METHODOLOGY FOR DESIGN AND INSTRUMENTATION OF A DOWNDRAFT GASIFIER

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Abstract. *The Gasification is one of the more promising technologies for thermochemical conversion of solids fuels such as biomass. The conversion is achieved by reactions between a feed gas and feedstock. Gasification, at least of coal, is one of the town gas industries until the widespread introduction of natural gas. The literature of gasification is fragmented with almost all recent, post 1990, contributions being confined to conference papers or articles in the appropriate journals. The knowledge of gasification is mostly confined to commercial process licensors and the operators of existing plants. Therefore there is little opportunity for outsiders to acquire an independent overview before embarking on a project of their own. In the practical realization of gasification processes a broad range of reactor types has been used. For most purposes these reactors can be grouped into one of these categories: moving bed gasifiers, fixed bed gasifiers, fluid bed gasifiers and entrained flow gasifiers. The aim objective of this work is to present a methodology for desing and instrumentation of a downdraft fixed bed gasifier. A series of parameters and components of the equipment were discussed. The criteria of choice and desing for different parts such as the reactor, the bed zone, the fuel feeding system, the air distribution system and others were presented. This work also aims to present the experimental planning and the instruments specification to be used for measurements during gasification tests. The result of this work includes a methodology: to identify the parameters to be monitored during the process, to specify the instrumentation involved, for choosing the parameters of the reactor project and all the major constituents of a gasifier*

Keywords*: design, instrumentation, downdraft gasifier.*

1. INTRODUCTION

The first experiments to convert coal to gas occurred in the 18 century, since then the gas industry of coal has developed new techniques for gasification, these techniques was emerged mainly in Europe.

At the start of First World War, small gasifiers were developed using charcoal or biomass in the operation of vehicles and electric generators, which most of them were made by amateurs. Currently there is a lot of material on gasification of biomass, books, articles, and the most important studies that serve as reference were conducted before 1950.

The gasification technology for the last decade has been commonly used in the electricity generation as part of the so-called "Clean energy", this occurs mainly due to the effect of high costs and the continuous increase of the oil price and the growing use of waste from industries, which were previously discarded and which now show attractive economically, turning into fuel for alternative power generation systems. Regarding other types of renewable energy, biomass energy is a chemical conversion, has reputation for its high energy density and the easy storage. Another important factor is the similarity between internal combustion engines and systems of energy production using biomass and using fossil energy.

Gasification is a process that converts carbonaceous materials to a combustible or synthetic gas (e.g., H, CO, CO, CH). Generally, the gasification process involves a carbon reaction with air, oxygen, steam, carbon dioxide, or a mixture of these gases at 1,300°F or higher to produce a gaseous product that can be used to provide electric power and heat or as a raw material for the synthesis of chemicals, liquid fuels, or other gaseous fuels such as hydrogen. When a solid or liquid material that contains carbon is converted to a gaseous state, some undesirable substances such as sulfur compounds and ash may be formed from the gas. Differently of combustion processes, which work with excess air, the gasification operates on substoichiometric conditions with the oxygen supply controlled.

Then the gasification is a process of converting solid fuel into gaseous fuel, formed by the partial combustion, knowledge about the relationship between the chemical and physical mechanism during gasification is of fundamental importance for the best design of a gaseifier.

Different gasifiers types could be applied to the biomass gasification process such as moving bed and fixed bed gasifiers.

Jayah T. H. (2002) developed a design of a downdraft wood gasifier for tear in Sri lanka. The gasifier has been fabricated in Sri Lanka for tea industry; the experimental tests with the reactor on several conditions produced later a simulation program. The aim of the numerical computer was to calibrate the models that were been developed, Jayah TH, *et al.* (2003).

Tiangco *et al*. (1996) proposed an experiment with four sizes reactors where it was evaluating the effect of the scale on. The reactor performance was demonstrated in this paper, a number of theoretical and experimental tests were carried out that help to establish the gasifier size according to various parameters as: cold gas efficiency, fuel flow, gas flow, gasification rate. From the results of experiments obtained by the author, it was possible to find an empirical relationship between the cold efficiency of gas depending on the LHV and the rate of gasification.

Coronado *et al.* (2006), proposed a work rich in information on how to design a trigger for a gasifier for internal combustion engine. In this investigation it was used a methodology for scaling a downdraft gasifier, it was also proposed an energetic analysis and selection of equipment for this gasifier type. The results include the methodology of how to select the type of gasifier, parameters of the design and data from the mass and energy balances.

The best design of downdraft gasifier produces tar; according to literature that is 50 times higher concentration in that ideal. The concentrations of tar are cleaned using an efficient system of cleaning as the scrubber systems reported in the work of Karuppaswamy *et al.* (1993).

The purpose of this paper is to present a methodology for the design and instrumentation of a small scale downdraft gasifier mounted in the laboratory of the EBMA (Grupo de Energia Biomassa e Meio Ambiente) of Mechanical Engineering School, Federal University of Pará. The study is a part of a project to implement a gasifier to produce gas for electrical energy generation to isolated communities on the Amazon region using açai as biomass.

2. THE PROJECT OF GASIFIER

The design of a gasifier begins with the choice of some parameter to keep it fixed. For this study the parameter was the amount of gas being produced. From this amount established, a methodology for calculating other variables was adopted. In sequence, the second step was to determine the quantities to be measured such as temperature, pressure, etc. Finally the instruments to obtain the quantities were specified.

2.1. Material selection.

The gasifiers are commonly constructed using a simple material and easily founded on the market, such as steel tubes, steel sheets among others. To select the material for a gasifier is necessary to evaluate a lot of parameters of its operation, such as the maximum pressure, temperature operating on this equipment, what type of fuel they use, and consider that some components of gasifier will be subject to corrosion. Generally downdraft gasifiers use three layers of different materials in the manufacture of the reactor. An outer layer of steel carbon usually have small thickness around 5 mm, this layer is called the structure of gasifier, a sublayer consists of an insulating material around 20 mm and its function is to absorb possible dilations, finally, inside the reactor has a brick refractory layer of around 110 mm and its function is to act as a thermal insulator. For the present gasifier it was used as insulating heat material the Manta Durablaket 128 kg/m3 which supports a maximum temperature of 1400 °C, the internal body consists of a ceramic refractory which supports a maximum temperature of 1800 °C, for the outer layer it was used a commercial stainless steel.

2.2 Scaling the reactor.

2.2.1. Cross section area of reactor

For scaling the gasifier it was used as reference the work of Tiango *et al.* (1996), the work presents a simple methodology based on several other works founded in literature.

First it is necessary to know the following: specific rate of gasification ψ [kg/m^2-h] what is between $100 \leq \psi \leq 400$. The initial value is 200 kg/m^2-h, desirable electric power generator for the group P_m [kW], lower calorific value of fuel (wet basis) low heating value LHV [MJ/kg], mass flow of fuel $\dot{m}_f$ [kg/h].

Initially the energy of the fuel (q_f) , was calculated by the equation (1)

$$q_f = \dot{m}_f . LHV_f \tag{1}$$

From the equation (2), the efficiency of gas.(η_g) was determined as:

$$\eta_g = \frac{1}{LHV}\left(17{,}8627 - \frac{930{,}7079}{\psi} - 0{,}0231\psi\right) \quad (2)$$

Subsequently, we determine the energy flow of gas (q_g) from the equation (3):

$$q_g = q_f . \eta_g [g] \quad (3)$$

The lower calorific value of gas LHV_{gas} can be determined through the equation (4):

$$LHV_{gas} = 5{,}9417 - 8{,}2893x10^3\psi [MJ/Nm^3] \quad (4)$$

Set the power lower calorie gas, it is possible to calculate the flow volume of gas (V_g) using the equation (5):

$$V_g = {q_g}/{LHV_g} [m/h] \quad (5)$$

The speed surface(ν) will be determined using the equation:

$$\nu = 2{,}7878\psi - 156{,}65[m/h] \quad (6)$$

Finally, to determine the area of cross section of the reactor(A_r) use the equation (7):

$$A_R = \frac{V_g}{\nu} \ [m^2] \quad (7)$$

2.2.2 Gasifier height.

To determine the minimum required gasifier height is necessary to establish the frequency with which the gasifier will be fed, in general, this time varies from ½ to 5 hours and the maximum height of gasifier depends on the maximum height of where they will install the equipment. With a known value of the mass flow fed and the time is possible to determine the mass of fuel that will be consumed in the process for a certain time, using the Eq. (8).

$$m_f = \dot{m}_f . t \ [kg] \quad (8)$$

From the known mass value, the height of the reactor is determined using Eq. (9).

$$H_R = m_f / A_r . \rho_f [\mathrm{m}] \quad (9)$$

Equation for calculate fuel mass flux is given by:

$$\dot{m}_f = \psi . A \ [kg/h] \quad (10)$$

For the design of the present gasifier it was used the following parameters:

The biomass used in this work was the Açaí seed. Table 1 and Table 2 present the ultimate and proximate analysis of the açaí seed.

It was define and set the volume of gas as a data input, the value was fixed was Vg = 12 m³ /h, and using the Eq. (6) for the four ψ (100, 200, 300, 400) the surface speed of the gas was determined, these values are shown in Tab.3.

Using the Eq. (7), the gasifier bed diameter (D) was obtained; the next step was to calculate the fuel mass flux $(\dot{m}_f)$ since we have Air and ψ , using the Eq. (10). The flow of energy from the fuel (q_f) can be calculated by Eq. (1) and using the LHV of fuel the cross section area of the gasifier are determined and shown in the Tab.4.

Table 1. Proximate analysis of the Açaí seed.

Biomass	**Açaí seed**
Proximate analysis	
Ashes [%]	1.10
Volatiles [%]	79.44
Carbon fixed [%]	19.45
Moisture Content [%]	34.99
Higher Heating Value [kJ/kg]	19158

Table 2. Ultimate analysis of the Açaí seed.

***Ultimate analysis* [%, in dry basis]**	
C	47,00
H	6,58
N	1,07
S	0,85
O^2	44,22
Cl	0,21
F^3	< 0,20
P	0,067

Table 3. Specific rate of gasification, surface speed,
flow volume of gas for the present study.

ψ [kg/m2-h]	**ν [m/h]**	**Vg [m3/h]**
100	122,13	12
200	400,91	12
300	679,69	12
400	958,47	12

Using the equation (2) the efficiency of gas can be obtained, and from the equation (3) the energy flow of gas can be determined, finally using the equations (8) and (9) the height of the gasifier can be established, these values are shown in Tab. 5.

Table 4. Cross section area of the reactor, diameter of the bed, flow of fuel, flow of energy

Ar [m2]	**D [m]**	$\dot{m}_f$**[kg/h]**	(q_f) **[w]**
0,098	0,353	9,825	42304,648
0,029	0,195	5,986	25774,695
0,017	0,149	5,296	22804,513
0,012	0,126	5,007	21562,142

Table 5. Cold gas efficiency, energy flow of gas, time of residence, fuel mass flux, height minimum of the reactor.

η	**(q_g) [w]**	**t[h]**	**$\dot{m}_f$ [kg]**	**H[m]**
0,402	17046,37	1	9,825	0,416
0,554	14282,77	1	5,986	0,833
0,505	11520,46	1	5,296	1,25
0,406	1,14E+11	1	5,007	1,666

2.3 Gasifier dimensions.

When scaling a gasifier it is very important to maintain the pressure in the system. The pressure has an influence in the gas composition because encouraging the reaction that reduces the number of moles. To high pressures create more methane.

2.4. Feedstock system.

The feedstock systems of solid fuels are generally composed of a silo and a supply system for the silo. The choice of the supply system is directly related to the distance to be travelled, the type, size and moisture of the biomass. Generally two types of supply systems are used: pneumatic or by feeding screws. The pneumatic type is not recommended for fixed bed gasifiers because the biomass size used in these type. Systems with feeding outlet screws are the most used for such gasifier.

2.5. Cleaning gas system.

The first step in the production of a clean gas is the choice of the gasifier type that provides to minimize the amount of tar and particles to be removed. The second step is to determine the contaminants sequence removal. It is necessary to remove the tar, water and particles in the right order and the ideal temperature to make the process efficient. If the gas is cooled immediately, coal waste on the water and the tar will be removed, but it is necessary to take precautions with the removal of such waste because the same form a single type of material could clog pipes and valves. Because of this, these contaminants are highly undesirable to the end of the gasification requiring a system for cleaning up from the gasifier. A gasification system to be used with internal combustion engines must emit gases with a maximum of 10mg/Nm³ tar and particulate.

3. INSTRUMENTATION

The selection of measuring and control systems have a fundamental importance for the monitoring and control of parameters such as temperature, pressure, flow and other important variables in the process of gasification. Some important considerations only on the instrumentation that can be employed in this type of equipment will be suggested on the previous paragraphs.

3.1. Temperature measurements.

In high temperature gasification processes, a hot partial oxidation gas is produced from hydrocarbonaceous fuels. In these processes, the hydrocarbonaceous fuels are reacted with a reactive oxygen-containing gas, such as air or oxygen, in a gasification reactor to obtain the hot partial oxidation gas.

In a typical gasification process, the hot partial oxidation gas will substantially comprise H2, CO, and at least one gas from the group HO, CO2, H2S, COS, NH3, N, Ar, along with particulate carbon, ash, and/or molten slag. The hot partial oxidation gas in the gasification reactor will commonly be at a temperature ranging from 927°C to 1649°C. Thermocouples are commonly used for measuring temperature in these high temperature processes. The thermocouples can be used to measure the temperature in the gasification reactor and also be used to measure the temperature in downstream process steps in which the effluent is cooled and particulate and gaseous contaminants are removed.

The choice of dissimilar metals used for the thermocouple will vary depending on, among other things, the expected temperature range to be measured. For instance, one type of thermocouple commonly employed under the conditions present in a gasification reactor has one wire that contains platinum and about 30% rhodium and a second wire that contains platinum and about 6% rhodium.

The thermocouple type S was chosen for this work and has these features: it can be used in inert atmosphere and oxidants and presents a stable over time at high temperatures, much higher than for thermocouples that not made of platinum.

3.2. Pressure measurements.

Manometers are used to measure the pressure through the gasifiers bed, cyclones, filters, pipes and other components, may be used manometer of tubes or electrical transducers that convert pressure difference into an electrical signal suitable for readout.

3.3 Gas Flow measurements.

In any manufacturing process involving fluids the rate of fluids flow in the process is typically very important. Many techniques have been developed for this measurement depending on the nature of the fluids.

Mechanics methods of flow measurements generally involve placing an obstruction in the path of the flowing fluid and measuring the mechanical force which the fluid exerts on the obstruction.

Since it is not appropriate to use an orifice meter or a rotameter before without the gas passing through a cleaning process, the flow of gases from the gasification will be measured through a venturi located in the output of gases.

3.3.1. Rotometers.

Clean gas flow can be measured using a rotometer flowmeter, the gas must be clean at the rotometer, therefore rotometers usually can be used only on air or oxygen streams at the gasifier inlet. In addition, rotometers must be calibrated for the specific gas to be used, and the reading also depends on the absolute gas pressure.

3.3.2. Orifice meter

The orifice meter is usually preferred over the other alternatives because it is low in cost, can use more rugged, less sensitive to small amounts of tars and particulates. The calibration can be predicted from the gas properties and dimensions of the pipe and orifice using formulas given in more detail in mechanics engineering texts and handbooks. The location of pressure taps on an orifice meter will significantly affect the calibration. For an accurate measurement, the orifice meter should be calibrated against a primary standard such as a Pitot tube or a dry gas test meter.

3.3.3. Venturi Flow meter.

Venturi flow meter provides a higher pressure signal with a minimum pressure drop across the meter, because the divergent downstream section of the meter conserves gas momentum by converting velocity back into pressure. The cost of a venturi meter is highest of any of the differential pressure methods of velocity measurements because of the amount of precise machining required for its production.

3.3.4. Computer data logging and control.

The data collected by instruments can be read in the proper instrument of measurement for further processing the data acquired or set up automatically with the help of slabs of data acquisition (hardware) and specific software for data acquired in the market for a variety of purchasing systems of comprehensive data (hardware + software) which facilitates the tracking and control operating parameters such as temperature, pressure and others.

4.RESULTS

The design of gasifier mounted in the laboratory of the EBMA has several features, such as the size of its geometry. For scaling geometry of a gaseifier usually start from input data, such as the biomass rate, the biomass type and of their properties as LHV, based on wet dry, HHV, etc. This work used a fixed value of the amount of gas as a basis to calculate the diameter and height of the reactor.

From the Table 5 it was chosen a gasifier height of 1,25m which correspond a diameter of 0,149m from the Table 4. In order, to simplify the gasifier construction, the dimensions were fixed in height of 1,5m and a diameter of 0,15m. The diameter was chosen slightly larger than that determined in the calculations to prevent a non-uniform or a partially burning of the biomass. We may notice that the values adopted are consistent with the rate for gasification of 300.

Figure 2 shows the design of the reactor. On the design it was established the construction of 30 holes positioned along the gasifier height, these holes allow the insertion of measuring instruments, the collection of gases for analysis, as well as the injection of gases and steam, depending on the case to be studied. Figure 3 shows the reactor constructed.

A peculiarity of the gasifier is shown in Fig.1. The reactor has two valves that can control the outlet of the produced gas, these valves offers versatility depending on the arrangement of them. In a first arrangement we may have a downdraft or also an updraft gasifier depending on which valve is opened or closed to carry out the suction of the produced gas.

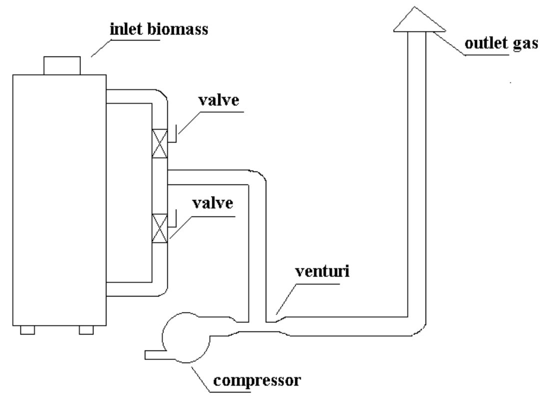

Figure 1. Reactor scheme updraft/downdraft.

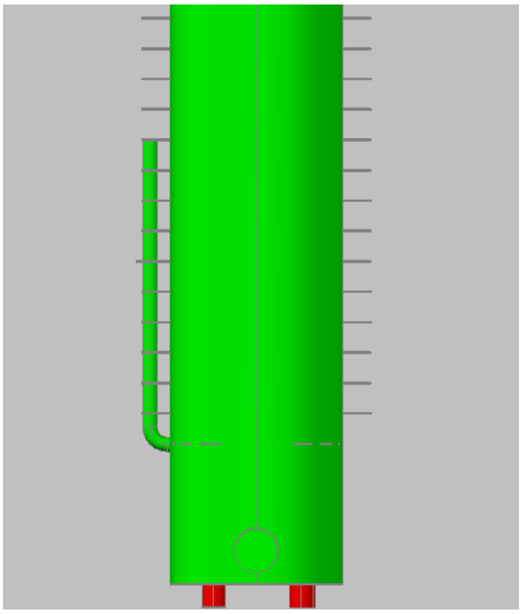

Figure 2. Reactor design.

Figure 3. Reactor constructed.

5. CONCLUSIONS

We can conclude that the design of a gasifier can vary considerably according to the application, but the instrumentation and control varies some what independent of the design of the gasifier. It was observed that the quantities to be measured are always the same: temperature, pressure and gas composition. According to the literature the use of downdraft gasifiers would have a limit of 1000 kg/h of biomass for feed.

This study showed a simple and consistent methodology to design a gasifier for small scales starting from the gas demand requested by the client until the details of the geometry and the instrumentation to be used.

It was possible to observed how the change on the gasification rate can affect the cold gas efficiency and on the gasifier geometry.

This preliminary work had achieved the objective in determining the size of a gasifier and will provided support for future experimental studies, such as the gasifier performance changing some parameters on the system as: humidity quantity, moisture content, residence time, air (oxygen) or water (water vapor)injection.

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