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Impact of the throat sizing on the operating parameters in an experimental fixed bed gasifier: Analysis, evaluation and testing

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ABSTRACT

The aim of this research is to contribute into the diffusion of biomass power systems by analyzing and testing the throat sizing influence on the operation of a gasification plant coupled with an internal combustion engine. In order to do this, the assessment of the proper operation range for some of the driving process parameters has been carried out. The analysis has been focused on such parameters as pressure drop of the fixed bed reactor, the inlet air flow, the syngas production, electrical power production and efficiency, looking for improving the performance and guaranteeing the proper system operation. Two different campaigns of tests have been carried out for figuring out the best design on the reactor. Based on this analysis, the most convenient throat diameter has been determined (in this case, around 10 cm), producing an increment in the production of syngas of about 31%. This modification has demonstrated also an increment of the electrical power produced by the gasification plant of about 40%, which means an increment in the motor generator efficiency of 35%.

1. Introduction

Continuous efforts have been made in exploration of renewable energy resources for a sustainable development as a consequence of the global economic crisis that has affected the energy market and the global economy during the recent years [1]. Among all of the renewable resources, biomass is the only one which contains carbon source to be converted into solid, liquid and gaseous products, and further into electricity, heat and transport fuels. Currently, biomass is the fourth largest energy source in the world after coal, petroleum and natural gas [2,3].

Like wind, solar, and other renewable energy sources, biomass can make a positive impact on the atmosphere facing the climate change induced by the green gas emissions (GHG) and decreasing the dependence on fossil fuels that still account for 80% of primary energy consumption [4]. The energy obtained from biomass, based on short rotation forestry and other energy crops, can significantly contribute towards the renewable energy target of the European Union, EU 20% by 2020 [5]. Biomass fuels and residues can be turned into energy via different processes (e.g. physical, thermal, chemical, and biological conversion) and all biomass can be burned in thermo-chemical conversion plants (i.e. combustion to produce steam useful for power production) [6]. Among the thermo-chemical processes, a considerable interest into biomass gasification has been growing worldwide in the last decades [7,8]. As a matter of fact, since any biomass material can undergo gasification, the gasification process is much more attractive than others such as ethanol production or biogas, where only selected biomass materials can produce the fuel [9]. The United States Department of Energy (DOE) has had a major goal in the development of cost competitive gasification technologies for the power production from renewable biomass crops [10,11]. Furthermore, an extensive review in Europe and Canada identified 50 manufacturers offering ‘commercial’ gasification plants from which 75% of the designs were downdraft type [12]. The downdraft technology owns the favorable characteristics of flexible adaptation of the syngas production to the load; low sensitivity to charcoal dust and tar content of the fuel (0.015–3 g/Nm^3); shorter time of ignition (5–20 min) and to reach the operating temperature than an updraft gasifier (30–60 min) [7]. Depending on the fuel used (its final form, size and moisture content) these technical aspects make downdraft technology preferable to others [13]. The gasification converts

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Nomenclature

$\dot{m}_a$	air mass flow (kg/s)
$\dot{m}_g$	syngas mass flow (kg/s)
g	gravitational acceleration (m/s^2)
ρ_a	air density (kg/m^3)
ρ_g	syngas density (kg/m^3)
ϕ_1	first campaign throat diameter (m)
ϕ_2	second campaign throat diameter (m)
A/S	air–syngas rate
A_0	inlet air section (m^2)
A_1	throat section at diameter ϕ_1 (m^2)
A_2	throat section at diameter ϕ_2 (m^2)
v_0	air inlet speed (m/s)
v_1	outlet gas speed at the section A_1 (m/s)
v_2	outlet gas speed at the section A_2 (m/s)
$\Delta z_2 = z_0 - z_2$	elevation betweens the measuring points (m)
$\dot{Q}_a$	inlet air volumetric flow (m^3/s)
P_0	atmospheric pressure (bar)
P_1	syngas pressure at the throat section A_1 (bar)
P_2	syngas pressure at the throat section A_2 (bar)
P_{elec}	electrical power at the generator terminals (kW)
$\Delta P_1 = P_0 - P_1$	bed pressure drop with ϕ_1 throat diameter (bar)
$\Delta P_2 = P_0 - P_2$	bed pressure with ϕ_2 throat diameter (bar)
L	length of the reduction zone (m)
d	equivalent diameter of the biomass particle (m)
u	superficial velocity (m/s)
Y	fluid viscosity (Pa·s)
ϵ	porosity
ρ_m	density of the suspension (kg/m^3)

biomass into a combustible gas mixture called syngas (synthesis gas) by its partial oxidation at high temperatures, typically in the range 800–1000 °C [8]. The syngas constitutes a mixture of carbon monoxide (CO), hydrogen (H_2), methane (CH_4), small quantities of other light hydrocarbons (C_nH_m), carbon dioxide (CO_2) and steam (H_2O), besides the nitrogen (N_2) present in the air supplied for the reaction [14].

It is a vital building block for the petrochemical industry and it is an important intermediate for synthesis of large numbers of industrial products. Thus, maximizing the syngas yield from biomass will largely promote the biomass utilization with high efficiency [15]. The syngas can be used to run internal combustion engines both compression and spark ignition, as substitute for furnace oil in direct heat applications or to produce, in an economically viable way, methanol which is useful both as fuel for heat engines as well as chemical feedstock for industries [16].

The gasification plant on which the experimental analysis is focused, adopts a downdraft fixed bed technology in which the air passes from the tuyeres in the downdraft direction. The gasifier has been coupled with an internal combustion engine (ICE) for a power production of 5 kWe. The ICE, traditionally working with gasoline, has been adapted to work with syngas characterized by a lower heating value (LHV) generally between 4 and 6 MJ/m^3 [17]. The gasifier is fueled with pellets, based on lignocellulosic biomass belonged to woody energy crops.

Although regional and national policies in different countries attempt to dampen their use and increase alternative energy, recent studies on biomass gasification for small scale application have demonstrated that it could be currently considered a quite mature technology [18–21]. Notwithstanding that greater efforts are still required in research to achieve further advances in the diffusion of gasification technologies [14,22,23].

In literature, different studies can be found on fixed bed gasification process. Previous works have studied the performance of the biomass gasifier system in terms of producer gas composition, gas production rate, zone temperatures and cold gas efficiency [24–26]. Guangui et al. show as preheating the gasifying air improves the outputs of the gasification process since the air flow rate has a significant effect on the quality of the producer gas [27]. The influence of the heating value and equivalent ratio on the performance of a downdraft fixed bed gasifier using different throat diameters was also presented by Gunarathne et al. [28]. However, they did not assess the relationship between throat diameter and bed pressure drop. The original mark of the present work lies in the analysis of the design of the throat on the gasification parameters, inlet air flow and bed pressure drop. Based on this analysis, the most convenient throat diameter has been determined, resulting in an increment in the production of syngas, efficiency and power generation. A methodology to evaluate and assess the behavior of the bed pressure drop and air inlet flow in function of the throat diameter has been implemented in order to achieve the feasible management of a downdraft fixed bed gasifier. The application of this methodology would allow designers and energy managers to increase the syngas production and, consequently, the power generation. Therefore, a higher reliability of the gasification plant can be achieved. Finally, the relationships between the characteristic process parameters have been investigated in order to favorite the widespread of this technology and enabling the gasification plant to properly operate at full capacity.

The paper is organized as follows: an overview about the experimental setup of the downdraft fixed bed gasification technology adopted in this study is presented in Section 2. Section 3 presents the proposed methodology for the evaluation and assessment of the effect of the gasifier throat diameter on the driving process parameters. In Section 4, the description of the modification performed on the gasification plant and some considerations about the gasification process parameters taken into account in the study are explained. The methodology is applied to a gasification plant designed at the Institute for Energy Engineering of Valencia (IIE), Spain, in Section 5. Finally, some conclusions are stated in Section 6.

2. Experimental setup of the gasification plant

The influence of the throat sizing on the characteristic process parameters was investigated and then tests were carried out on the experimental gasification plant developed by the Laboratory of Distributed Energy Resources (LabDER) of the IIE [18]. The initial design of the reactor throat was modified so that the diameter of the throat was increased with a constant geometry.

2.1. Characterization of the lignocellulosic biomass: pellets

During the tests, the power plant was fueled with waste biomass derived from different woody energy crops. Cellulose, hemicellulose and lignin and extractives are found to be the major components of the woody biomass. The biomass composition in terms of these elements is reported in Table 1, including the proximate and ultimate analysis. Proximate analysis gives the composition of the biomass in terms of gross components: moisture (M), volatile