SUSTAINABLE ENERGY FOR ETHANOL DISTILLERIES

By

G. ARIAS POLO

Cuban Sugar Research Institute
gariaspolo@yahoo.com.mx

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Abstract

The production of ethanol from the sugar containing feedstock generates waste waters coming from the bottom of distillation towers, well-known as vinasse. These constitute the biggest load pollutant. Using a group of parameters found in a wide list of international references, the present paper shows energy balances (of steam and electricity) using Excel, to demonstrate that biogas produced from the anaerobic digestion of this polluting load, besides degrading the vinasse, can contribute to the supply of energy demand to an ethanol distillery. The results are presented for medium, low and high values of pollutant concentration. It is intended also to use this energy to feed gas burners at conventional steam generators, removing the H_2S that contains the biogas in a process called desulfurisation. At the end, the main methods for desulfurisation for this combustible gas are recommended.

Introduction

The production of ethanol from the sugar industry generates waste waters coming from the bottom of distillation towers, well-known as vinasse. These constitute the biggest load pollutant.

The biogas production is one of several alternatives frequently used internationally for degradation of this polluting load.

There are reliable references about significant energy advantages that this alternative offers such as in Godbole (2002).

The target of the present paper is to show that biogas which can be generated from anaerobic digestion of vinasse in an ethanol distillery, besides degrading the vinasse, can contribute to a high percent of its energy demand.

Pollutant loads

Vinasse is defined as a solution of substances and mineral and organic salts with relative value and with potential for diverse uses.

COD (Chemical Oxygen Demand) measures the value of the contamination present in vinasse.

Factor selected for this calculation

The values of load pollutant selected for this work will be those proposed by Estévez (2007a) that are shown in the Table 1.

Table 1—COD characterisation of vinasse from the cane sugar industry (Estévez, 2007a)

Indicator	Non-harvest season	Harvest season
COD (kg/m^3)	60–80	30–40

As may be observed in Table 1, there are differences in COD vinasse composition generated in the harvest season period compared to those generated in the non-harvest season. This is due to a fundamental difference in the preparation of the substrate.

Harvest season period

To prepare the substrate, filter juices previously subjected to a purification process in the sugar factory are used. These juices can be blended with molasses B or may be added directly to reactors, as required.

Non-harvest season: Molasses 'B' or second crystallisation is used.

As the critical period for the energy demand of a distillery is the non-harvest period, because the energy from bagasse is not available, this paper will use the values of the range of the COD presented in Table 1 for this scenario. The volume of vinasse of 17.4 L vinasse/L ethanol is the value considered by this paper such as in Estévez (2007a).

Removing polluting load and conversion to fuel (methanisation)

Not all the COD becomes biogas. Five references are presented in Table 2 related to removal percent.

Table 2—COD removed by anaerobic digestion.

References	% of COD removed
www.monografias.com/trabajos15/tratamiento-destileria/tratamiento-destileria.shtml (2008)	75.0
Valdés (2007)	70.0
Estévez *et al.* (1975)	79.0
Moletta (2005)	80.0–95.0
Aroca *et al.* (2006)	93.0

Biogas produced from removed COD

In Table 3, three references related to removal rate are presented. It can be seen that practically they are similar.

Table 3—Rate of removal from COD to biogas.

References	Biogas production (Nm^3/kg COD removed)
www.monografias.com/trabajos15/tratamiento-destileria/tratamiento-destileria.shtml (2008)	0.45
Moletta (2005)	0.4–0.6
Aroca *et al.* (2006)	0.49

Efficiency of methanisation

The previously described process produces a methane porter gas. Its composition is presented in Table 4 from Domenech (2008a). In Aroca *et al.* (2006) and Molleta (2005), similar figures for methane content are given.

Table 4—Biogas composition.

Gas	Symbol	Vol **%**
Methane	CH_4	55–70
Carbon dioxide carbono	CO_2	30–45
Hydrogen	H_2	1–3
Nitrogen	N_2	0.5–3
Hydrogen Sulfide	H_2S	1.8–3

The biogas is a mixture of fuels, and methane is the one that gives the energy qualities.

Steam and electricity balances for a typical ethanol distillery of 50 000 L/day

Table 5 shows results of energy calculations, made by a calculation table using Excel from Microsoft Office, where the indicators and parameters discussed in Tables 1, 2, 3, and 4 are used. The steam and electricity balances for the distillery example of 50 000 L/day are shown.

The values of load pollutant are those that were presented in Table 1 and the rest of the calculations will be carried out in a range with a medium value and their two extreme values (low and high), using the previously analysed data.

Table 5—Biogas energy available for a distillery example.

1	Parameter	Low value	Medium value	High value	Unit
2	Ethanol production	50 000	50 000	50 000	L ethanol/day
3	Vinasse content	17.4	17.4	17.4	L vinasse/L ethanol
4	Ratio of COD produced	0.06	0.07	0.08	kg COD/L vinasse
5	COD removed	70.0	80.0	90.0	%
6	Ratio of biogas production	0.4	0.5	0.6	Nm^3 bio/kgCOD rem
7	Biogas produced	14 616.0	24 360.0	37 584.0	Nm^3 biogas/day
8	Methane in biogas	55.0	62.5	70.0	%
9	Methane produced	8038.8	15 225.0	26 308.8	Nm^3 methane/day
10	Fuel oil equivalent	6.88	13.02	22.50	t fuel oil/day

Table 5 shows figures of equivalent fuel oil obtained by biogas production. Further on will be determined what this biogas represents in energy availability with regard to steam and electricity demands for a distillery example.

The steam and electricity generation have a first and fundamental dependence on steam parameters. For this calculation, two levels will be considered: saturated steam at 11.35 bar abs and superheated steam at 18.25 bar abs and 330ºC.

A boiler efficiency of 88% with regard to the low heating value of the fuel is assumed.

A value of 100ºC water temperature for feeding the boiler is also assumed. Such water temperature value can be assumed when the vinasse is cooled using this water, a practice used in several factories of Torula yeast in Cuba according to Doménech (2008b).

Steam balance with saturated steam at 11.35 bar abs

In Table 6A, the steam balance carried out for the selected distillery is presented.

Table 6A—Steam balance with saturated steam at 11.35 bar abs.

	Parameter	Low value	Medium value	High value	Unit
1	Steam pressure	11.35	11.35	11.35	bar abs
2	Temp. steam superheated	185.48	185.48	185.48	ºC
3	Boiler Efficiency	88.00	88.00	88.00	%
4	Steam Enthalpy at boiler outlet	2779.95	2779.95	2779.95	kJ/kg
5	Feedwater Enthalpy	418.93	418.93	418.93	kJ/kg
6	Steam demand as Estévez (2007a)	0.294	0.294	0.294	t steam/hL
7	Available steam from biogas	4.25	8.04	13.90	t steam/h
8	Steam demand by Distillery	6.13	6.13	6.13	t/h
9	Steam generation by biogas	69.34	131.33	226.94	%

Table 6A shows results of steam generation by biogas in this steam variant. They are significant, even in the low extreme value (69.34%) with regard to steam demanded by the distillery. This confirms the benefit of using biogas. For the medium value analysed (131.33 %), the steam demand for the distillery is totally covered, which eliminates the necessity to use other fuels in the non-harvest season period.

Table 7A—Electricity balance with saturated steam at 11.35 bar abs.

	Parameter	Low value	Medium value	High value	Unit
1	Steam pressure at turbo inlet	10.70	10.70	10.70	bar abs
2	Exhaust pressure at turbo outlet	2.05	2.05	2.05	bar abs
3	Steam temp. at turbo inlet	182.70	182.70	182.70	ºC
5	Steam Rate of Turbo generator	21.00	21.00	21.00	kg/kW-h
6	Electrical demand standard as in Estévez (2007b)	17.33	17.33	17.33	kW-h/hL
7	Available electricity from biogas	202.25	383.05	661.92	kW
8	Electricity demanded by distillery	361.01	361.01	361.01	kW
9	Electricity generation by biogas	56.02	106.11	183.35	%

Electricity balance with saturated steam at 11.35 bar abs

Table 7A shows the results of the electricity generation by biogas in a turbo-generator which uses direct steam from a boiler considering some data presented in Table 6A. In the worst variant from the low value using biogas, more than half of the electricity (56.02%) is produced with regard to electricity demanded by the distillery.

In this case, for the medium value of electricity produced by biogas (106.11%), there is enough to cover the electricity demand by the distillery.

Steam balance with superheated steam at 18.25 bar abs and 330ºC

For this steam parameters level, more fuel by unit of mass will be necessary for generating the available steam from biogas. Table 6B shows that less quantity of steam will be available in this variant than in the previous one analysed.

Nevertheless, a significant 61.16% steam generation by biogas with regard to steam demand of the distillery is provided with the low value, and a large surplus in the medium (116.84%) and high values (200.16%) is achieved.

Table 6B–Steam balance with superheated steam at 18.25 bar abs and 330ºC.

	Parameter	Low value	Medium value	High value	Unit
1	Steam pressure	18.25	18.25	18.25	bar abs
2	Temp. steam superheated	330.00	330.00	330.00	ºC
3	Boiler efficiency	88.00	88.00	88.00	%
4	Steam enthalpy at boiler outlet	3095.80	3095.80	3095.80	kJ/kg
5	Feeding water enthalpy	418.93	418.93	418.93	kJ/kg
6	Steam demand as Estévez (2007a)	0.294	0.294	0.294	t steam/hL
7	Available steam from biogas	3.75	7.09	12.26	t/h
8	Steam demand by distillery	6.13	6.13	6.13	t/h
9	Steam generation by biogas	61.16	115.84	200.16	%

Electricity balance with superheated steam at 18.25 bar abs and 330ºC

Table 7B shows that the steam rate of the Turbo-Generator can diminish significantly with regard to Table 7A. As a consequence of this, the available electricity from biogas will be considerably higher in all cases, with regard to the variants previously analysed for saturated steam. In the low value, a good electricity generation by biogas (86.62%) and surpluses in the medium (164.05%) and high (283.48%) values are achieved.

Table 7B—Electricity balance with superheated steam at 18.25 bar abs and 330ºC.

	Parameter	Low value	Medium value	High value	Unit
1	Steam pressure at turbo inlet	17.56	17.56	17.56	bar abs
2	Exhaust pressure at turbo outlet	2.05	2.05	2.05	bar abs
3	Steam temp. at turbo inlet	310.00	310.00	310.00	ºC
5	Steam rate of turbo generator	11.98	11.98	11.98	kg/kW-h
6	Electrical demand standard as in Estévez (2007b)	17.33	17.33	17.33	kW-h/hL
7	Available electricity from biogas	312.70	592.23	1023.38	kW
8	Electricity demanded by distillery	361.01	361.01	361.01	kW
9	Electricity generation by biogas	86.62	164.05	283.48	%

It can be concluded that steam and electricity generation by biogas could be significantly beneficial for both levels of steam parameters studied, with the characteristic that there will be more steam generation by biogas in the variant at **11.35** bar abs (saturated steam) than at 18.25 bar abs and 330ºC (superheated steam). However, in this last alternative, there is more electricity generation by biogas than the first one. A particular study would help to decide the selected alternative. It is necessary to point out that steam generation in excess of the distillery demand has no practical sense in the analysed conditions. In this circumstance, biogas could be stored.

Elimination of hydrogen sulfide H_2S **from biogas (Desulfurisation**)

As was shown in Table 4, there is always significant sulfur content in the form of H_2S in produced biogas. The use of biogas directly as a fuel in steam boilers without purification has resulted in serious corrosion problems, which have led to failures such as in eco-efficiency for Australian dairy processors (2004).Therefore, in order to be able to use the biogas as fuel in steam boilers, it is necessary to carry out a desulfurisation process.

The commonly used desulfurisation processes, in general, can be classified in two categories, that is: (A) Desulfurisation in dry and (B) Desulfurisation in liquid phase.

(A) Dry Desulfurisation as in Kapdi (2004) is often used in homemade productions. This paper is related only to industrial productions.

(B) Desulfurisation in liquid phase.

One solution for H_2S removal in liquid phase is a commercial technology called Greenlane of FLOTECH as in www.flotech.com (2006). The raw biogas under pressure enters a scrubber through the bottom, making contact with water in a counter flow process, and the clean gas goes to an outlet at the top part. The CO_2 and H_2S are absorbed by the water.

Other processes frequently used for removal of H_2S consist of scrubbing of biogas with an alkaline solution. In the references are:

- *The use of hydrated lime as in Marchaim (1992)* in solid or liquid form. This substance has not been applied on a great scale for a long time, because of the big quantity of residuals with bad smell that occur and that cannot be eliminated satisfactorily. Big concentrations of CO_2 that are present in biogas composition make the satisfactory removal of H_2S difficult, since the CO_2 also reacts with the live or hydrated lime. Of course, the elimination of CO_2 is also convenient for using biogas as fuel. For this reason, this desulfurisation process could be considered if:

- Limestone is available in the market.
- When the residuals destination from the process is very secure.

- *Use of NaOH.* In a commercial system called THIOPAQ as in www.sta-at.com, NaOH is described as a washer or scrubber for biogas desulfurisation. The NaOH consumed in absorption of H_2S is continually regenerated in a bioreactor (biological method). The absorption of H_2S inside the scrubber is given under basic conditions. The washer liquid that contains the extracted sulfur of H_2S is transferred to the bioreactor where this sulfur is oxidised to elementary sulfur by use of a series of bacteria.
- *Using ferric solutions or ferric salts as ferric chloride.* There is a commercial system from Eco-Tec as in www.eco-tec.com BgPurTM or cleanser of the biogas, which is based on a high effectiveness device of contact gas-liquid. The scrubber or cleanser removes the H_2S from a current of gas using a purifying solution that uses a very well-known ferric chemical reducer. The vessel for regeneration of the polluted purifying solution uses atmospheric oxygen to convert H_2S to elementary sulfur. The regenerated solution, now free of H_2S, is returned to the cleanser vessel. The catalyst, the products of the reaction, and the preservative buffer are all acceptable environmentally.
- *Novel patent of Habets (1999).* The natural alkalinity generated during aerobic biological processes for purification of waste waters, i.e. a biomass carrier, can be used as washer instead of adding some alkaline chemical products. The aerobic treatment of the waste waters, which has an acquired alkalinity in a natural way, contacts the biogas that contains H_2S. The H_2S will be absorbed from the biogas in a water phase. The advantage of this treatment is that some chemical product is not added; therefore, the operational costs are low. An additional advantage is that the washer liquid which, at the end of process, contains the absorbed H_2S, can be recycled toward the aerobic treatment without difficulty and without some additional treatment. The scrubbing liquid that contains the extracted sulfur of the hydrogen sulfide is transferred to a bioreactor, where this sulfur is oxidised until elementary sulfur due to a series of bacteria.

Conclusions

Steam and electricity generation with the biogas production

The non-harvest season period was analysed because of the non-availability of bagasse as fuel. The generated energy by biogas was calculated by a program using Excel applied to a distillery example of 50 000 L/d. Steam and electricity balances were carried out for two levels of steam generation parameters: 11.35 bar abs saturated steam and 18.25 bar abs and 330ºC superheated steam. It was calculated for a medium value and extreme high and low values.

Steam generation

For the generation at 11.35 bar abs (steam saturated), the steam available is highly significant since, in the low value, there was an important steam generation by biogas of 69.34% of steam demanded and a wide surplus for the medium (131%) and high values (226.94%).

For 18.25 bar abs and 330ºC, an important steam generation by biogas of 61.16% for the low value with regard to steam demanded by the distillery and a large surplus in the medium (115.84%) and high (200.16%) values, although not as high as the previous case of saturated steam.

Electricity generation

For generation at 11.35 bar abs (steam saturated), the available electricity was significant since, for the low value, there was an electricity production by biogas of 56.02% of the demand and a large surplus in the medium (106.11%) and high (183.3%) values.

For 18.25 bar abs and 330ºC, more electricity was produced by biogas. In the low value, there was a good electricity generation by biogas (86.62%) and surpluses in the medium (164.05%) and high (283.48%) values.

It can be concluded that steam and electricity generation by biogas could be significantly beneficial for both levels of steam parameters studied, with the characteristic that there will be more steam generation by biogas in the variant at 11.35 bar abs (saturated steam) than at 18.25 bar abs and 330ºC (superheated steam) although, in this last alternative, there is more electricity generation by biogas than the first one.

Biogas desulfurisation systems that would be of use in ethanol distilleries offered for industrial scale presented here:

System GreenlaneTM of FLOTECH as in www.flotech.com (2006).

This system uses under pressure biogas at counter flow with water (It does not use chemical products) with a later recovery system for the same water using atmospheric air.

Use of hydrated lime as in Marchaim (1992)

This is in solid, or in liquid form. This means besides the H_2S, the CO_2 is also eliminated in biogas which is also convenient, provided that limestone is available and there are reliable means of disposing of the residuals with bad smell.

System THIOPAQ of STA-AT as in www.sta-at.com

The biogas enters in a washer with a liquid that contains caustic soda that absorbs H_2S. For regeneration of the scrubber liquid, this is transferred to a bioreactor, where the sulfur is oxidised thanks to a series of bacteria.

System BgPurTM of Echo-Tec as in www.eco-tec.com

The washer removes the H_2S using a watery solution for scrubbing with a very well-known ferric reducing substance. For regeneration of the washer solution, atmospheric oxygen is used which converts H_2S to elementary sulfur.

Novel patent of Habets (1999)

The natural alkalinity generated during an aerobic biological process for purification of waste waters; carrier of biomass, can be used as washer instead of addition of alkaline chemical products; therefore operational costs are low. Washer liquid, the one that contain the absorbed H_2S, can be recycled toward the aerobic treatment without difficulty and without some additional treatment.

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BILAN ÉNERGIE DURABLE POUR LES DISTILLERIES D'ÉTHANOL

Par

G. ARIAS POLO
Cuban Sugar Research Institute, La Havane, Cuba
gariaspolo@yahoo.com.mx

**MOTS-CLÉS: Traitement de Vinasse,
Production de Biogaz, Biogaz de Vinasse.**

Résumé

LA PRODUCTION d'éthanol à partir des substrats contenant du sucre génère des eaux usées provenant de la partie inférieure de tours de distillation, connues comme la vinasse. Celle-ci constitue le plus fort polluant du procédé industriel. À l'aide d'un groupe de paramètres selectionnés dans une large gamme de références internationales, le présent document comporte des bilans d'énergie (vapeur et électricité) pour démontrer à l'aide d'Excel que du biogaz produit à partir de la digestion anaérobique de ce polluant, en outre de la dégradation de la vinasse, peut contribuer à satisfaire la demande d'énergie d'une distillerie d'éthanol. Les résultats sont présentés pour des concentrations de vinasse à taux faible, moyen et élevé. L'étude vise également à utiliser cette énergie pour alimenter les chaudières conventionelles à vapeur, tout en supprimant le sulfite d'hydrogène contenu dans le biogaz par un procédé appelé desulfurisation. À cette fin, les meilleures méthodes pour desulfurer ce gaz combustible, sont recommandées.

ENERGÉTICA SOSTENIBLE PARA DESTILERÍAS DE ETANOL

Por

G. ARIAS POLO
Cuban Sugar Research Institute
gariaspolo@yahoo.com.mex

**PALABRAS CLAVE: Tratamiento de Vinazas,
Producción de Biogas, Biogas de Vinazas.**

Resumen

LA PRODUCCIÓN de etanol a partir de materias primas azucaradas genera aguas residuales del fondo de las columnas de destilación, bien conocidas como vinazas. Éstas constituyen la mayor carga contaminante. El presente trabajo, empleando un grupo de parámetros hallados en la larga lista de referencias internacionales, muestra balances de energía (de vapor y electricidad) empleando Excel, para demostrar que el biogas producido de la digestión anaeróbica de esta carga contaminante, además de degradar las vinazas puede contribuir a a abastecer las demandas de energía de una destilería de etanol. Los resultados se presentan para medianos, bajos y altos niveles valores de concentración de polutante. Se intenta, igualmente, emplear la energía para alimentar quemadores de gas en calderas de vapor convencionales, removiendo el H2S que contiene el biogas, por un proceso denominado desu; furización. Finalmente se recomiendan los mejores métodos para desulfurizar este gas combustible.