

A COMPARATIVE EXPERIMENTAL STUDY ON THE IMPACT OF STANDARD AND TORREFIED WOOD PELLETS ON THE DRIVE PARAMETERS OF A STRATIFIED BATCH GASIFIER

M. GRIGIANTE, Department of Civil, Environmental and Mechanical Engineering, University of Trento, Italy
maurizio.grigiante@unitn.it

D. ANTOLINI, Department of Civil, Environmental and Mechanical Engineering, University of Trento, Italy
M. BRIGHENTI, Department of Civil, Environmental and Mechanical Engineering, University of Trento, Italy

In these last years gasification studies have mainly involved raw biomasses. Recently, torrefied lignocellulosic materials have become particularly attractive but the majority of the investigations regarding this thermal treatment have been limited to the characterization of the feedstocks submitted to a wide range of working conditions. Only a limited and well documented number of works specifically dedicated to gasification of torrefied biomasses have been till now published. Most of these works, indeed, report results refer to industrial or pilot plants working within limited range conditions. As a consequence, extended investigations of the impact of the guide parameters of this process on a wide working conditions spectrum are not so easy to found. This work presents the results of an extended experimental campaign carried out on a specific small gasifier designed for a batch configuration and using air as gasification agent. The peculiarity of this experimental study consists in an on line monitoring of the biomass loss during the gasification process and in a direct experimental determination of the main parameters of the process as: the productivity of the syngas, its heating value, the amount of the remaining char, the power of the gasifier and the cold efficiency of the process. In particular the role of the air flow rate as critical parameter and its impact on the cited quantities is highlighted. For this investigation the results obtained for gasification tests of both commercial pellet (*CP*) and torrefied pellet (*TP*) characterized by a Mass Yield close to 80% are presented. The adopted experimental device allows to select several air flow rate ranging from 15 to 30 $\text{NI}\cdot\text{min}^{-1}$.

The L.H.V. of the syngas reaches values in the range $3.51 < \text{L.H.V.} < 3.85$ and $4.14 < \text{L.H.V.} < 4.31$ for *CP* and *TP* respectively. The maximum power values set at 2.73 kW for *CP* and 3.53 kW for *TP*. Interesting results can be deduced by reporting the trend of the cited quantities Vs. the air flow rate. As general result, the use of torrefied material confirms a significant improvement of the performances of the gasification process compared to those involving conventional biomasses.

1. Introduction

Gasification confirms as an important route for conversion of biomass materials to useful gaseous products: fuel gas for direct firing in thermal applications, such as kilns and boilers, co-firing in existing coal-fired boilers, gas for engines, turbines and fuel cells generating electricity, as well as raw gas for production of fuels or chemicals [1-3]. In the last years torrefaction has gained an increasing attention as an attractive process to upgrade the biomass quality in view of its applications on most of the cited processes. It is well known indeed that this mild thermal treatment enhances the physical and chemical properties of the treated biomass by raising, in particular, its energy density and, from a general point of view, by uniforming the quality of the torrefied feedstocks. This thermal upgrade of the biomass can have a positive impact on gasification process. The investigation of the influence of the torrefied biomass on the guide parameters of the gasification process is the aim of this paper. This has been made taking into consideration that only recently works concerning gasification of torrefied biomass have been published. Reference is made in particular to the work of Prins et al. [4] that reports an extended analysis involving both energy and exergy balance and Courtier et al. [5] that presents the results of an experimental investigation, carried out on a small batch scale entrained reactor working at high temperature, where it is in particular evidenced the increasing of the syngas production with the severity of the torrefaction. The experimental activities presented with the present paper aim at exploring the impact of the torrefied biomasses when they are gasified by investigating, in particular, the role of the air flow rate on both the final parameters of the process and on the quality of the obtained syngas. This work looks promising to encourage the use of torrefied biomasses as substitute of conventional raw feedstock to improve the spread of gasification process both on renewable energy and industrial scenarios [6,7].

2. Experimental

2.1 Biomass material characterization

Pellets are standard commodities commercially available in large quantities in several countries and the stable long-term supply chain may be easily secured for large scale processing plant. *Spruce* has been selected as

typical feedstock for these tests: Austrian pellet has been utilized as standard material due to its consolidated market prospective and indicated in this paper as *Commercial Pellet (CP)*. Wood particle torrefaction was carried out in a dedicated designed batch reactor enabling an accurate control of the temperature inside the sample biomass bed and a rapid removal of the product gas. The Mass Yield of the torrefied material is close to 80%. Reference is made to [8] for a detailed description of this reactor, the working conditions and the parameters characterizing the obtained torrefied samples. The pelletization of the torrefied material has been performed using a Bühler DPCB pelletizer (Bühler AG, Uzwil, Switzerland), with rotating die and a maximum softwood pellet production capacity of approximately 50 kg/h. *Torrefied pellet* is here indicated as (*TP*). The L.H.V. (Low Heating Value) of the biomass samples has been measured by using the Oxigen Bomb Calorimeter Mod. IKA C5000 (Isoperibolic Calorimeter).

2.2 Laboratory batch reactor

The experimental activities have been carried out on a lab-scale batch gasifier specifically developed for this study at the Thermochemical Biomass Energy Laboratory (TheBEL) of the University of Trento. The configuration of the reactor adopted for these tests leads back to the so called stratified gasifier described also on the reference Handbook of Biomass Gasifier [9]. The main difference pertains to the fact that the working conditions refer to a batch reactor so that each biomass layer uniformly changes from the unreacted biomass condition to the inert char zone. The reactor consists of a cylindrical vessel of stainless steel with a diameter of 60 mm and a length of 1300 mm. Pellets are loaded from the upper part of the reactor and held inside the reactor through a distributor plate grate located at 100 mm above the bottom. Each charge allows to reach a biomass bed at about 960 mm height. Air, utilized in this study as gasification agent, is inserted from the bottom section and is forced to flow at selected and constant flow rates by an electronic controller in conjunction with a controller readout (Bronkhorst). The composition of the flow gas leaving the reactor is measured by electrochemical sensors equipped on an emission monitor system (MRU GmbH Delta 1600). Four thermocouples are symmetrically placed inside the biomass bed from the bottom to the top and located in the center of each section. A three-necked flask device, acting as trapping system, is positioned out of the reactor to clean the syngas flow from condensable compounds: the first flask sets in ambient conditions, the others contain gasoline through which the syngas is forced to flow. The cleaned syngas flows through a filter to remove the carbon soot particles before being sampled and sent to the MRU device to monitor continuously the composition of the obtained syngas and its L.H.V. (Low Heating Value). Considering that the air flow follows an updraft configuration and the ignition occurs at the upper section, the flaming pyrolysis zone advances from the upper to the bottom section of the reactor. Making reference to Fig. 1-a, four zones can be identified in correspondence to a generic time set of the working conditions: moving from the bottom to the upper section, the first encountered is the *unburned biomass* zone through which air flows; the second corresponds to the *flaming pyrolysis* zone where the biomass reacts with air; the third one, which is made up of char produced on the second zone, is the *reacting char (reduction)* zone where the pyrolysis gases are reduced. The upper zone is the *non reactive (inert) char* zone that constitutes the fourth layer normally too cold to cause further reactions.

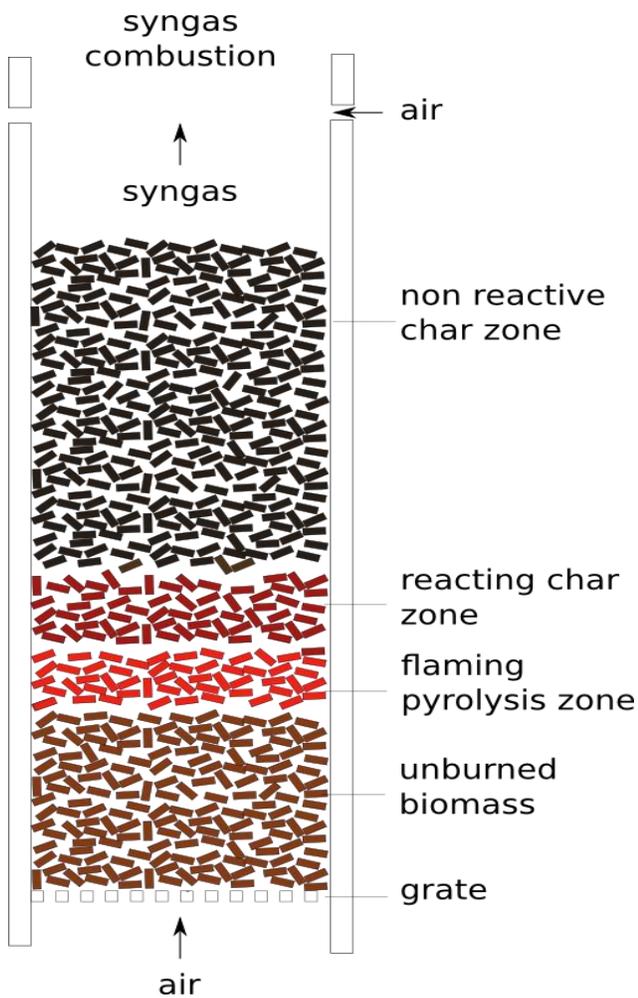


Fig. 1-a. Schematic representation of the four conversion zones and air flow configuration of the pilot plant.

Fig. 1-b. Photo of the gasifier evidencing the syngas burning section

The reactor, together with the facilities devices, is set on a digital balance to monitor on line the biomass mass loss. The continuous monitoring of the mass weight represents a peculiar aspect of this investigation. The produced syngas is directly burned once it reaches the top of the reactor. A photo of the lab-scale plant during a gasification test is shown on Fig. 1-b.

2.3 Operating conditions

First of all, the effect of different air flow rates ranging from 15 to 25 $\text{NI}\cdot\text{min}^{-1}$ for CP and from 15 to 30 $\text{NI}\cdot\text{min}^{-1}$ for TP have been investigated. The continuous monitoring of the mass loss together with the control of the air flow rate allows to directly derive the mass balance of the process and, consequently, the syngas production. Knowing the L.H.V. of both the CP and TP feedstocks and monitoring this quantity for the syngas, it is possible to calculate the cold efficiency of the process for each of the selected air flow working conditions. The weight of the biomass before and after each test provides the amount of residual biomass classified as char. Six test have been carried out for CP by progressively increasing the air flow rate amount and indicated from CP-1 to CP-6. The same has been done for the five tests involving torrefied biomass named from TP-1 to TP-5. The adopted working conditions and the obtained results are summarized on Table 1 in correspondence to each test.

	Biomass characterization			Syngas quantities		Process parameters				
	Charge (Kg)	L.H.V. (MJ·Kg ⁻¹)	Moisture (%wt)	Production (Kg·h ⁻¹)	L.H.V. (MJ·Kg ⁻¹)	Air flow (NI·min ⁻¹)	Mass Loss (Kg·h ⁻¹)	Cold Eff. (%)	Res. Char (%) ^c	Power (kW)
Samples				Commercial Pellet						
CP-1	1.90	17.20	6.92	1.792	3.70	15	0.632	61.06	9.17	1.84
CP-2	1.85	17.29	6.48	1.987	3.76	17	0.672	64.38	8.38	2.08
CP-3	1.85	17.19	7.00	2.176	3.78	19	0.706	67.90	6.34	2.29
CP-4	1.85	17.19	6.99	2.369	3.83	21	0.744	71.00	3.31	2.52
CP-5	1.85	17.21	6.87	2.561	3.85	23	0.781	73.08	1.2	2.73
CP-6	1.85	17.27	6.56	2.680	3.51	25	0.745	73.15	0.5	2.62
Samples				Torrefied Pellet						
TP-1	1.80	19.67	3.90	1.781	4.14	15	0.620	60.43	19.8	2.05
TP-2	1.80	19.69	3.85	2.216	4.21	19	0.745	63.58	16.5	2.59
TP-3	1.85	19.68	3.89	2.622	4.31	23	0.842	68.15	15.4	3.14
TP-4	1.78	19.33	5.59	2.979	4.26	27	0.890	73.82	5.8	3.53
TP-5	1.75	19.32	5.62	3.254	4.18	30	0.932	75.59	2.0	3.78

^c=% value with respect to charge

Table 1 – Working conditions and results of the main gasification process parameters.

3. Results and Discussion

The data reported on Table 1 evidence the role of the air flow rate as guide parameter of the gasification process due to its relevant impact on the performances of the process. As expected, an increasing of the air flow entails a corresponding increase of the syngas production due to the augmented mass loss rate of the biomass. This emerges from Fig. 2-a that highlights also how the syngas production is only marginally influenced by the use of *CP* or *TP*. As depicted on the following Fig. 2-b, the mass loss rate of the biomass and the syngas chemical species are kept significantly constant during the entire charge gasification that occurs at a selected constant air flow rate. Making reference to Fig. 2-b, the monitoring of the syngas composition starts after the stability of the mass loss appears to be stabilized. This avoids also the circulation of the syngas on the monitoring device that, during the beginning of the test, is inevitably dirty. The same Fig. 2-a indicates that the production of syngas, that originates from *CP*, can be detected up to an air flow rate value close to 25 NI·min⁻¹, while for higher values the gasification process moves to combustion. This problem is not observed when *TP* is used till the maximum limit of 30 NI·min⁻¹ is reached. Values higher than 30 NI·min⁻¹ have not been considered for the presence of relevant lugging phenomena due to the increase of the gas velocity.

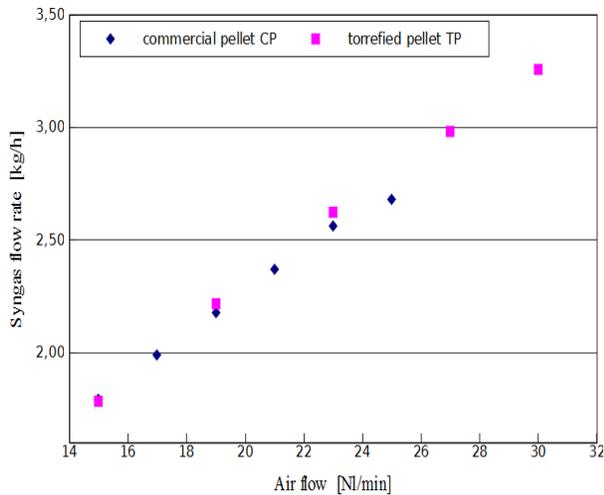


Fig 2-a. Syngas production Vs. air flow rate for the gasifier supplied with CP and TP.

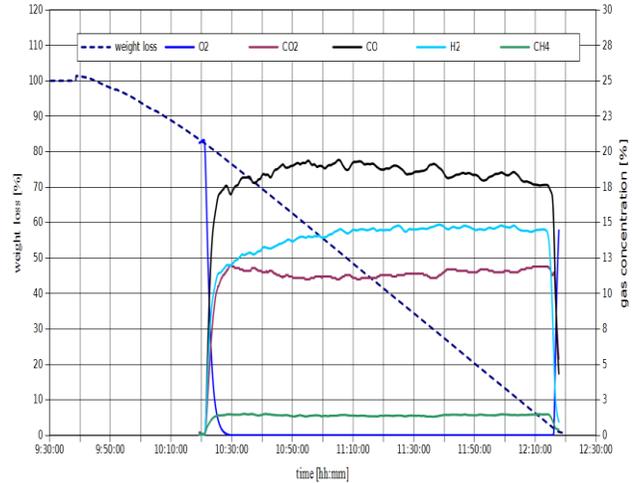


Fig. 2-b. Monitoring of the biomass loss and concentration of the syngas components for a gasification test.

On the following Fig. 3-a the effects of the use of both CP rather than TP and different air flow rates on the L.H.V. of the produced syngas are evidenced. Within an air flow rate limited to 24 Nl·min⁻¹, the L.H.V. follows a similar trend for the two investigated biomasses even if the results are significantly higher for TP syngas. For TP, the maximum L.H.V. value increases of nearly 12% with respect to same quantity obtained by using CP. Considering the impact of the air flow rate, it emerges that when this parameter reaches values higher than 25 Nl·min⁻¹, the L.H.V. of the CP syngas decreases very rapidly while, for TP, this property maintains a regular trend for all the air flow rates within the investigated range, with the presence, in this case too, of an optimal working condition.

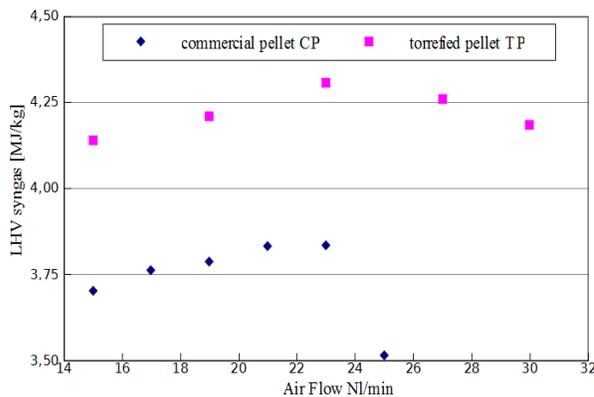


Fig 3-a: L.H.V. of the syngas Vs. Air flow rate for the gasifier supplied with CP and TP.

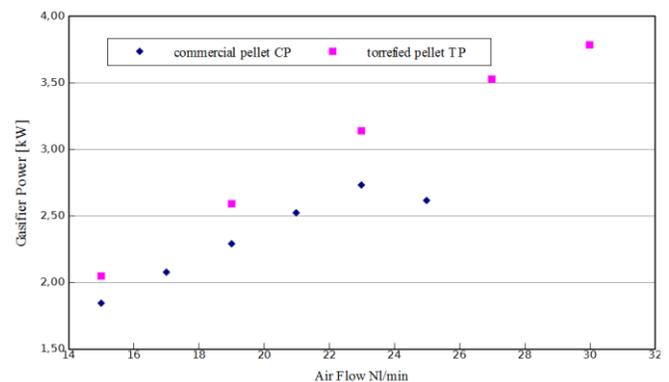


Fig 3-b: power of the gasifier Vs. Air flow rate for the gasifier supplied with CP and TP.

This behavior has a direct impact on the power trend of the gasifier as evidenced on Fig. 3-b: the use of CP limits the power to a maximum value in correspondence to a precise air flow rate, while this limit does not affect the gasifier when fed with TP. From a different point of view, the amount of energy of the produced syngas can be referred to the mass supplied biomass unit (kg). The trend of this parameter is reported on the following Fig. 4-a and confirms the results indicated on previous Fig. 3-b. This representation shows that the air flow rate has to be selected within a narrow range to optimize the energy content of the syngas referred, in this case, to the mass unit of CP as supplied biomass. For the same air flow rate range, the energy content of the syngas produced by TP is significantly lower. For TP this condition will be reached for higher air flow rate outside the

range considered in this study and, for this reason, not observed. This approach provides two considerations: the first pertains to the fact that an analysis based only on the L.H.V. of the syngas and on the obtained gasifier power could provide a limited vision of the performances of such a process that can work with different biomasses; the second evidences the role of air flow rate as critical parameter of this process, considering the fact that each type of biomass, in this case *CP* and *TP*, presents the maximum syngas energy content in correspondence of an air flow rate range that is specific for each biomass.

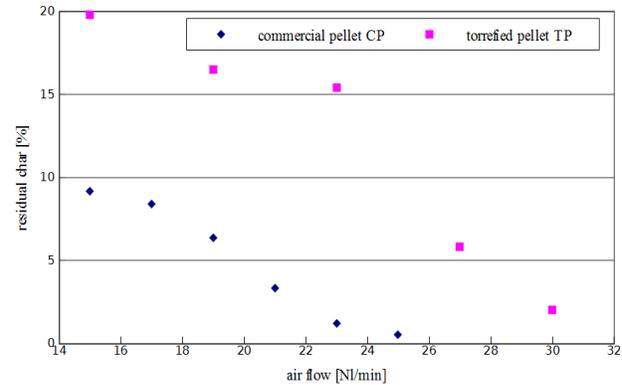
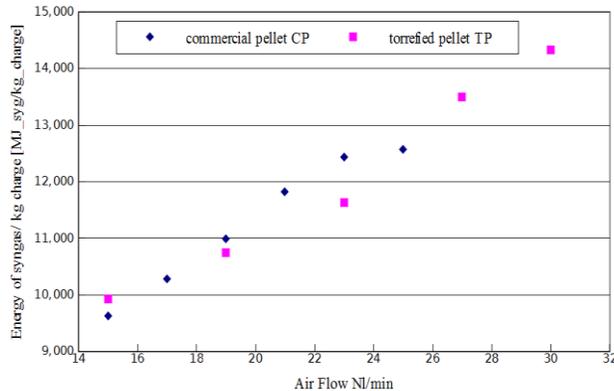


Fig 4-a: Specific energy content of syngas Vs. Air flow rate referred to the unit supplied biomass.

Fig 4-b: Residual % of char remaining for CP and TP gasification Vs. Air flow rate.

Even if a complete explanation of these statements will required a more deep investigation, an important role is played by the impact of the air flow rate on the amount of char available at different working conditions, as depicted on Fig. 4-b. Considering the importance of the char reacting zone for the adopted gasifier configuration (Fig. 1-a) and the fact that the air flow rate has a significant impact on the resulting amounts of char (significantly higher for *TP* than for *CP*, Fig. 4-b) and on the corresponding thermal profile (not investigated), the resulting thermo-chemical conversion significantly has effects on both the amount and the quality of the produced syngas. As general comments, even if the performances obtained with the use of *TP* are significantly better, this statement has not a general validity.

4. Conclusions

This paper is part of an experimental work in progress dedicated to study the impact of pretreated (torrefied) biomasses on the main quantities of the gasification process. The role of the air flow rate as guide parameter on both the process parameters and the quality of the obtained syngas has been investigated. It is confirmed that the use of torrefied biomasses enhances the performances of gasification referred to the conventional parameters usually introduced for this process. This study highlights that the air flow rate has a significant impact on selecting the optimal working conditions. The use of *commercial pellet (CP)* presents an optimum of the performances in correspondence to a narrow range of the cited guide parameter while these limiting working conditions do not affect the use of *torrefied pellet (TP)* within the adopted air flow rate range. This preliminary study provides significant information even if they have to be referred to the specific configuration of the adopted small batch gasifier. In particular the role of char conversion has to be deeply investigated by including also the use of models actually out of the aim of this study. As general results, this experience look promising to encourage the use of torrefied materials for gasification process and to extend such results to reactors presenting a continuous configuration and power.

References

- [1] Maniatis K. Progress in biomass gasification: an overview. In: Bridgwater AV, editor. Progress in thermochemical biomass conversion. London: Blackwell Science. (2001) 1–31.
- [2] Kwiatkowski K., Dudyński M., Bajer K. Combustion of low-calorific waste biomass syngas. Flow Turbul. Combust. 91 (2013) 749–772.
- [3] Pereira E.G., da Silva J.N., de Oliveira J.L., Machado C.S. Sustainable energy: a review of gasification technologies. Renew. Sust. Energy Rev. 16 (2012) 4753–4762.

- [4] Prins M.J., Ptasinski K.J., Janssen F.J.J.G. More efficient biomass gasification via torrefaction. *Energy* 31 (2006) 3458–3470.
- [5] C. Couhert, S. Salvador, J.M. Commandré. Impact of torrefaction on syngas production. *Fuel* 88 (2009) 2286–2290.
- [6] Klose W., Wolki M. On the intrinsic reaction rate of biomass char gasification with carbon dioxide and steam. *Fuel* 84 (2005) 885–892.
- [7] Di Blasi C. Combustion and gasification rates of lignocellulosic chars. *Prog. Energy Combust Sci.* 36 (2009)121–40.
- [8] Grigiante M., Antolini D. Mass yield as guide parameter of the torrefaction process. An experimental study of the solid fuel properties referred to two types of biomasses. *Fuel* 153 (2015) 499–509.
- [9] Reed, T. B., Graboski M. S., Levie B. Fundamentals development & scale-up of the air-oxygen stratified downdraft gasifier. Biomass Energy Foundation Press, 1994.