained through biogas and other energy resources is highly expensive. (Valencia Ochoa, et al., 2016, a, b, c, d). Though, with the application of an energy management system for energy planning the operation cost can be regulated, (Valencia et al., 2017), (Ramos

Please cite this article as: Valencia Ochoa G., Obregon Quinones L., Cardenas Y., 2018, Multi-objective analysis of a chp system using natural gas and biogas on the prime mover, Chemical Engineering Transactions, 65, 313-318 DOI: 10.3303/CET1865053

et al., 2017). The main contribution of this paper is to show a technical study of the CHP system using biogas as a primal fuel resource. An analysis of a single system working with biogas will be compared with the CHP conventional system, with the main objective of identifying new alternatives of electric generation systems with less greenhouse gas emission, instead of the traditional alternatives of electric generation systems.

2. Methodology

It was designed a system with two electric generators to supply an energy load of 24 MWh/day. The generators are two parallel gas micro-turbines with an individual output power of 1MW. A boiler with cogenerative system was required to supply 60 MWh/day of thermal load. This boiler was connected to the output gas of the gas micro-turbines to reduce the amount of heat generated by the thermal load. Both systems (electric and thermal) works with the same fuel, natural gas or biogas. A diagrammatic scheme for this system is shown in Figure 1.

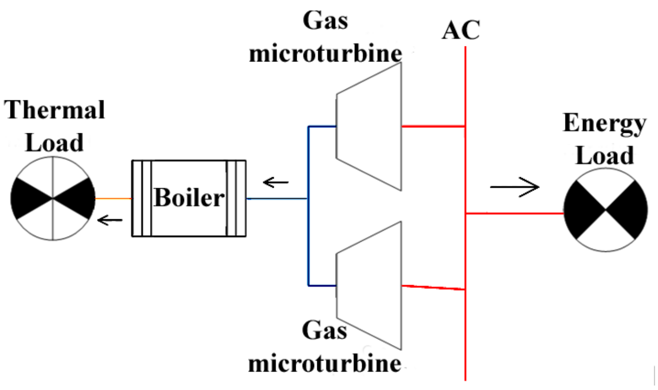

Figure 1. CHP system scheme

Two types of fuel were selected for this simulation, natural gas, and biogas. The natural gas is a fossil fuel obtained by mean of drilling a gas deposit inside the earth's crust, and the price for this study case was 0.28 €/m^3. The biogas is a renewable fuel obtained from biomass through anaerobic digestion, which is a process where the biodegradable material is discomposed in an environment without oxygen. This complex process is integrated by at least four stages, as shown in figure 2, where the microorganisms degrade the material causing a release of gases (carbon dioxide and methane with the highest proportion) that are implemented as a fuel resource to generate heat and power (Osorio and Valencia, 2017).
The biomass resources available are manure from livestock sector, urban organic solid waste, and others from the agricultural sector. Also, the biogas can be implemented to generate bio-methane which is fuel for vehicles or can be used to create organic compost. For this case study, the biomass resource is obtained from manure livestock sector with a price of 21.28 €/ton.

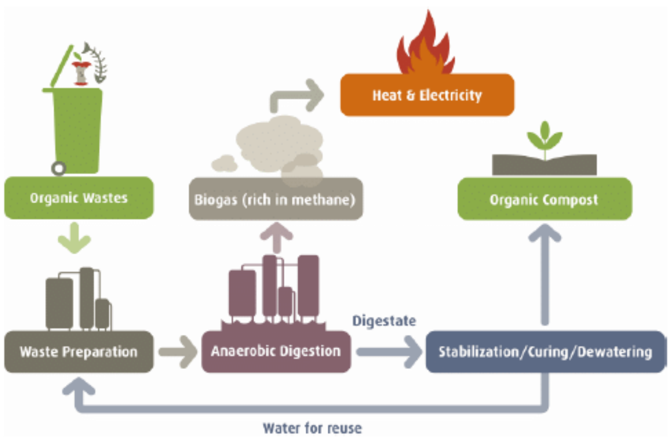

Figure 2. Biomass processing cycle

HOMER uses total net present cost (*NPC*) to represent the life cycle cost of the system as follow:

$$NPC\ (\$)=TAC/CRF \qquad (1)$$

where TAC is the total annualized cost, and *CRF* is the capital recovery factor calculated as follow:

$$CRF\ (\$)= ((1+i)N)/((1+i)N-1) \qquad (2)$$

where N is the number of years, and i is the annual real interest rate (percentage).
The cost of energy (*COE*), which is the average cost per kilowatt-hour ($/KWh) of electricity produced by the concerned system, is estimated as

$$COE\ (S)=Cann,ot/E \qquad (3)$$

Where, $Cann,ot$ is the annual total cost, $. *E* is the total electricity consumption, KWh/Year.

3. Results Analysis

An analysis of the energy load is required to determine the optimal devices needed for the case study where the energy load has an annual scaled average of 24 MWh/day, an average of 1 MW, and a pike of 1.8332 MW. As this metallurgical plant works continuously, the daily average load profile is constant for the 24 hours of the day as shown in Figure 3.

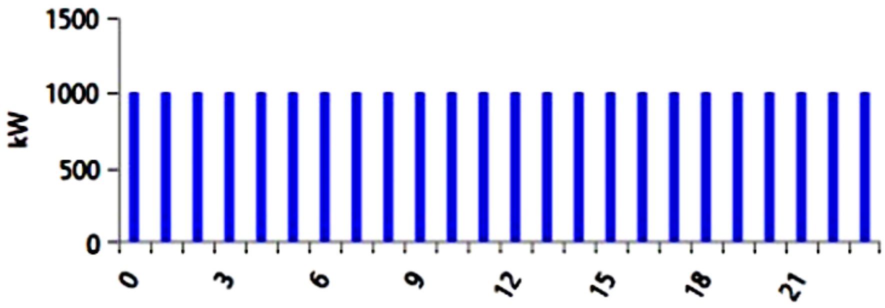

Figure 3. Daily average load profile

Because of the different factors that can change the load profile at different times of the day, the daily load profile shown in Figure 4 is just an expectative behavior of the load profile that can be changed due to irregular behaviors.

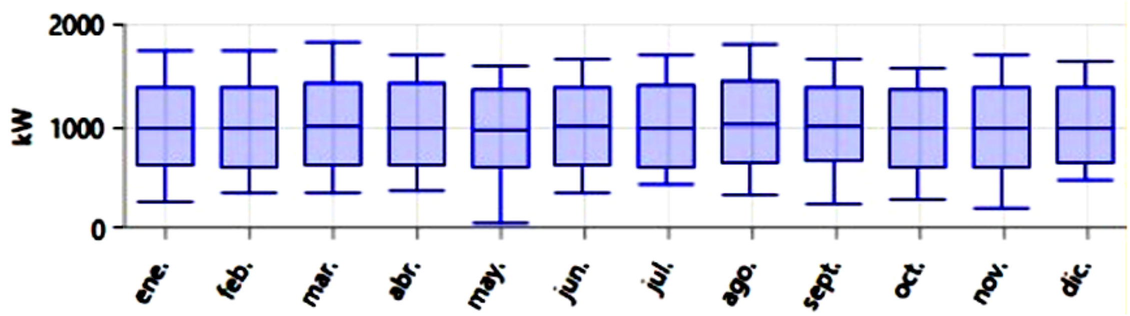

Figure 4. Monthly load profile

Finally, an annual load profile scheme can show how the load profile changes as a function of time. With the assistance of HOMER Pro software, the annual load profile was simulated only with the daily average load profile, and a fraction corresponding to a random variability that determines how the load profile changes over the time, is shown in Figure 5, with a random variability of 10% for this case study.

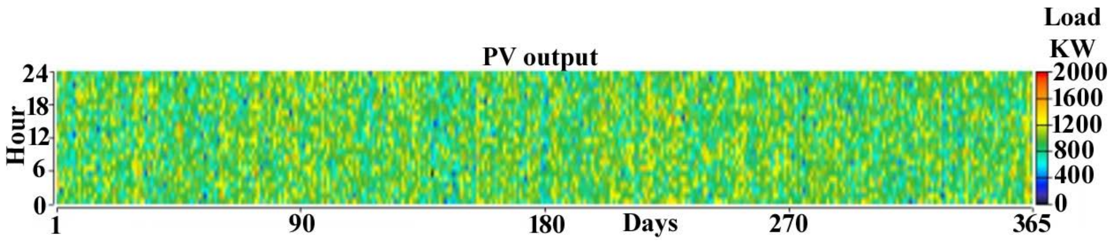

Figure 5. Annual load profile

A comparison of the annual operation cost, the total operation cost and the renewable fraction for both types of fuel allow determining the optimal system for this case study, as shown in Table 1. Then, it is possible to estimate which of those fuels are the most efficient for the system.

Table 1. Annual operating cost (AOC), total operating cost (TOC) and renewable fraction

Fuel	TOC (€/10years)	AOC (€/years)	Renewable Fraction (%)
Biogas	17.7 M	2.38 M	26.7
Natural Gas	16.68 M	2.26 M	0

It can be seen that the Biogas system has a total and annual operation cost, which is the operation cost for ten years of simulation and one year of simulation respectively, higher than the system working with natural gas. However, the system with Biogas has a renewable fraction of 26,7 %, while the other system has zero.
The system working with natural gas had a decrease of 5.76 % in the TOC and a decrease of 5.04 % in the AOC. The system working with Biogas had an increase of 26.7 % in the renewable fraction with respect the other system.
An energy production analysis is necessary to understand how the CHP system works and reduce the operating cost concerning systems with power and heat generations, as shown in Figure 6.

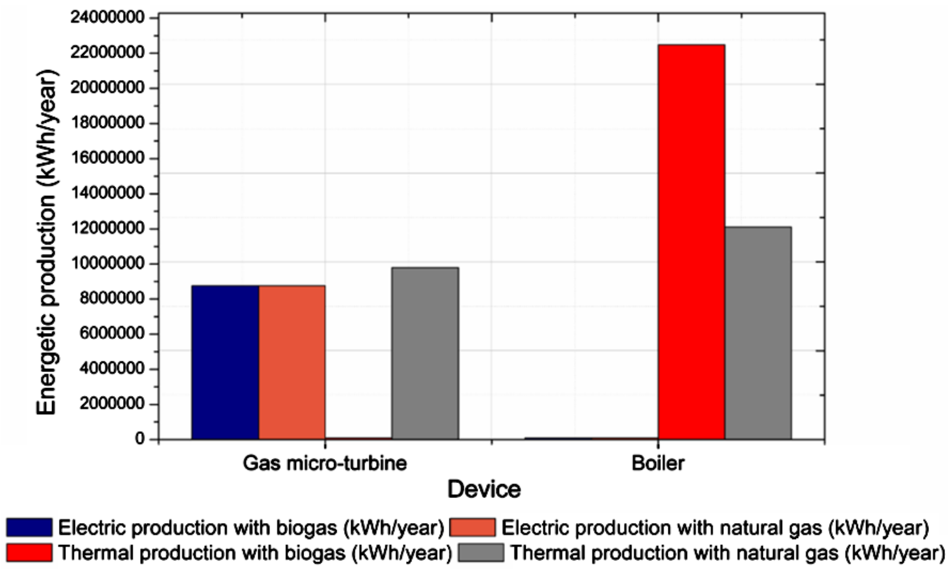

Figure 6. Electric and thermal energy production for Gas micro-turbine and Boiler

It can be seen that the thermal production for the Gas micro-turbine working with Biogas is zero, then if the system is working with Biogas as fuel resource, the Boiler will generate the total amount of the thermal energy required.
The electric production is the same working with both fuels because the cogenerative system is located on the boiler and not on the electric generator. Due to the boiler is a thermal device, the electrical energy production is zero. The thermal production for the system working with biogas is 44.7% less than the system working with

natural gas because the gas micro-turbine supply the 44.7% of the thermal load when the system works with natural gas.
Figure 7 shows that the system working with Biogas generates lower gas emissions than the system working with natural gas, reducing the harmful environmental effects.

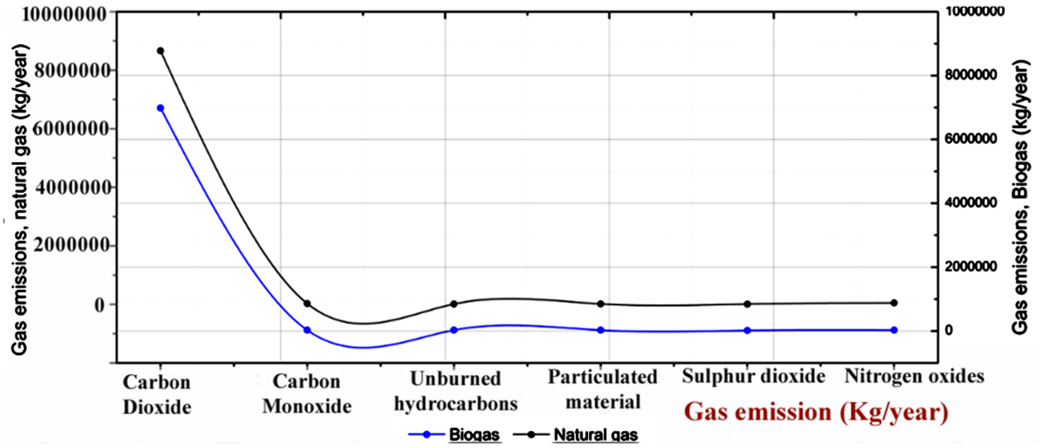

Figure 7. Gas emission comparison for Biogas and Natural gas

Considering that the amount of gas emission obtained for each component, and the operating cost using biogas and natural gas on the system, the use of biogas facilitated by natural gas is an economic and ecological solution that must be explored in different applications to replace the energy needs of the CHP.
Biogas can be used in generation systems in places where the availability of natural gas may be compromised, while natural gas is used in conventional electricity distribution services. Environmentally, the use of biogas contributes to the decontamination of waste and the reduction of soil, air and water pollutants, contrary to natural gas. Regarding the agricultural aspect, biogas can be considered as a natural fertilizer, which generates in its production effluents concentrated in nutrients such as nitrogen, phosphorus and potassium.

4. Conclusions

When there is a requirement to design a CHP system with a specific fuel resource, the Biogas is not the better choice. However, a system working with Biogas cause a decrease of 19.39% of the CO2 respect to the system working with natural gas, in comparison with the 5% of operating cost increase. It decreases the possibility of a CHP system as an option to consider when considering the protection of the environment.
The simulation did not consider the remuneration that many countries give to the industries and factories for reducing the gas emissions considerably. It makes the operating cost of the system working with biogas lower than the simulated.
The CHP is a possibility for a rural community energy generation system using biomass. However, a techno-economic study should be done to guarantee the right use of the renewable source of energy available. Stand-alone generation systems with biomass are financially viable at the short time under cogeneration systems.

Acknowledgments

This research was supported in part by the Mechanical and Chemical Engineering Department of Universidad del Atlántico with the Kai and the Sustainable Chemical and Biochemical Processes Research Group respectively. Y. Cardenas participation was granted by GIOPEN Research Group and Energy Department from Universidad de la Costa.

References

Batidzirai B., van der Hilst F., Meerman H., Junginger M., 2013, Optimization potential of biomass supply chains with torrefaction technology, Biofuels, Bioproducts and Biorefining, 8, 2, 25–282.

Basu A., Bhattacharya A., Chowdhury S., 2012, Planned scheduling for economic power sharing in a chp-based micro-grid, IEEE Transactions on Power Systems, 27, 1, 30–8.
Benelmir R., 1998, Energy cogeneration systems and energy management strategy, Energy Convers Manage, 39, 1791–802.
Lacko R., Drobni B., Mori M., Sekavnik M., 2014, Stand-alone renewable combined heat and power system with hydrogen technologies for household application, Energy, 77, 164–70.
Persson M., Jonsson O., Wellinger A., 2006, Biogas upgrading to vehicle fuel standards and grid injection. IEA Bioenergy, 37, 18–55.
Petchers N., 2012, Combined heating, cooling & power handbook: technologies & applications: an integrated approach to energy resource optimization, Fairmont Press, NY, United States.
Zafra A., Ridao M., Alvarado I., 2008, Applying risk management to combined heat and power plants, IEEE Transactions on Power Systems, 23, 3, 938–45.
Barrozo F., Escorcia Y., Valencia G., 2017, Hybrid PV and Wind grid-connected renewable energy system to reduce the gas emission and operation cost, Contemporary Engineering Sciences, 26, 1269-1278.
Barrozo F., Valencia G., Cárdenas Y., 2017, An economic evaluation of Renewable and Conventional Electricity Generation Systems in a shopping center using HOMER Pro, Contemporary Engineering Sciences, 10, 26, 1287-1295.
Barrozo F., Valencia G., Cárdenas Y., 2017, Biomass generator to reduce the gas emission and operation cost in a grid-connected renewable energy systems. International Journal of ChemTech Research, 10, 13, 311-316.
Valencia G., Vanegas M., Martinez R., 2016, Estudio de la persistencia del viento en la región Caribe colombiana con énfasis en La Guajira. Ed. Universidad del Atlántico, Barranquilla, Colombia
Valencia G., Vanegas M., Polo J., 2016, Análisis estadístico de la velocidad y dirección del viento en la Costa Caribe colombiana con énfasis en La Guajira, Ed. Universidad del Atlántico, Barranquilla, Colombia
Valencia G., Vanegas M., Villicana E., 2016, Atlas solar de la Costa Caribe colombiana, Ed. Universidad del Atlántico, Barranquilla, Colombia
Vanegas M., Valencia G., 2016, Atlas eólico de la Costa Caribe colombiana, Ed. Universidad del Atlántico, Barranquilla, Colombia
Ramos E., Valencia G., Cárdenas Y., 2017, Energy Saving in Industrial Process Based on the Equivalent Production Method to Calculate Energy Performance Indicators, Chemical Engineering Transactions, 57, 709-714.
Valencia G., Ramos E., Merino L., 2017, Energy Planning for Gas Consumption Reduction in a Hot Dip Galvanizing Plant, Chemical Engineering Transactions, 57, 697-702.
Osorio M., Valencia G., 2017, Exergoeconomic Analysis of a 30 kW Micro Turbine Cogeneration System Using Hysys and Matlab, Chemical Engineering Transactions, 57, 475-480.