Experimental comparison on real m-CHP fuelled by different biomasses

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Micro Combined Heat and Power (mCHP) based on biomass gasification represents a viable substitute to traditional energy conversion units to supply energy standards to decentralized communities by using locally available resources. The use of organic waste material for energy purposes is nowadays strongly incentivized as a practice of circular economy, whose need has recently grown due to the increasing concerns about the release of greenhouse gases (GHGs) emissions and the related effects on climate changes.
At present, only a few solutions have yet achieved a level of full development for commercialization. Reliable and flexible performance can be found in the system developed by CMD, the CMD ECO20, made of a gasifier, a syngas cleaning system and a spark ignition (SI) internal combustion engine (ICE) working as a co-generator. The gasification process allows producing a syngas that is cooled and cleaned before being employed to power the ICE; exhaust gases from the ICE are exploited to preliminary dry the treated biomass, hence to further enhance the properties of the energy carrier. Up to 20 kW electrical energy generation is achieved and waste heat recovery is performed to gain up to 40 kW of thermal energy.
Since the main problem of powering mCHP plants with syngas is just the low quality of this fuel and the extreme variability of its composition, it is important to characterize how the performance of the whole system is affected by changing the feedstock and, fixing the initial raw material, how it is possible to improve the overall efficiency by changing the operating conditions.
The here presented work shows an extended experimental activity made on the CMD system fueled by different typologies of biomass. Through the use of numerical models, properly validated on experimental data, the performance of the system is predicted with reasonable accuracy to also derive hints for improvement in the set of the operating parameters. The behaviour of the system is determined for each of the processed biomasses, with a complete analysis of the gasifier, the cleaning system, the engine and the waste heat recovery section. By monitoring pressure and temperature at different locations of the reactor it is possible to determine the global efficiency of the process. The cleaning system is characterized by bubbling and collecting the quantity of dust and tar present in the syngas in a bottle trapped in ice to maintain the producer gas cooled both upstream and downstream of the cleaning devices. In this way, it is possible to correlate the biomass typology with the production of undesirable compounds, harmful for the engine and the environment if released into the atmosphere. The syngas composition is analyzed both online, thanks to a Portable Emissions Measurement System, the HORIBA OBS 2200 and offline by capillary column gas chromatograph, type Plot Carboxen 1006. The more correct engine calibration of the engine is evaluated with a spark plug-

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in sensor, type AVL ZI45-F5D, based on the principle of operation of the piezo quartz sensor, that is very accurate and sturdy, and located in one of the cylinders for each syngas produced, in term of Spark Timing, Air/Fuel Equivalence (λ) Ratio and the ratio of exhaust gas recirculation, with the aim of maximizing the energy efficiency of the plant together with the minimization of polluting emissions.
The baseline of CMD ECO20 is fixed with woodchip deriving from mixed wood, whose analysis made, according to reference standards ASTM D 5142 for Proximate analysis and ASTM D 5373 for Ultimate one, are presented respectively in table 1 and 2.

Proximate Analysis	
Moisture	21.0 %
Ash	1.7 %
Volatile matter	63.2 %
Fixed carbon	14.1 %

Table 1. Proximate analysis of mixed woodchip used for the baseline characterization

Ultimate analysis			
	Dry basis	Daf basis	As received
Carbon	53.8 %	55.0 %	42.5 %
Hydrogen	6.5 %	6.6 %	5.1 %
Nitrogen	0.7 %	0.7 %	0.6 %
Oxygen	36.8 %	37.6 %	29.1 %
Ash	2.1 %	-	1.7 %
Moisture	-	-	21.0 %

Table 2. Ultimate analysis of mixed woodchip used for the baseline characterization

The syngas composition, achieved with an Equivalence Ratio (ER) of 0.32, is shown in table 3. This composition will be used as baseline for the evaluation of the effect of the variation of biomass on the Lower Heating Value (LHV).

Syngas composition	
H2 %	17,71
N2 %	47,31
CO %	17,95
CH4 %	2,08
CO2 %	11,86
H2O %	3,09
LHV [MJ/Nm3]	4,92
LHV [MJ/kg]	4,44

Table 3. Syngas composition

The operating reference configuration consists of the spark advance fixed at 34° before the top dead center (BTDC) and the maximum production of electric power. 500 consecutive cycles were acquired at the baseline configuration, whose average pressure cycle is presented in figure 1. Emissions of the engine were acquired and the results are shown in figure 2.

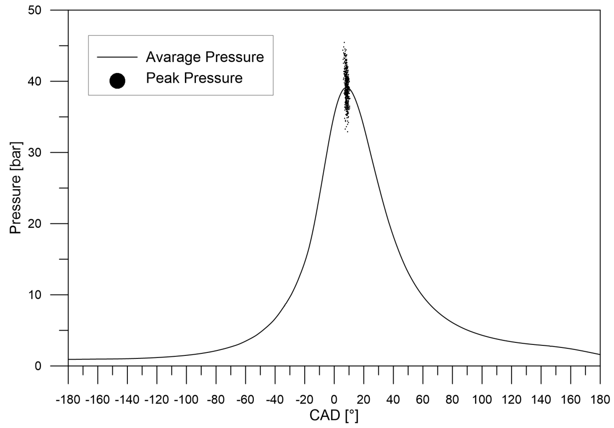

Figure 1. Average pressure cycle

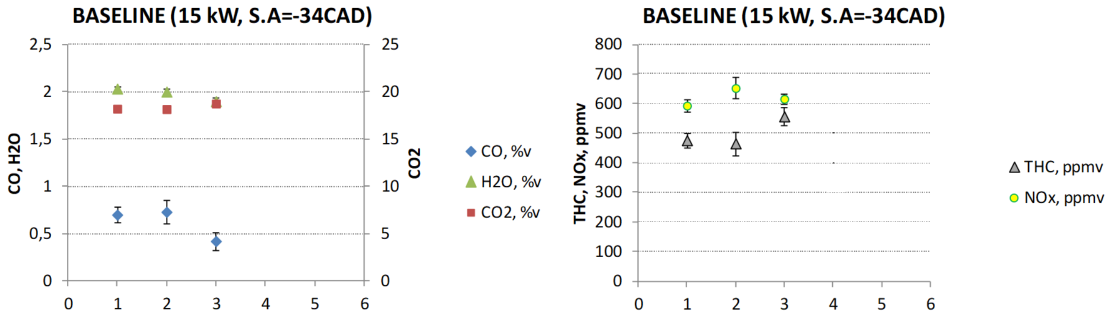

Figure 2. Emissions analysis of system fueled with mixed woodchip

A numerical model for the syngas production and cleaning section is developed within the Thermoflex™ environment, while a one-dimensional (1D) model of the ICE module, from its intake mouth until the exhaust pipes, is built within GT-Suite®: the simulation model, covering the entire engine cycle is validated under these real operative conditions. Figure 3 and 4 show the good agreement of numerical results with experimental data in terms of syngas composition and engine pressure cycle.

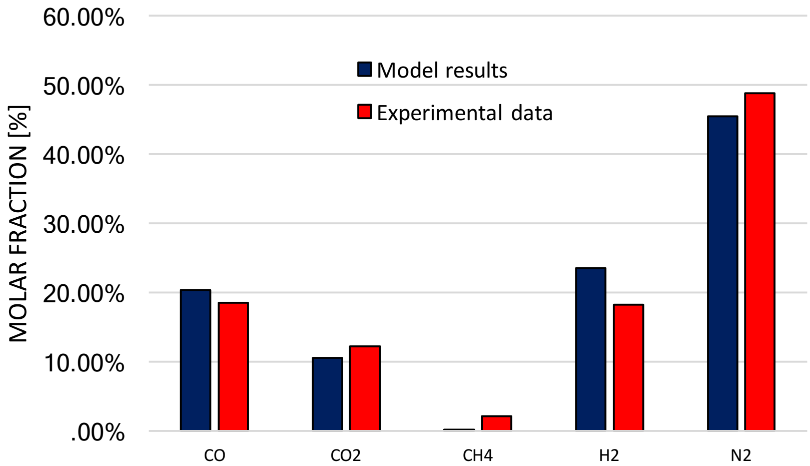

Figure 3. Model results compared with experimental data for syngas composition.

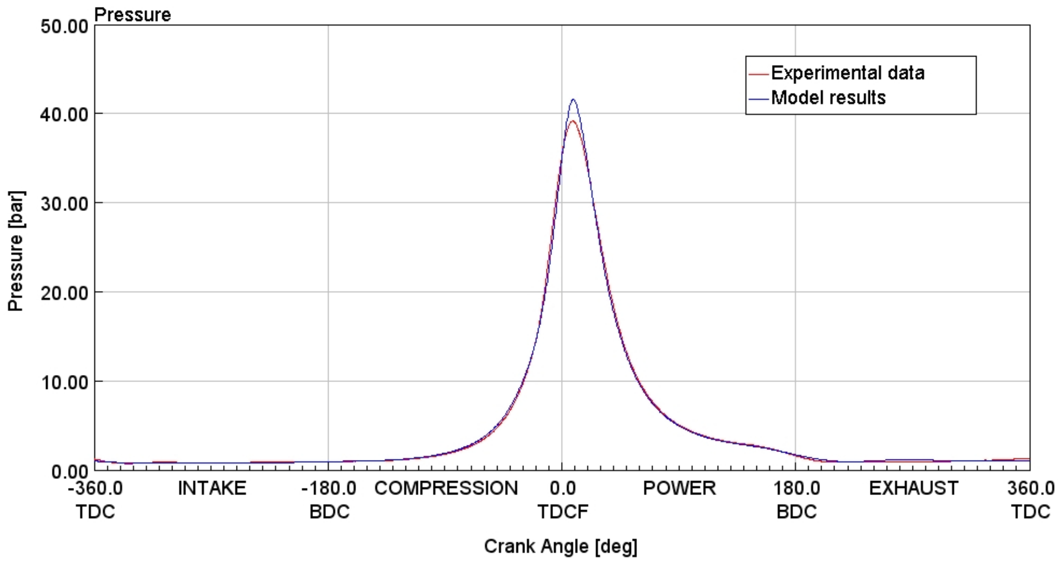

Figure 4. Comparison between model results and experimental data for the engine pressure cycle

The two approaches, numerical and experimental, allow estimating the effects of important parameters on the syngas quality and the CHP unit behavior in terms of electric and thermal output. The versatility of the CMD ECO20 system is shown as different biomasses are processed, or, alternatively, solutions are highlighted to improve functioning or extend the operating range in the absence of faults.