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Porous filtering media comparison through wet and dry sampling of fixed bed gasification products

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Abstract.
The syngas produced by fixed bed gasifiers contains high quantities of particulate and tars. This issue, together with its high temperature, avoids its direct exploitation without a proper cleaning and cooling process. In fact, when the syngas produced by gasification is used in an Internal Combustion engine (IC), the higher the content of tars and particulate, the higher the risk to damage the engine is. If these compounds are not properly removed, the engine may fail to run. A way to avoid engine fails is to intensify the maintenance schedule, but these stops will reduce the system profitability. From a clean syngas does not only follow higher performance of the generator, but also less pollutants in the atmosphere. When is not possible to work on the gasification reactions, the filter plays the most important role in the engine safeguard process. This work is aimed at developing and comparing different porous filters for biomass gasifiers power plants. A drum filter was developed and tested filling it with different filtering media available on the market. As a starting point, the filter was implemented in a Power Pallet 10 kW gasifier produced by the California-based company "ALL Power Labs". The original filter was replaced with different porous biomasses, such as woodchips and corn cobs. Finally, a synthetic zeolites medium was tested and compared with the biological media previously used. The Tar Sampling Protocol (TSP) and a modified "dry" method using the Silica Gel material were applied to evaluate the tars, particulate and water amount in the syngas after the filtration process. Advantages and disadvantages of every filtering media chosen were reported and discussed.

1. Introduction

The increasing cost of conventional energy sources is a matter of serious concern worldwide [1]. The unceasing increasing of greenhouse gas emissions enhances the global warming causing a global climate change. In addition, the energy demand doubled in developed countries in the last years and this is mostly fulfilled through the use of conventional fossil fuels [2]. Between the renewable technologies which can relieve this condition, fixed bed biomass gasification is probably the most promising technology due to its high potential for rural power generation and for its neutral carbon balance [3].

Fixed bed biomass gasification is a thermochemical conversion composed of four different steps: drying, pyrolysis, oxidation and reduction [4, 5]. This thermal process generates a combustible gas, known as syngas, composed by CO, CO_2, N_2, H_2 and CH_4. Syngas can run IC engines for generating electricity and heat reducing greenhouse gas emissions [4]. In addition, small-scale district power generation enables off-grid villages to get access to electricity for the first time. A small scale gasifier ensures a complete permeability of the territory and it supplies energy to small users or isolated villages in developing countries. Furthermore, the plant cost is low compared to other renewable energy plants of same size [6].

In order to meet the requirements of IC engines, the syngas from fixed bed reactors must to be properly clean. In particular, an IC engine can be operated successfully with particulate content below 50 mg/Nm^3 and tars content below 100 mg/Nm^3 [5].

There are many methods and processes for hot gas cleaning process, i.e. the cyclones or other gravitational methods separate the particulate from the gas [7]. These systems are not highly efficient and they can separate only big solid particles, besides they require big spaces and they may need to be heated in order to avoid the condensation of water and tars on their inner surfaces. More efficient cleaning systems are other dry methods like electrostatic filters or wet method such as scrubber with oil or water as working fluid. Above all these methods, bio-filters are the only kind of filters where the filtering bed material can be gasified. Moreover, the cost of installation and maintenance is low [7]. For these economical and technical reasons, a dry bio-filtration system with a woodchips filter bed is the most appropriate solution especially for small size gasifiers [8].

This work aims to select filtering bed materials which ensure a good filtration of the syngas produced by a 10 kW$_{el}$ APL Power Pallet [9]. Woodchips, corncobs and synthetic zeolites were tested as filter media and the amounts of particulate, tars and water in the filtered syngas were evaluated and discussed.

2. Material and methods

2.1. Experimental setup and sampling procedure

The facility used in this work is depicted in Fig. 1. The device "A" is the APL downdraft gasifier, at the bottom of the reactor there is the first pressure port "P reactor". "B" is the drum filter equipped with another pressure port "P filter". During the tests, the filtered gas is burnt into a torch while a little amount of it is analyzed in the device "C" which is the Tar Sampling Protocol apparatus or the Silica Gel apparatus sketched in Figures 3 and 4. During each test, after about 30 minutes of reactor warmup, 30 minutes of Tar Sampling Protocol was carried out setting a syngas flow rate of about 1 Nm^3/h. Subsequently, the Tar Sampling Protocol apparatus was substituted with the Silica Gel one for other 30 minutes test maintaining fixed the flow rate. After that, a tedlar bag was filled with cleaned syngas in order to analyze it into a gas cromatographer.

The drum filter used in this work is basically a closed cylinder containing: two grates, two sponges and the chosen porous media. Under and above the filtering media there is some space for the gas to spread and slow down. The filter was filled with different materials then tested with the methods previously described. The media choice occurred on the basis of several criteria, such as material availability and quality/price ratio. The choice fells on the following three illustrated in Fig. 2:

- **Woodchips G10 W5:** it is currently the most used as syngas biofilter bed. The average dimension of the chips about 10 mm and the moisture is below 5%.
- **Corncobs:** chosen for their high surface area in relation to their size. The properties of the corncobs adopted in this work are reported in Reference [6].
- **Composite filter**: it is a material based on synthetic zeolites.

At the beginning, the height of the filtering bed was the same for each material. However, tests shown that the syngas residence time inside the filter depends on the materials used as

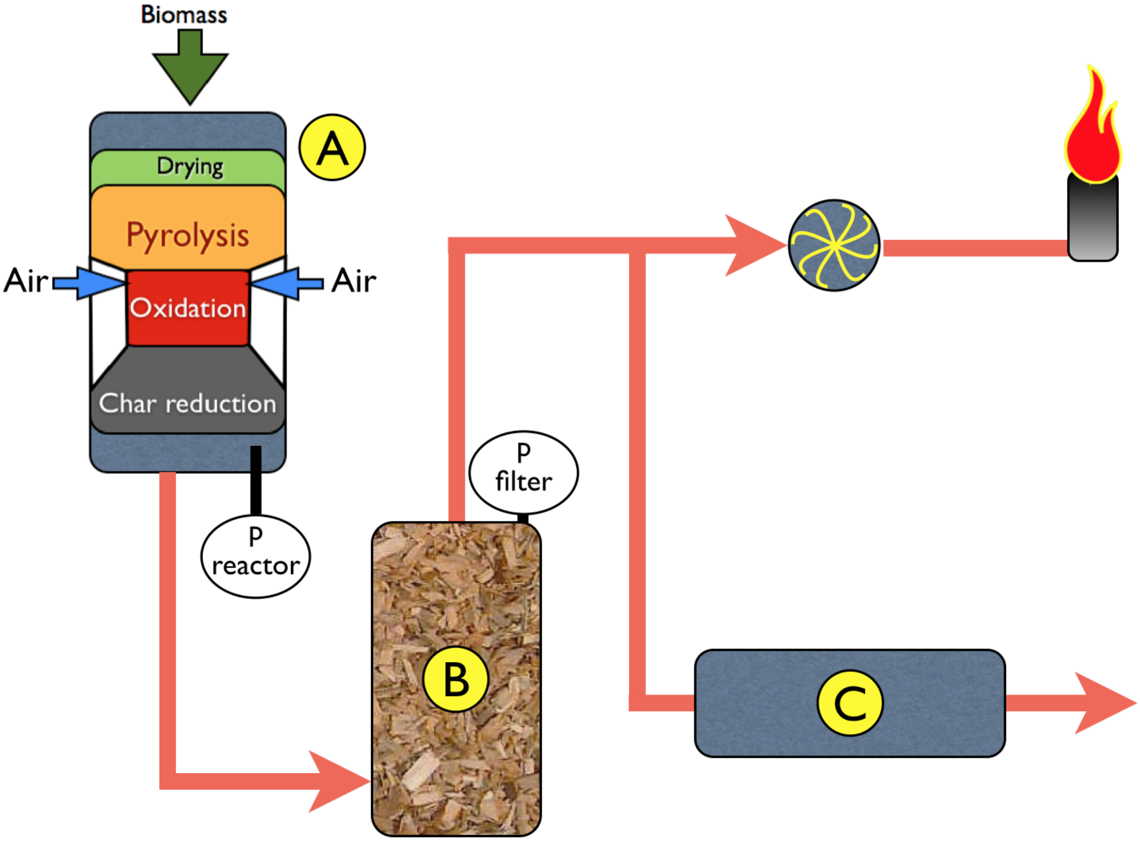

Figure 1. Facility adopted in this work

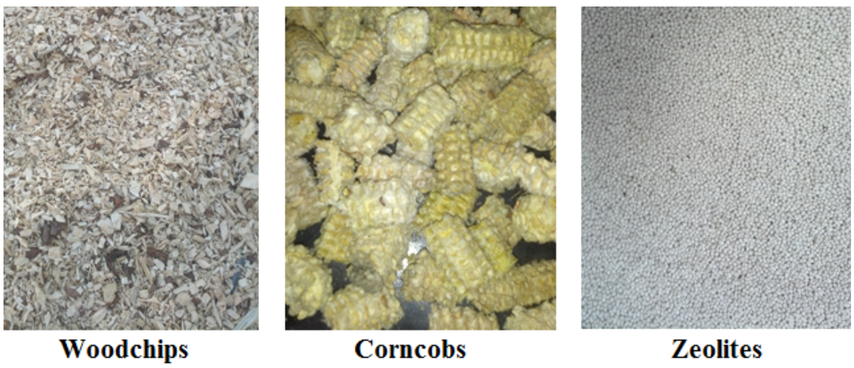

Figure 2. Filter porous media

result of their different porosity. Therefore, the bed height was varied to ensure a fixed value of differential pressure between the input and the output of the filter during all the tests. A metal mesh with 1 mm holes was placed at the bottom of the filter to support even the finer material. The filter material was laid on the grate and covered by two sponges with different porosity. The sponge placed below has a porosity of 65 dpi and the sponge placed above has a porosity of 45 dpi. A second metal mesh ensured that the height of the bed during the test was constant. Physical properties of the filter media are reported in Tab. 1. Furthermore, heights and differential pressures measured during the tests are reported in Tab. 2.

Table 1. Physical properties of the porous media

Filtering materials	True density [g/cm^3]	Bulk density [g/cm^3]	Porosity [%]	Moisture [%wt.]
Woodchips	1.450	0.218	85.97	10
Corncobs	1.360	0.107	92.13	9.4
Zeolites	2.910	0.902	69.00	≅ 0

Table 2. Parameters of the filter drum

Filtering materials	Height [m]	Superficial area [m^2]	Volume [m^3]	P reactor [kPa]	P filter [kPa]
Woodchips	0.330	0.113	0.0373	6.23	6.97
Corncobs	0.475	0.113	0.0537	6.23	6.97
Zeolites	0.100	0.113	0.0113	6.23	6.97

2.2. Physical and chemical methods
All tests performed were carried out after a 30 minutes start up. During the tests, were taken several gas samplings in order to analyze syngas quality and composition. In particular, the syngas was analyzed through the following chemical and physical methods:

- Tar Sampling Protocol;
- Silica Gel analysis;
- Gas Chromatographic analysis.

In order to analyze tar, particulate and water content in the syngas and to compare the filtering properties of the three different porous materials, the Tar Sampling Protocol was adopted [10]. The method consists in a series of 6 impingement bottles in which the syngas flows and where the first one acts like a moisture collector in which water is condensed. After the moisture collector, the gas flows through a series of 4 impinger bottles filled of approximately 70 ml of isopropyl alcohol that is the solvent used to dilute the tars and particulate of the syngas. The last bottle is intentionally empty to ensure the collection of final condensates. The heat released by gas cooling and tar condensation is removed through an external bath, that consists in a mixture of dry ice and glycol. Six standard glass impingers of 250 ml each are used while the external bath is maintained at a constant temperature of -18 ^{o}C as shows in Fig. 3.

The whole system is maintained in depression by a pump positioned downstream which draw the syngas after the drum filter. In the sampling line it is also implemented a rotameter with adjustable valve that allows the measurement and the regulation of the syngas flow rate [10]. After tars dilution in the impingement bottles, tars content was approximated proportional to the concentration of six compounds in the isopropyl alcohol according to Basu and Milne [5, 11]:

- Benzene
- Toluene
- Naphthalene
- Xylene
- Styrene
- Ethylbenzene

As suggested by [12, 13], these compounds can be detected with gas chromatography-flame ionization detection (GC-FID), gas chromatography-mass spectrometry (GC-MS), or gas chromatography-Fourier transform infrared detection (GC-FTIR). In this work the gas

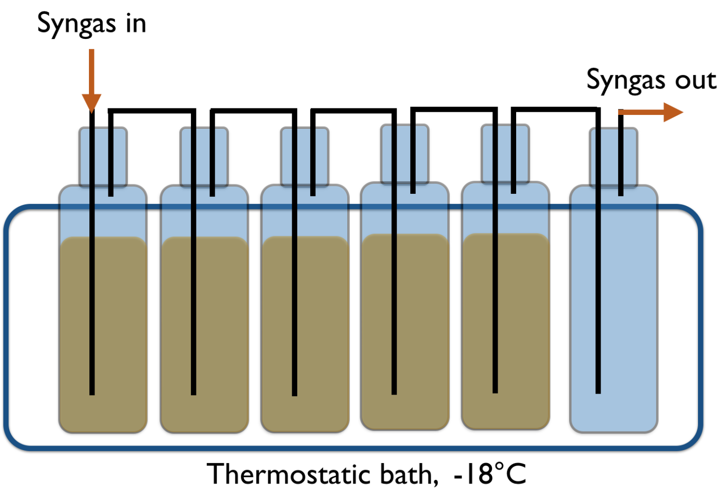

Figure 3. Tar Sampling protocol apparatus

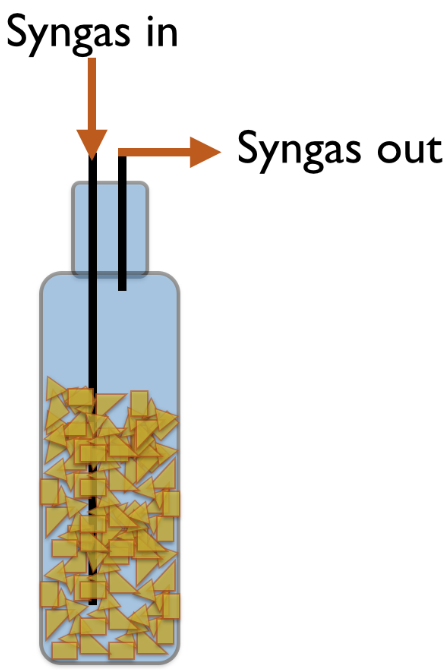

Figure 4. Silica gel apparatus

chromatography-mass spectrometry (GC-MS) was used successfully through the adoption of a specific column for hydrocarbons detection.

In addition to the Tar Sampling Protocol, another tests with Silica Gel was carried out in order to validate the results. The analysis was performed with the same procedure described for the Tar Sampling Protocol using only one impingement bottle filled with about 70 ml of Silica Gel instead of isopropyl alcohol as shown in Fig. 4. This method is carried out at room temperature and it is already adopted in literature coupled with a charcoal filter [14]. In this case the condensates amount is evaluated weighting the gel before and after the tests.

During each test, a bag of syngas was sampled from the top of the biofilter and then it was analyzed by a double coloumn portable gas chromatographer using argon as gas-carrier. This analysis allows to determine the composition of the gas and therefore to monitor the gasification process in order to validate the assumption of constant particulate content and tars production in all the tests.

3. Results

In this section, results concerning Gas Chromatograpy, Tar Sampling Protocol and Silica Gel analyses are reported and discussed. Each filtering medium was tested under steady state conditions of gasification. Tab. 3 summarizes the results of the Gas Chromatograpic analyses in order to check the reliability of the test. The composition of the syngas is affected by the presence of little amount of O_2. This is symptomatic of some air leakage inside the syngas flow lines as result of holes in the seals. However, the amounts of combustible gases CO, CH_4 and H_2 are high, therefore the gasification is efficient and the syngas produced is adequate to run an IC engine.

Table 3. Results of the syngas Gas Chromatograpic analyses

	Woodchips	Corncobs	Zeolites
N_2 fraction [% vol.]	60.5	62.8	60.0
O_2 fraction [% vol.]	9.5	9.2	11.7
CH_4 fraction [% vol.]	2.7	4.0	5.1
H_2 fraction [% vol.]	10.6	8.9	8.0
CO_2 fraction [% vol.]	6.7	5.2	5.8
CO fraction [% vol.]	10.0	8.3	11.0
Higher Heating Value [MJ/Nm^3]	3.69	3.77	4.44

The results of the Tar Sampling Protocol analyses are reported in Tab. 4. The concentration of water and particulate in the syngas were obtained from the difference between the mass of matter collected in the impinger bottles and the mass of tars detected by the GC-MS. In every test, the great part of tars (about 80 %) is benzene, while about 15% is toulene as shown in Tab. 4. The total amount of tars, particulate and water (TPW) collected in the impingement bottles gives the filtering performance of the porous medium. In particular, corncobs reveals the greater performance. The volumetric tar amount in the syngas filtered by corncobs is the lower (1.32 g/Nm^3), therefore this feedstock is able to adsorb water and particulate very efficiently when compared to woodchips and zeolites. This behaviour is related to the high porosity of corncobs compared to the other porous media. In addition, corncobs can be further gasified after their use as filtering medium, instead zeolites need to be rigenerated or disposed.

Tab. 5 summarizes the results of the Silica Gel analyses. The total amount of tars, water and particulate is similar to the value obtained by the Tar Sampling Protocol. The corncobs results confirmed the great performance of this feedstock which is able to reduce at 6.59 g/Nm^3 the T&P&W volumetric amount in the syngas. The values referred to zeolites and wood chips are two and three times grater than the corncobs one. Fig. 5 shows the filtering performance comparison of the porous media analyzed in terms of T&P&W volumetric amount in the syngas and Fig. 6 depicted the comparison in terms of tars volumetric amount.

4. Conclusion

This work discusses the comparison of three different porous materials used as filter in a small scale gasification power plant. Results show that all the filters investigated reduced the tar

Table 4. Results of the Tar Sampling Protocol analyses

	Woodchips	Corncobs	Zeolites
Duration [min]	30	30	30
Average Syngas Flow [Nm^3/h]	0.96	0.96	0.96
T&P&W amount [g]	10.58	2.83	7.48
T&P&W volumetric amount [g/Nm^3]	20.3	5.43	14.4
P&W amount [g]	9.55	2.14	6.65
P&W volumetric amount [g/Nm^3]	20.31	4.11	12.76
T amount [g]	1.03	0.69	0.83
T volumetric amount [g/Nm^3]	1.97	1.32	1.60
Benzene fraction [%]	79.2	80.9	79.1
Toluene fraction [%]	15.2	16.4	16.8
Ethylbenzene fraction [%]	0.52	0.24	0.49
Xylene fraction [%]	0.56	0.18	0.64
Stirene fraction [%]	1.64	1.07	1.24
Naphthalene fraction [%]	2.84	1.20	1.73

Legend: T = tars; P = particulate; W = water.

Table 5. Results of the Silica Gel analyses

	Woodchips	Corncobs	Zeolites
Duration [min]	30	30	30
Average Syngas Flow [Nm^3/h]	0.96	0.96	0.96
T&P&W amount [g]	10.2	3.43	7.65
T&P&W volumetric amount [g/Nm^3]	19.6	6.59	14.7

Legend: T = tars; P = particulate; W = water.

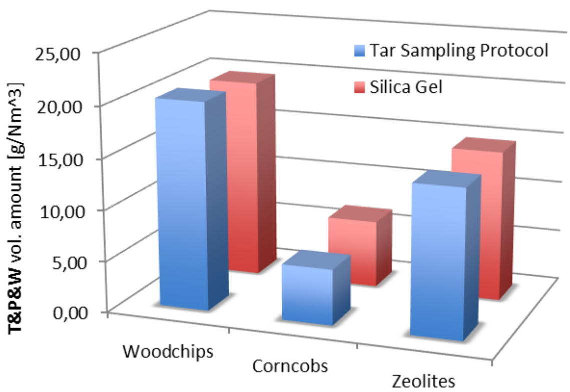

Figure 5. Porous media T&P&W content comparison

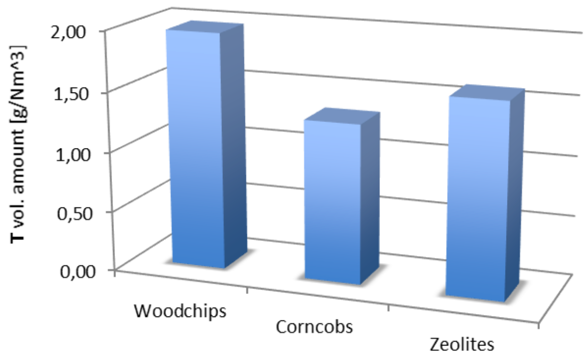

Figure 6. Porous media tar content comparison

content under 2 g/Nm^3. Furthermore, even if the woodchips are widely used as biofilter material, the corncobs resulted to be almost twice better in terms of water, particulate and tars absorption. On the other hand, the zeolites filter investigated in this work gave results halfway between the woodchips and the corncobs.

Corncobs, as well as the other parts of the corn stover, are a by-product with marginal applications. This work opens the possibility of finding new purposes for this material. It can efficiently substitute or complement woodchips in the drum filters. Even though other filtering solutions may produce a cleaner gas, biofilters remain a simple and inexpensive solution that founds a perfect match with small scale gasification systems. In these micro power plants, the simplicity and handiness are more desirable than high perfomance. Moreover, the BEELab is investigating the behavior of corncobs as fuel in downdraft reactors, this solution will lead to a filtering system that has no disposed materials.

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