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Biomass carbonization: process options and economics for small scale forestry farms

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Abstract

Bioenergy represents a unique opportunity for forestry companies to diversify the sources of income and create new stable business opportunities: a large number of initiatives has started in the last decades especially regarding decentralized power generation; nevertheless the conversion of the farmers to energy producers is not a trivial issue. The present work has focused on a possible alternative to biopower generation for forestry farms: the biomass carbonization (i.e. biomass slow pyrolysis). Charcoal making presents good prerequisite conditions for successful biomass based systems in the forestry sector: the system results incentive-independent, the power generation represents the co-product of a different primary production (resulting a real additional income), the plant capital cost is affordable for small scale farmers, operations requires technical skills normally available in the forestry sector and the reliability of the system is proven and credible, reducing the risks contained in business plans based on "number of hours of operation over several years". Moreover charcoal is a well known product, familiar to forestry companies for a very long time, the market is well defined, the technology is known but still offers opportunities for further improvements (in terms of efficiency, costs and environmental impacts), the technology does not present major risk, the investment is well suited to small farmers and the process and technology gives a great opportunity for small scale and local supply chain development.

Based on these considerations, the present work investigated the technological opportunities for small scale charcoal making systems. Various process configurations have been examined, focusing on advantages and disadvantages representative of each solution in view of small scale application suitable for the Italian case and a designed pilot plant has been proposed.

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Keywords: Carbonisation, Slow Pyrolysis, Lignocellulosic Biomass, Small scale farmers

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1. Introduction

Carbonization is a well known process that allowed humans to produce charcoal, the first biofuel that has been used by humans to step out of the stone-age by refining ores into metals. As a premium solid fuel, charcoal is used around the world for domestic cooking, the refining of metals and the production of chemicals [1]; moreover with the industrial development charcoal has become the most valued reducing agent for the metallurgic industry.
Charcoal making could, at the same time, represent a new opportunity for forestry companies to diversify the sources of income as well as create new stable business opportunities other than the typical decentralized power generation. Small scale farmers, typical of Southern Europe Countries, are normally not structured to easily deal with issues such as grid connection and authorizations, emission regulation and compliance, management and operation of biomass power generation systems, etc.
Moreover, their financial capability is often limited, which means that investing in bioenergy plants and/or providing financial guarantees to obtain loans is not an easy task for most of them, thus representing a significant barrier to a wide deployment of these systems.
Finally, bioenergy generation can be economically sustainable only in case economic incentives are made available by the State or the Region: this fact creates uncertainty in the investor and risks in financing, as any change in the policy framework can directly and negatively impact on the whole business. This represents a relevant obstacle to investments in stationary decentralized biomass based systems.
In this context the present work focused on charcoal production as possible alternative to biopower generation for forestry farms.
In fact, charcoal making was identified as an interesting alternative based on the following assumptions that can be considered as prerequisite conditions for successful biomass based systems in the forestry sector:

- The system must be incentive-independent as much as possible
- Renewable power generation – if present – should represent the co-product of a different primary production, i.e. a real additional income.
- The plant capital cost must be affordable for small scale farmers, and operation should requires technical skills normally available in the forestry sector
- The reliability of the system must be proven and credible, reducing the risks contained in business plans based on “number of hours of operation over several years”
- The system must be environmentally friendly

Based on this consideration, the present work investigated the technological opportunities for small scale charcoal making system analysing various process configurations, focusing on advantages and disadvantages representative of each solution in view of small scale application suitable for the Italian case and presenting a carbonizer designed on the basis of the previous remarks.

2. Process Technology

Focus has been placed on the development of reactors conceptually similar to the original charcoal pile but in an improved form that allows to enhance the yield and reduce the conversion time of the process.
Biomass pyrolysis at moderate temperature and low heating rate generates carbon as preferred product with a vapour phase composed of carbon dioxide, water, methane, and traces of carbon monoxide. The thermochemical equilibrium calculation represents the limits of the maximum yield of carbon that can be obtained from a particular biomass feedstock. The efficiency of the process can be measured as comparison between the fixed carbon of the charcoal and the maximum (theoretical) yield of carbon from the feedstock [3]. Current technologies, also the industrial ones, are not efficient and present efficiencies in a wide values range (8-36%) [3-6].

In order to improve charcoal yield and reduce the time of the process, carbonization at elevated pressure was studied, founding that operating with high pressure generates a secondary reaction that improves charcoal production through the decomposition of tarry vapours on its surface [3], enhancing the process efficiency.
During the low temperature pyrolysis, the main important parameters to be kept under control are the heating rate and the peak temperature, that influence the quality of the charcoal and the time of the process. The peak temperature is the highest temperature reached during the carbonization process. This temperature largely controls the quality, influencing the volatile matter content, and other properties of the charcoal product Indeed, biomass is subjected to various transformations that occur at different temperatures: wood retification occurs at 230-250 °C transforming the colour of wood into reddish brown and making it resistant to biological attack torrefaction occurs between 250 and 280 °C creating a black product with little strength [3] while carbonization occur at increasingly higher peak temperature usually in the range of 450-550 °C. Low carbonization temperatures give a higher yield of charcoal but the charcoal is low grade, is corrosive due to its content of acidic tars, and does not burn with a clean smoke-free flame. Good commercial charcoal should have a fixed carbon content of about 75% and this calls for a final carbonising temperature of around 500°C.
Generally, slow heating rate produces a charcoal enhanced in quality and with an higher yield but, some works [1,7], showed that no significant improvements have been found when the heating rate was reduced as an asymptote in the char yield is reached.
However, from a design perspective and in economic terms it is not so practical to employ very low heating rates because the required reaction times are uneconomical: the system we designed want satisfy this condition through a reactor that allows a process time of about two hours, that works on continuous mode (continuous reactors are capital intensive due to the high costs of their components) and, finally, on which it is possible to control the heating rate through a temperature profile similar to that one showed by the gasification technology.

2.1. Plant size and set-up basis

A small scale size forestry farm in Italy manages, generally, an amount of biomass of around 6000-7000 t/y in according to our case study. It has been hypothesized that around 20% of the total biomass available can be used to produce charcoal resulting in a carbonization plant that may convert more than 1200 t/y of biomass. Considering a productivity of 5000 h per year, the size of the plant should convert at least 250 kg/h of biomass. The objective is therefore to design a carbonization plant targeted on this size that could be innovative and easy manageable. A pilot plant of 50 kg/h has been designed in order to validate the slow pyrolysis process proposed, testing the main components and investigating for a possible successful scale-up. In addiction other systems could be tested downstream the pilot plant after the first construction to fulfill all the prerequisite listed above and in particular to succeed in power generation.

3. Oxidative carbonization Pilot Plant Design

Different configurations of the pilot plant have been proposed valuating the possibility of recycling pyrolysis vapours in the reactor for supplying the necessary thermal energy of the process in order to increase the conversion efficiency. To cut the overall cost, the chosen process has been simplified such as the number of components are limited maintaining the functionality of the carbonizer. For instance, the reactor designed operates below the atmospheric pressure in an open-top configuration avoiding the installation of a controlled feeding system on the top.
The pilot plant is essentially composed by three main sections: loading and conversion of biomass; discharge and cooling system; extraction and burning of the vapour gases. The first section is characterized by an open top reactor where biomass is converted in controlled oxidative environment at

temperature in a range of 450-500°C. The heat is supplied burning a part of pyrogenuos vapours and a part of the biomass. Vapours are extracted from the bottom of the reactor using an ejector placed downstream. The ejector also controls the air ratio in the process and allows to operate in slightly below atmospheric pressure conditions. Additional openings with valves at different height are located on the side of the reactor in order to control the heating rate that would be of about 10 °C/min. The discharge and the cooling system (second section) is composed by a screw conveyor which must ensure many features: extraction, cooling, reliability, flow-rate control, air-tightness. After the screw conveyor, charcoal is collected in an airtight removable tank for a lapse-time necessary for cooling down the product up to a safe temperature for handling and storage. The third section concerns the extraction and burning of the pyrogenous vapours and the recovering of waste heat of the process. An ejector has been designed to extract the desired quantity of vapour from the reactor, and consequently to feed in oxygen inside, creating a sub-pressure that draw the air. It is important to note that the piping system must be kept at temperatures of 400°C to avoid tars condensation and the consequent possible clogging of the line. Between reactor and ejector a cyclone removes solids and particles. As mentioned, a burner linked with a heat recovery exchanger is installed downstream the ejector to complete the combustion of gas and tars that represent a sensible pollution emission source. The recovered heat can be used for internal need of the forestry farm or to provide energy for other processes as, for instance, the biomass drying.

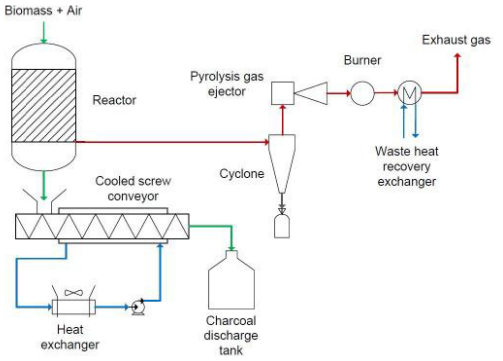

Figura 1 Carbonization Pilot Plant Scheme

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