Energy Balance Development in a Cogeneration with Biogas for H_2 Production by Catalytic Reforming

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ABSTRACT

The main objective of this research was to carry out technically a mass and energy balances in an energy cogeneration plant with cattle excrement having biogas + natural gas as a fuel. It was used like raw material for hydrogen production.

Also to evaluate the economic pre-feasibility of the steam reforming plant using GN and Biogas + GN mixture fuels. An analysis of an electric energy cogeneration plant was carried out; this plant used biogas and GN. Based on these fuels, an industrial significant scale for this research was fixed, as a consequence an installed power of 75 MW was selected. Mass and energy balances were carried out over this installed power.

1 INTRODUCTION

Hydrogen can be produced in big amounts starting from primary energy sources such as fossil fuels (coal, petroleum or natural gas), different intermediaries (refinery products, ammonia and methanol) and alternative sources like biomass, biogas and waste materials. Water steam reform of natural gas represents approximately three quarter of the total hydrogen production. The process is based on the water steam reaction and the high- temperature methane over a catalyst. Other gases that have hydrocarbons are also suitable for the hydrogen production, such as different gases (biogas) coming from the biomass and waste anaerobe fermentation. [1,2,3]

A project that has the hydrogen production by the gas reforming, as a product of the biomass decomposition, is the example of the cogeneration plant in Tizayuca Hidalgo. The object of this plant is to obtain biogas, organic fertilizer and a water treatment plant. However it is also possible to obtain hydrogen by catalytic reform starting from biogas obtained from the cattle excrement wastes; as a consequence the biogas plant energy balance

will be perform, this balance will start from the plant process that will have the following stages: cattle excrement accumulation, anaerobe treatment digestores, liquid/solid separation, biogas production, motors and thermal recovery to give us electricity and heat. These results will permit us to determine by the biogas reforming the hydrogen quantity that was produced. It can be used as a fuel for the cogeneration equipment motors.

2 BIOMASS

In this research the following **Buswell** equation for the excrement biological reaction was used:

$$C_n H_a O_b + (n - a/4 - b/2) H_2O =$$
$$(n/2 - a/8 + b/4) CO_2 + (n/2 + a/8 - b/4) CH_4 \quad (1)$$

In the natural process the production is 60-70 by 100 CH_4 and 40-30 by 100 CO_2. It is constant basically for each type of biomass. This final gaseous product of the reaction is commonly named biogas. [7]

3 STEAM REFORMING

Steam reform is the common method to produce gases enriched in hydrogen. Methane, main component of the natural gas, reacts with steam according to the following equilibrium [8,9,10]:

$$CH_4 + H_2O \longrightarrow CO + 3H_2 \quad \textbf{(2)}$$

3.1 Reforming by Natural Gas, Biogas (methane) and GN + Biogas mixture

This section shows that starting from choosing the steam reforming process for hydrogen production, the energy balances will be used starting from three possibilities of fuels to know about the hydrogen production. It will be possible with the characteristics of the plant and of the reformer.

Fig 3.1 shows three possibilities of fuels in the steam reformer using the Tizayuca plant diagram. In this figure the steam reformer is added to produce hydrogen starting from three possibilities of fuels to develop material and energy balances; table 3.1 gives the calculation of the percentages that will be used in the RV.

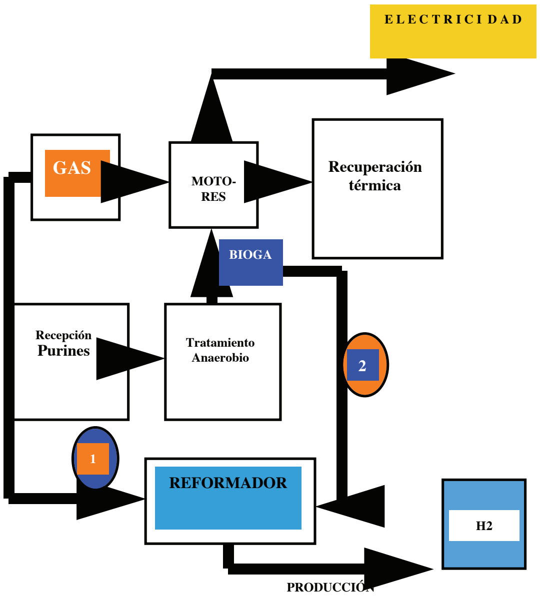

Fig. 3.1 Diagram of the different fuels for feeding RV to produce hydrogen in the Tizayuca Plant.

Table 3.1 Percentages of the compositions fuels.

	GN	Biogás	Mezcla Biogás + GN
Composición original (ton/d)	10.14	70.2	80.34
Composición original (m^3/d)	13170	58,500	71670
%	18.38	81.62	100

4 MASS AND ENERGY BALANCE RESULTS

We consider a global mass and energy balance of the steam methane reforming plant in a stationary state.

1. Reforming (molar)

$$CH_4 + 2H_2O \longrightarrow CO_2 + 4H_2 \quad (3)$$

$$\Delta H_R = 15.8 \left[\frac{MJ}{kg_{CH4}} \right]$$

2. Combustion (molar)

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O \quad (4)$$

$$\Delta H_R = -55 \left[\frac{MJ}{kg_{CH4}} \right]$$

When the mass and energy balance is performed for the steam methane reforming plant, the following reactions in a mass base are (kg).

1) $1CH_4 + 4O_2 \longrightarrow 2.75CO_2 + 2.25H_2O$
2) $3.48CH_4 + 7.83H_2O \longrightarrow 9.57CO_2 + 1.74H_2$

$4.48\ CH_4 + 4O_2 + 5.58H_2O \longrightarrow 12.32CO_2 + 1.74H_2$
$\Leftrightarrow$ $1CH_4 + 0.89O_2 + 1.25\ H_2O \longrightarrow 2.75CO_2 + 0.39H_2$

The one estequiometricamente molar is to:

$$1CH_4 + O.44O_2 + 1.12H_2O \longrightarrow 1CO_2 + 3.12H_2$$

4.1 Balance analysis

When we had the composition of the excrement reaction, we developed the mass and energy balance where we obtained, after developing a mass and energy balance in a stationary state, the following global process result expressed in molar terms (volumetrical): the first and third hypotheses gave the same result, 3.120 mol of hydrogen and 2.184 mol of hydrogen with regard to the second one. In conclusion biogas can be a fuel for the steam reforming process that can produce the same hydrogen quantity; also it can be produced using 100% of GN.

According to the excrement quantity used in the plant, it will be required a double increase of the quantity. As a result the steam reforming plant will work with 100% of biogas as a fuel. It is also important to mention that this biogas can be richer with regard to its calorific heat if different excrement mixtures are used such as excrements of pigs, cows and organic wastes. This is an important fact that can be part of later researches.

5 ECONOMIC EVALUATION

It was possible to calculate the following economic indicators, VPN and TIR because of the balances.

Table 5.1 Economic indicators that were obtained for the steam methane reforming process.

	RV	RV
	100% GN	**70%Biogás + 30%GN**
VPN (miles de US$)	$885.292	**924.557**
TIR	152%	152%

The balanced generation cost is the quotient of VPN cost and VPN of electricity production.

Costo nivelado de generación US$/kW	RV	RV
	100% GN	70%Biogás + 30%GN
	4.066	**1.539**

The one that emerged for biogas + GN mixture is 2.64 times smaller, regarding to the generation balanced cost.

5.1 Economic evaluation analysis

By the economic evaluation we have that the net present value VPN is bigger than zero in both cases, this is because of the investments costs, therefore they are part of the same magnitude. In conclusion the project is profitable. The internal rate of rebate is bigger than the deduction rate (9%); it is totally possible to obtain great benefits using biogas (methane) as a fuel in the steam reformer.

The main difference in the project profitabilities is because of the changeable costs. Using biogas (methane) as a fuel only the water process costs, cooling water and electricity have an influence, the raw material costs are reduced in a 70% because only 30% of GN is used.

6 CONCLUSION

It is technically feasible to operate a combine biotechnological plant of hydrogen production with the biogas properties and the mass and energy balances under the used conditions.

The biogas is generated starting from a solid waste quantity (excrement); when it is used as a fuel in a steam reformer we get the following mass and energy balance percentages for the hypotheses used in this work:

- First hypothesis: 100% of GN we obtain 99% of hydrogen.
- Second hypothesis: 100% of biogas we obtain 70% of hydrogen.
- Third hypothesis: a mixture of biogas + 30% of GN we obtain 99% of hydrogen.

It is feasible to use a biogas + GN mixture with regard to the economic evaluation since the hydrogen production costs by the steam methane reforming technology using as a fuel the biogas + GN mixture is cheaper; from the order of **US$0.1994 kg H_2**, in comparison with the hydrogen production costs using GN of the order of **US$0.469 kg H_2** as a fuel. As a result we get in both cases an annual production of **29.683.500** kg/year of H_2.

The result obtained for the biogas + GN mixture regarding to the generation balance costs is = **US$1.539/kW** and the one of GN is **=US$4.066/kW.** The first one is 2.64 times smaller.

This result proves that it is attractive, for the businessman, to invest in this type of combined biotechnological plants.

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