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# Small scale plants for energy production: environmental impact of biomasses pyro-gasification

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**Abstract**

The production of both thermal and electrical power in pyro-gasification micro co-generative plants sized for small enterprises (sawmills, farms, cattle farms, etc.) is nowadays a growing trend. The electrical power is generated by an engine powered by the syngas produced through a pyro-gasification process; the nominal electric power of the considered plants is in between 30 and 90 kW.There are different types of plants currently available on the marketeither able to process only pure wood pellets either high quality virgin wood chips or raw and mixed bio-based materials, such as crops, secondary quality chips and other agricultural residues.In present framework our measurements are related to the third type, fed by secondary quality biomasses. The impact on the environment is due to the combustion of the syngas through the torch, switched on when the engine is off, due to the engineemissions, due to the tar and aromatic compounds intercepted by the filtering systems (according to the types either dry filters or water scrubbers) and finally due to the large amount of biochar resulting from the pyro-gasification process.In the present study the aero-dispersed pollutants measured are both dusts (in diametric classes from 1 to 10 μm) and the concentration of few chemical compounds (such as sulfur dioxide, carbon monoxide, nitrogen dioxide and oxides).The concentration of atmospheric pollutants from the engine is related to the engine set-up and to the engine behavior and it is not only strictly related to the biomass quality. The main solid residue is the biochar, that can be a dangerous waste if stocked in unappropriated way but that can provide a beneficial impact in agriculture as well, when distributed and processed with the due techniques and concentrations.



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## 1. Introduction

Renewable wastes such as biomass agricultural residues derived, are increasingly being recognized as valuable feedstock because of their rich carbon composition (Proto, Zimbalatti, Abenavoli, Bernardi & Benalia, 2014). The production of both thermal and electrical power in pyro-gasification micro co-generative plants sized for small enterprises is a growing trend. The electrical power is generated by an engine powered by the syngas produced through a pyro-gasification process. Pyrolysis is carried out under complete or partial exclusion of oxygen and relies on capturing the off-gases from thermal decomposition of the organic materials (Moneti, Delfanti, Marucci, Bedini, Gambella, Proto & Gallucci, 2015).

Gasification is a process that converts carbonaceous materials (organic or fossil based) mainly into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (>700 °C) without combustion, with a controlled amount of oxygen and/or steam.

The resulting gas mixture is called syngas (from synthetic gas) or wood gas and is itself a fuel. The power derived from gasification and combustion of the resultant gas is considered to be a source of renewable energy when the gasified compounds are obtained from biomass.

The impact on the environment of these kind of plants is due to the combustion of the syngas through the torch, switched on when the engine is off, due to the engine missions, due to the tar and aromatic compounds intercepted by the filtering systems (according to the types either dry filters or water scrubbers) and finally due to the large amount of biochar resulting from the pyro-gasification process.

## 2. Background

The International Energy Agency (IEA) *Bioenergy Task 32 on Biomass Combustion and Cofiring* is promoting the utilization of clean biomass combustion applications to replace fossil fuels and to reduce $CO_2$ emissions.

Unfortunately the biomass combustion process, especially in small-scale applications, is related to high emissions of particulate matter (PM) smaller than 10 microns (PM10). Since PM10 is regarded as a major indicator for the health relevance of ambient air pollution, a further propagation of biomass combustion is hindered by the disadvantage of high PM emissions (Nussbaumer, Czasch, Klippel, Johansson & Tullin, 2008).

The combustion of wood can form a variety of particulates that include:

- carbon particles and soot;
- unburned wood dust;
- poly-aromatic hydrocarbons (PAH) compounds;
- semi-volatile organic compounds (e.g., tars and condensables);
- ash (minerals, metals, dirt).

Even in a modern, small scale, automatic burning plant the exhaust gaseous emissions, such as CO, $NO_x$,$SO_2$, IPA and VOCs, are not negligible, whilst can be largely higher in old or even modern normal plants (Pieratti, Antolini, Baggio & Negri, 2010).

Table 1. Emission factor for biomass small scale combustion installation [EMEP/CORINAIR, 2005].

| | CO (g/GJ) | $NO_x$ (g/GJ) | IPA (mg/GJ) | COV (g/GJ) | PM10 (g/GJ) |
|---|---|---|---|---|---|
| Standard stove | 7000 | 50 | 820 | 1200 | 800 |
| Post-combustion stove | 3000 | 150 | 400 | 250 | 400 |
| Pellet stove | 500 | 150 | 50 | 20 | 120 |
| Innovative stove | 3000 | 150 | 150 | 250 | 230 |
| Automatic wood stove | 500 | 150 | 40 | 20 | 70 |

To face the above mentioned critical issue related to the thermal conversion of biomasses through the direct combustion process, thepyro-gasification process of biomassestargeted to produce syngas should be considered as a possible solution. The syngas is a particularly environmental friendly since it contains methane, hydrogen and carbon monoxide and does not – in principle – generate any hazardous emissions for the environment when burning. Syngas can be either directly burnt either used as a fuel within an engine to produce power and/or heat.

Wood gasification technologies have been tested and developed for over 100 years, even though managing andcontrolling a clean gasification process is still a technical challenge, at least for power generation; the main critical issue is the filtering of tar residues resulting from the pyrolysis process, able to damage engines during long-term use.

## 3.Material and methods

The flue gas analyzer is an handheld MRU Optima 7, in accordance with EN 50379-1. The instrument is equipped with an electrochemical sensor O2, CO sensors, NO, $NO_2$, $NO_x$, $SO_2$, temperature and fumes velocity. In conjunction with measurements of emissions were carried out velocity measurements of the smoke through the pitot tube.The sampling pipe has been inserted in the chimney with a sampling rate of 1,3 l/h.

The airborne particulate has been measured by the means of a handheld laser scattering device, the TSI AeroTrak Particle Counter (Model 9306, requirements according ISO 21501-4), providing the particulate frequencies according to six dimensional classes from 0.3 to 10 μm simultaneously.The sampling has been done close to the chimney with a sampling rate of 2,8 l/min.The gasification plant is fed by 65 kg/h of dried biomass and produce a flow of syngas of about of 130 $m^3$/h, sent to an engine power unit producing 30 $kW/h_{el}$**.**

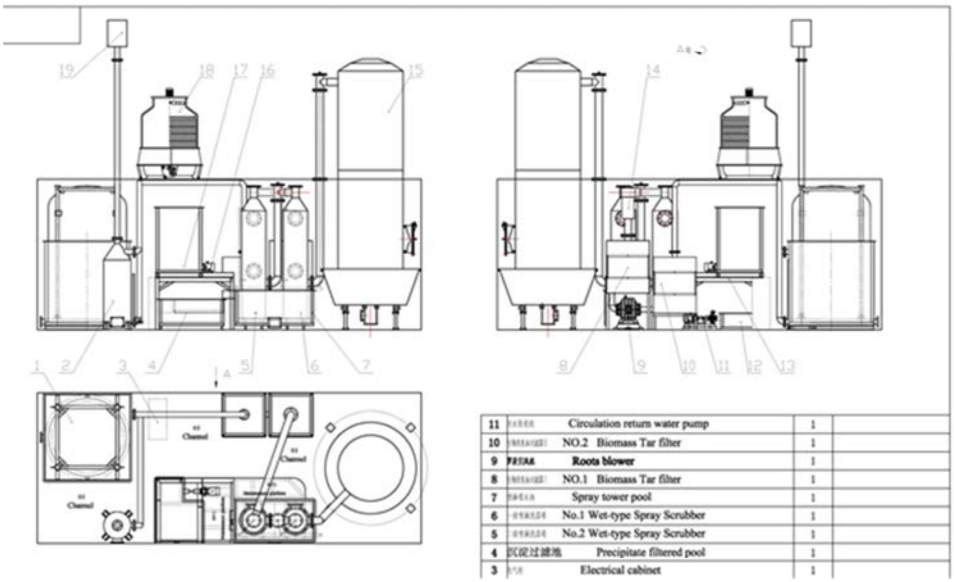


Fig. 1. The gasification plant tested.

## 4. Results

### *4.1 Exhaust gaseous emissions*

The chemical concentrations of exhaust gaseous emissions of chimney engine power unit are reported in table 2; the values are averaged in the range of one minute and refer to a standard of 11% oxygen, in five different testing sessions, named with capital letters.

The measurements regarding particulate emissions show little obvious differences between the counts in the various diameter classes and the various sampling sites. Data on PM10 are also conveniently converted to concentration by volume of air (μg / m$^3$) and presented in an additional table. This makes it possible to compare the air measured values in the adjacency of the plant with the limits prescribed by law on air pollution control and the sample values shown in the second table. The measurements of airborne particulate in the vicinity of the gasifier fully observe the legal limits. The measurements made in the vicinity of the gasifier are largely inferior to those of a comparative urban environment along an artery road.

It is not possible to compare these results with emission limits in the Italian laws DL. no. 152/2006 and DL no. 128/2010, because the sampling took place in the environment and not within the chimney flow. The legal limit of 100 mg / m$^3$ is expected for plants using solid fuels with a rated thermal power installed starting from 150 kW. The plant has an installed capacity of 35 kW, and is therefore excluded from this legislation.The airborne particulate emissions in this session were extremely modest, never exceeding the threshold of 50 μg/m$^3$. The details are presented in Figure 2.

Table 2. Exhaust gaseous emissions per volume at 11% reference oxygen.

| [mg/m³ 11%O2] | CO | NO | $NO_x$ | $SO_2$ |
|---|---|---|---|---|
| A | 684 | 337 | 544 | 24.8 |
| B | 659 | 589 | 916 | 9.2 |
| C | 2076 | 473 | 736 | 87.3 |
| D | 1782 | 761 | 1191 | 167.3 |
| E | 449 | 533 | 872 | 0.0 |
| Average | 1130 | 539 | 852 | 58 |
| St.dev | 664 | 139 | 214 | 63 |
| Cov | 0.59 | 0.26 | 0.25 | 1.09 |
| Max | 2076 | 761 | 1191 | 167 |
| Min | 449 | 337 | 544 | 0 |

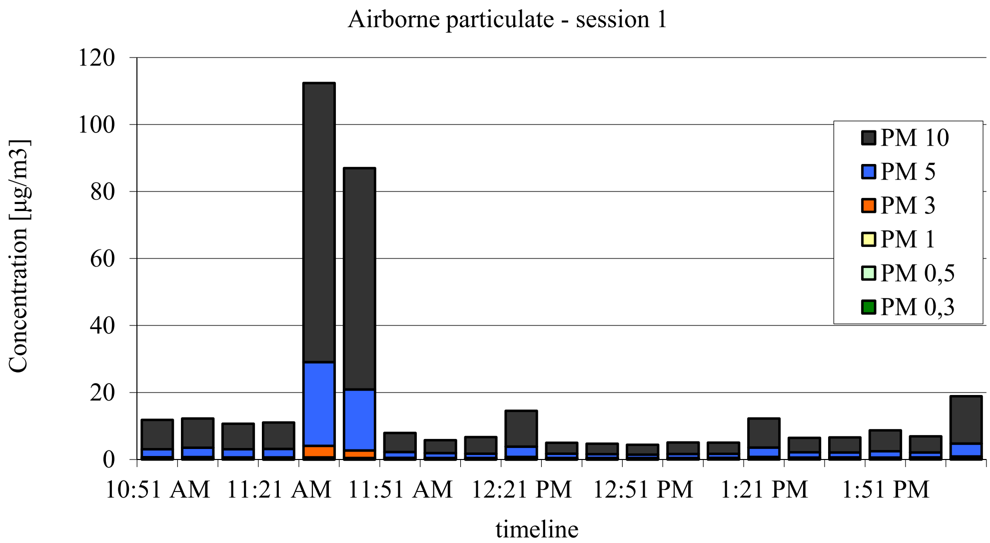


Fig. 2. The airborne particulate.

Table3. Reference values for PM 10.

| | | | | | | |
|---|---|---|---|---|---|---|
| Annual average limit value | | | | | | 40 |
| Maximum daily limit value (24-hours) | | | | | | 50 |
| Urban environment (data APPA, 3-5 march 2012, 632 samples, Trento) | | | | | | 30 |
| | PM 0,3 | PM 0,5 | PM 1 | PM 3 | PM 5 | PM 10 |
| | µg/m3 | µg/$m^3$ | µg/$m^3$ | µg/$m^3$ | µg/$m^3$ | µg/$m^3$ |
| Average | 0,06 | 0,08 | 0,14 | 0,57 | 3,80 | 12,69 |
| St.dev | 0,01 | 0,02 | 0,10 | 0,79 | 6,06 | 21,00 |
| Cov% | 23 | 20 | 68 | 138 | 160 | 165 |

Table 4. Output and destinations according to Italian laws and codes.

| Output | Destination | Italian Laws |
|---|---|---|
| Chimney emissions | Monitoringnot due | D.L.152/2008 e s.m. |
| Biochar | Used as fertilizer | Gazzetta Ufficiale, Serie Generale n° 186 del 12-8-2015 |
| Ash | negligible | D.L.152/2008 e s.m. |

## 5. Conclusions

The analysisor investigations on the chimney emissions have detected typical concentrations for these industrial processes with a rather high variability in time. The current legislation does not set limits to this type of low power plants. The analysis of airborne particulate showed temporary out oflimit values referred to a plant under non-optimal operating conditions. The legal limits also refer to the annual and daily average values, which according to measurements made, seem to be fully satisfied. Overall, there were no potential adverse effects on ecosystems and humans.

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