Biomass Gasification Unit Using Sugar Cane Bagasse for Power Generation

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Abstract: - The current need for sources of renewable energy towards the production of electric power and liquid fuels of synthetic basis have resulted on the development of strategies and technologies by many countries. Gasification processes present an interesting potential solution, but require the development of this technology operating with available biomasses. These systems based on renewable bio-fuels may not only supply the increasing demand of electric power but also replace existing conventional thermoelectric processes, therefore decreasing overall CO_2 emissions. However, there is plenty of room for the optimization of gasification technology using biomasses. Since 1978, Brazil has invested into bio-fuels alternatives, especially ethanol from sugar-cane processing and that has increased the bagasse production, which requires proper destination. The present study considers air as gasification agent in a flexible configuration of bubbling fluidized bed reactor operating from atmospheric pressure up to 20 bar. In the first condition it would provide net power output (referred at gas cold conditions) of 3 MWt and 66 MWt if operating at the latter higher pressure. In this last case, the gas may be used not just as a fuel for gas turbines and internal combustion engines for power generation but also as *syngas* to feed Fischer-Tropsch processes. The optimized conceptual design of the gasifier is described here and was achieved after optimization using the CSFMB (Comprehensive Simulator of Fluidized and Moving Bed Equipment). Simulations predicted the production of a syngas with high heating value as well stable operations at both atmospheric and pressurized conditions.

Key-Words: - Biomass, gasification, simulation, fluidized bubbling bed, power generation, syngas.

1 Introduction

Gasification technology has been developed over the last decades as an additional option for fuel production, as well as chemical substances, at a competitive price when compared with crude-oil based products. Even though such a technology has been extensively investigated and some high-power plants are operating around the world, many unknown variables are yet to be evaluated especially when related to operational conditions. Gasification plants have been applied for thermal and gas fuel production, but other units, which operate at output power above 200 MWt, have also been used for liquid fuel production upon applied Fischer-Tropsch technology. However, the main development has been performed when using coal as energetic [1,2] but the possibility on using biomasses for this purpose must be considered. In this last case, the use of waste biomasses can and should be applied for thermal and fuel gas production as an alternative source of available power to be integrated in many countries' energy matrix.

In countries with surplus of biomasses that are usually discharged to the environment, the use of such energy source as a baseline for the development of gasification units may be explored. Today, most systems used to produce thermal power in Brazil are either obsolete or present low performance; however, modernization is at a high speed. In this case, the application of gasification process using biomasses can be an option to improve the cycle's efficiency upon integrating it in a so-called BIG-GT (Biomass Integrated Gasification-Gas Turbine) [3-9] combined with Rankine Cycle (also called BIG-GT-CC). The overall cycle's efficiency is then higher than in standard equipments using boilers, which is also associated with low CO_2 emissions.

Depending on the range of power that the gasification unit should operate a given gasification technology could be applied but is not limited to the technology itself. Simple gasification units such as the ones using moving bed technology could be applied to operate at output powers as high as 2

MWt, which is also suitable for bubbling fluidized bed equipments. Following this route, gasification units operating on a given output power using bubbling fluidized bed can also find units working with circulating beds. The choice of technology that should be applied is dependent on the designers' experience, as well as the available budget and domain of the knowledge.

Since gasification has been extensively investigated mainly for coal, the use of biomass has found a wide range of applications in order to have a new option for power production. As biomasses usually present lower heating values when compared to coal, the design of the gasification unit must be carefully evaluated so the system can present high efficiencies and availabilities. Focusing on the need to develop highly efficient biomass gasification units, this paper has the objective to present the conceptual design of a unit able to operate within the range between 3 MWt (under atmospheric condition) up to 66 MWt (at a pressurization of 20 bar). For this design, a mathematical model called CSFMB (Comprehensive Simulator for Fluidized and Moving Bed) was used, which has been extensively validated over the last years [10,11] with remarkable correlation between real and calculated data.

2 Gasification Unit Characteristics

According to the needs for the market, considering the potential applications for this technology in 5 to 10 years, the biomass gasification units shall be able to deliver at least 200 MWt, which should be integrated in BIG-GT systems. In this case, one of the characteristics established by the market is the concept of modular units so parallel circuits could be implemented on the BIG-GT systems. Following this scope, along with the output power needed, units able to operate at least at 50 MWt would be suitable for the integrated systems, which would demand known technology and medium level of investments. During the time spent on the market evaluation and the need for power generation, it was found that units operating at a pressure of 20 bar would be suitable for the gas turbines that should be integrated on the system.

Following the requirements and characteristics taken from the market, the BIG-GT should present a biomass gasification system able to attend the following aspects:

- Bubbling fluidized bed technology should be applied;
- Flexible operation between atmospheric and pressurized condition;
- Output power of 3 MWt (worst case scenario) for sugar cane bagasse at atmospheric condition;
- Pressurized operation at 20 bar with sugar cane bagasse slurry feeding, based on the same equipment, generating an output power of 66 MWt.

The worst case scenario is related to the bagasse the way it comes out from the milling process, i.e. with moisture of 50%. For the particle distribution range, the costumer would supply this information and the equipment would be adjusted. Anyhow, for the conceptual project, a particle distribution range was established and will be presented later.

3 Conceptual Design – Mathematical Modeling

Figure 1 presents the schematics of the conceptual design for the biomass gasifier, which could operate at both atmospheric and pressurized conditions, while Fig 2 presents the details at the bed level. Differences on the fuel injection system are predicted, as for the atmospheric condition, regular biomass feeding systems can be applied with slight pressurization. For the 20 bar operation, pneumatic fuel injector or slurry feeding system are required. One should note that this level of pressurization is related to the injection pressure to the gas turbine for a cogeneration plant, as this project is related to multiple applications for the *syngas* as well as for synthetic fuel production.

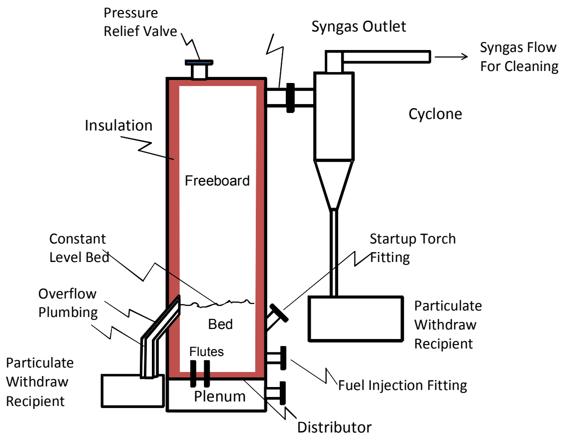

Figure 1. Conceptual design for the gasifier.

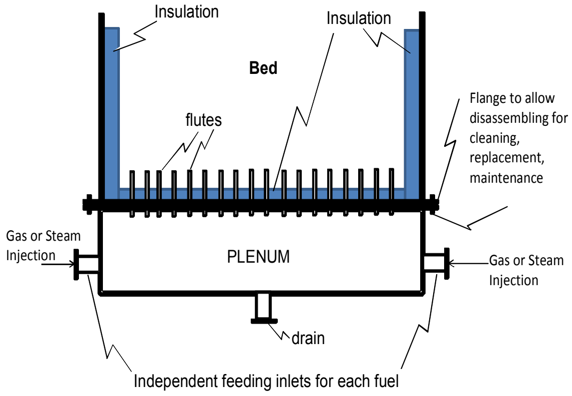

Figure 2. Project details at the bed level.

For the conceptual design of the gasification unit, the CSFMB software was used as it represents the most reliable tool to simulate fluidized bed equipments available on the market. Several validations have been performed in the past [10,11], which are the baseline for the application of this software on the future designs of gasification units. The latest version of this software (24.5) has been used with outstanding correlation regarding real equipments.

Exhaustive simulations were performed in order to achieve a unit with high cold efficiency at the output range established by the design requirements, along with optimized injection system in the bed with flutes. After an optimization procedure, the geometric characteristics of the biomass gasifier are as presented by Table 1. For the operational conditions, the biomass gasifier presents the flow rates and capacities as presented on Table 2.

4 Results and Discussion

Following the parameters established for the project, the biomass gasification unit cold efficiency around 50% and generating an output power of 3 MWt when at atmospheric conditions. In this case, the inlet air admitted in the plenum is around 350 °C in order to increase the overall cycle's efficiency upon recovering the heat available in the fuel gas. In this case, the output gas is fairly good even though it can be improved by making a few changes on the process in order to increase the CO, CH_4 and H_2 content. Table 3 present the gas composition and Figs. 3 to 5 present the bed temperatures, superficial velocities and temperature profiles in the freeboard obtained for the process, respectively.

Table 1. Main geometric characteristics of the gasifier.

Parameter	3 MWt (atmospheric) / 66 MWt (20 bar)
Bed diameter (m) / depth (m)	2.7 / 2.0
Reactor diameter (m)/ height (m)	2.7 / 5.0
Number of orifices for gas injection	64,000
Diameter of orifices for gas injection (m)	1 x 10^{-3}
Position of main gas withdraw (m)	7.0

Table 2. Flow rates and operational conditions.

Parameter	3 MWt (atmospheric)	66 MWt (20 bar)
Carbonaceous feeding rate (kg/s)	0.714	14.0
Gas feeding rate (kg/s)	0.785	15.0
Temperature of carbonaceous feeding (K)	293.0	293.0
Temperature of gas feeding (K)	650.0	300.0
Cold efficiency (%)	45.60	55.48
Combustion Enthalpy of Cold Gas (MJ/kg)	2.50	3.01

Table 3. Gas composition – gasifier at 3 MWt atmospheric operation.

	MASS PERCENTAGE	MOLAR PERCENTAGE
Ar	0.0000	0.0000
H2	1.6372	21.2412
H2O	0.0000	0.0000
H2S	0.0055	0.0042
NH3	0.0407	0.0625
NO	0.0277	0.0242
NO2	0.0001	0.0001
N2	54.1002	50.5130
N2O	0.0000	0.0000
O2	0.0000	0.0000
SO2	0.0074	0.0030
CO	5.4051	5.0473
CO2	38.6849	22.9908
HCN	0.0000	0.0000
CH4	0.0547	0.0892
C2H4	0.0125	0.0117
C2H6	0.0056	0.0049
C3H6	0.0065	0.0040
C3H8	0.0000	0.0000
C6H6	0.0117	0.0039
Tar	0.0000	0.0000
H-Tar	0.0000	0.0000

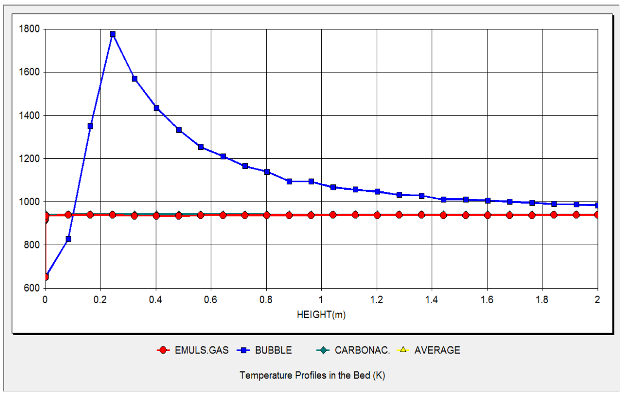

Figure 3. Bed temperatures – gasifier at 3 MWt atmospheric operation.

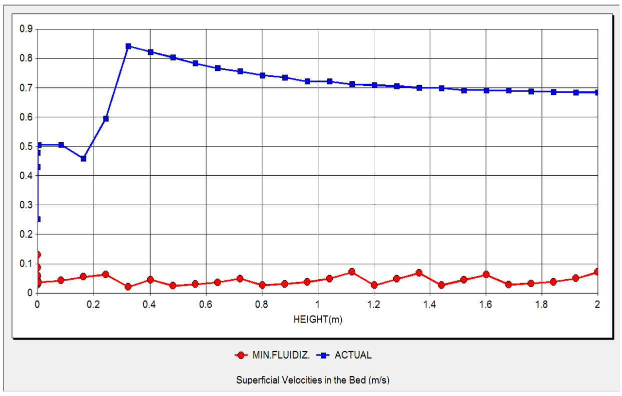

Figure 4. Superficial velocities – gasifier at 3 MWt atmospheric operation.

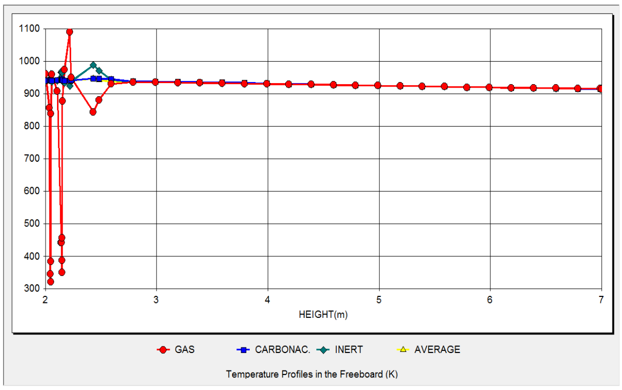

Figure 5. Temperature profiles in the Freeboard – gasifier at 3 MWt atmospheric operation.

Even with a moisture content of 50% in the sugar cane bagasse, the gas quality is relatively good and can be improved upon adding inert (like sand) and adjusting the operational mode of the gasifier in order to improve its thermochemical process, or drying it for moisture levels between 25 and 30%. Since the gasifier at 3 MWt operating at atmospheric condition represents the worst case scenario, improvements on the equipments performance is possible.

For the operation at 66 MWt, an increase on the flow rate of air and biomass is necessary to overcome the gasification requirements for higher performance and output power. In this case, the gasifier is fed with slurry composed by glycerin and sugar cane bagasse, which solves two emerging problems: 1) the use of glycerin as the slurry agent helps giving a proper destination for this biodiesel by-product and 2) biomass feeding at pressurized conditions is a major problem in gasifiers and slurry is recommended. For this operation condition, the gasifier presents a cold efficiency above 50% with a gas with good quality, which is suitable for injection in gas turbines. Table 4 present the gas composition, and Figs. 6 to 8 present the bed temperatures, superficial velocities and temperature profiles in the freeboard obtained for the process, respectively.

The conditions at which the gasifier operates with the slurry feeding (glycerol + sugar cane bagasse) at 20 bar requires around 50 ton/h of injection, which is significant on the point of view that a considerable stocking area is necessary. On the same way, gas cleaning systems need to be correctly sized to be able to deal with the gas flow rate, temperature and pressure, which shall then be injected in the gas turbine grid for power generation.

Table 4. Gas composition – gasifier at 66 MWt and 20 bar operation.

	MASS PERCENTAGE	MOLAR PERCENTAGE
Ar	0.0000	0.0000
H2	1.7284	22.1238
H2O	0.0000	0.0000
H2S	0.0061	0.0046
NH3	0.0480	0.0727
NO	0.0187	0.0161
NO2	0.0000	0.0000
N2	52.3824	48.2527
N2O	0.0000	0.0000
O2	0.0000	0.0000
SO2	0.0072	0.0029
CO	6.5466	6.0311
CO2	38.7131	22.6987
HCN	0.0000	0.0000
CH4	0.4600	0.7400
C2H4	0.0254	0.0233
C2H6	0.0150	0.0129
C3H6	0.0175	0.0107
C3H8	0.0000	0.0000
C6H6	0.0315	0.0104
Tar	0.0000	0.0000
H-Tar	0.0000	0.0000

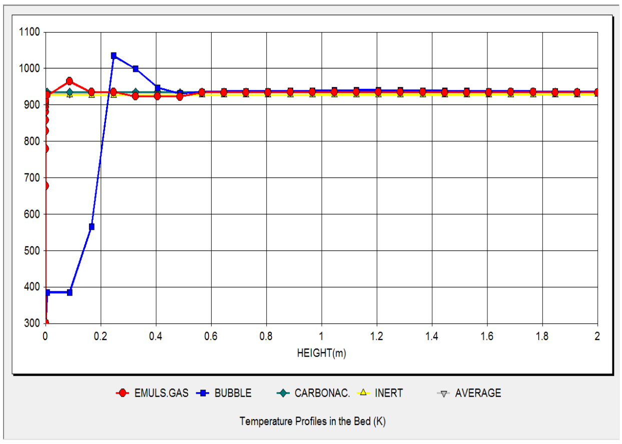

Figure 6. Bed temperatures – gasifier at 66 MWt at 20 bar operation.

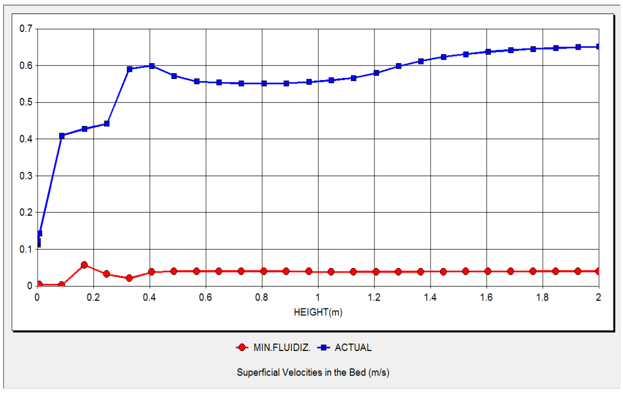

Figure 7. Superficial velocities – gasifier at 66 MWt at 20 bar operation.

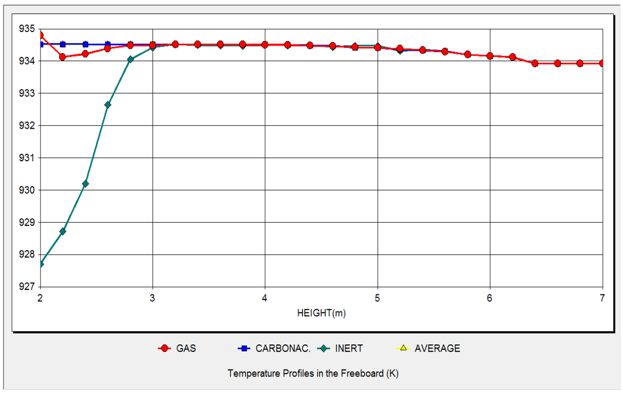

Figure 8. Temperature profiles in the Freeboard – gasifier at 66 MWt at 20 bar operation.

The conditions at which the gasifier operates with the slurry feeding (glycerol + sugar cane bagasse) at 20 bar requires around 50 ton/h of injection, which is significant on the point of view that a considerable stocking area is necessary. On the same way, gas cleaning systems need to be correctly sized to be able to deal with the gas flow rate, as well as it must comply with alkaline removal and particulate filtering for the gas turbines requirements, temperature and pressure, which shall then be injected in the gas turbine grid for power generation. Heat recovering systems that use the waste heat to generate steam are also considered on this project, in order to have steam power generation to improve the cycle's efficiency.

In the case of BIG-GT units, they shall be installed in the field where the sugar cane plantations are located in order to minimize the logistics with the bagasse transportation. Parallel grids of gas turbines with heat recovery systems for steam generation and steam turbines shall be integrated in the system in order to improve the overall cycle efficiency, in such a way that a maximization of the power production is achieved. Depending on the costumer's needs and requirements, the generated *syngas* can be used to produce synthetic liquid fuels upon applying the Fischer-Tropsch technology [12]. Such application is highly desirable in order to have different products coming from the same plant, as electricity can be generated from part of the *syngas* and the remaining can be used for extra production of ethanol, methanol, diesel and gasoline, among other sub products that are highly desirable by chemical purposes, such as Dimethyl Ether (DME).

5 Conclusions

The conceptual design of a biomass gasifier that operates on a BIG-GT cycle has been presented, showing flexibility to operate between 3 MWt (atmospheric condition) and 66 MWt (pressurization of 20 bar), using the same structure and reactor. The mathematical simulations showed high efficiency for the equipment operating with sugar cane bagasse with moisture of 50% when operating at atmospheric condition and slurry formed with glycerol for the 20 bar condition. For such an operational condition, the gas generated can be applied for power generation upon injecting it in gas turbines with heat recovery systems for steam production, in order to improve the cycle's thermal efficiency. The *syngas* generated with the gasifier operating at 20 bar can be applied for synthetic fuel production, expanding the number of final products available from the same plant, ranging from electricity to fuels such as ethanol, methanol, diesel, gasoline and Dimethyl Ether (DME). The overall application of the presented conceptual design will be of great importance for the future of the power matrix in Brazil, as well as in other countries where the biomass is available and can be used for energy (thermal and electric) generation.

Considerations are being done regarding the increase on the ethanol production, as well as other fuels, using Fischer-Tropsch technology [12], which would directly impact on the sugar cane production associated with sugar and ethanol. In this case, the increase on the sugar cane plantation is not necessary as the biomass is enough to meet those expectations, which will be properly presented in future reports.

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