SCHOOL OF DOCTORAL STUDIES IN ENVIRONMENTAL ENGINEERING – XIX Cycle

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BIOMASS THERMOCHEMICAL CONVERSION: PROCESS ANALYSIS AND ENERGY PERFORMANCES

Abstract of the doctoral thesis

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Currently there is a strong worldwide interest in the development of technologies that allow the exploitation of renewable energy sources, both for environmental reasons (release of pollutants and fossil reserves depletion) and economical ones (the continuous rise of the oil price that is driving up the costs of all the traditional energy resources). In short, if the energy sources were renewable, we would have an ecologically compatible and sustainable energy cycle. One of the most promising renewable energy sources is biomass: as of today there are large amounts of biomass, with an energy content that could be usefully exploited, which, instead, are disposed of as waste (in some case aggravating environmental problems). In perspective, more energy from biomass will be obtained from the cultivation of selected energy crops (energy farms). The use of biomass as an energy source, nevertheless, is not always, by itself, an environment friendly process: wood combustion, for example, can be a rather dirty process that causes the release to the air of several dangerous compounds. For the aforementioned reasons it is important to develop approaches aimed at the use of biomass in the cleanest possible way, avoiding, whenever possible, direct combustion of solid biomass and, rather, pursuing fuel upgrade processes allowing a better combustion or direct conversion to electricity through fuel cells. In this context, is especially interesting the development of technologies for syngas (i.e. synthesis gas) production through biomass gasification and for syngas utilization in fuel cells system, in order to product energy from renewable resources.

The aim of the research is the study of a process for the production of syngas from renewable sources and the assessment of its efficiency and environmental impact considering different energy production solutions. The research in particular focuses on the experimental and theoretical characterization of a biomass conversion process, which can be considered as the core of a future plant for the syngas (and possibly hydrogen) production from biomass. There are, basically, two proposed pathways to obtain syngas starting from biomass: partial oxidation and steam gasification (and also pyrolysis). From an energy balance perspective they differ in the way of feeding the energy necessary to break down the organic molecules forming biomass: partial oxidation obtains energy from the biomass itself but has the drawback that, since air is used as the oxidant agent, the produced syngas has a very low heating value due to the dilution with nitrogen; steam gasification allows to obtain a much better (and hydrogen rich) fuel gas but requires an

external heat source to allow the reaction to proceed. In particular, the steam gasification represents a suitable utilization of the biomass, since the volatile substances from the feedstock are subjected to a reforming process with water steam causing an inhibition of the dioxin-production mechanisms and usually leading to a high-quality effluent.

The research objectives are:

- contribute to the knowledge about biomass and solid waste pyrolysis and gasification;
- optimize the biomass gasification process in order to improve the syngas quality (possibly increasing the hydrogen content) and to obtain high energy efficiencies;
- design and construct a bench-scale reactor for the research purposes, in order to perform experimental activities about pyrolysis and gasification;
- compare traditional and alternative energy production systems and assess, in addition to the feasibility of the process, also the energy and environmental balance.

This thesis can be roughly divided up into three different areas two of these are focused, respectively, on the experimental and theoretical characterization of the thermo-chemical conversion process; and a third activity deals with energy and environmental balance performed at the plant scale, in order to compare different plant layouts.

The theoretical analysis is focused on the development of a mathematical model of the gasification process, including thermal analysis and chemical equilibrium modelling, to be solved with numerical methods. The thermodynamic equilibrium composition of the products (syngas and char) is evaluated through the minimization of Gibbs free energy, while the finite element method is used to evaluate the spatial distribution of the temperature (and of the other parameters) relevant to the biomass conversion process.

The research activity is supported by the application of this equilibrium model comparing traditional and alternative power generation systems (both from an energetic and an environmental point of view) by means of process modelling at a plant scale. In fact, to assess the efficiency of a real process, some plant simulations have been carried out, supplementing the chemical analysis for the reacting stages, with an evaluation of the energy fluxes arising from the other components needed for the actual operation.

To support the model predictions the numerical results have been used to study the feasibility of a small-scale gasifier, calculating the design parameters (temperature, pressure, type and amount of gasifying agent and reactor geometric characteristics).

The experimental activity centers on the design, the construction and, finally, the utilization of an experimental gasifier apparatus, consisting of an indirectly heated batch reactor operating at variable pressure. With the same equipment it is possible to perform pyrolysis experiments or, by fluxing a gasifying agent (air, water steam or industrial oxygen), to implement a gasification process. The purpose of this part is to characterize the syngas yield and composition as a function of the most important process parameters, and the characterization of the effluent gas will be conducted by means of gas-chromatography technique that has been foreseen in the experimental plant layout.