Solid biomass combustion plants and by-products

Combustion: general aspects and analysis of by-products

THE BIOMASS COMBUSTION
General aspects

Combustion is a complex phenomenon: the output of this violent reaction is, in the first instance, the heat and, simultaneously, a series of by-products and wastes that, in many cases, have got characteristics and properties harmful to human and to the environment.
Combustion takes place in dedicated plants: **biomass boilers** especially designed with devices that can handle the fuel characteristics and specificity.

The boilers feed with wood biomass require specific constructive philosophy that allows to have an efficient use of fuel from a variable calorific value, tendentially medium-low, characterized by a high moisture content (up to a relative humidity of 60% by mass) and by a discrete variability of the characteristics in the medium term and in seasonality (humidity, PCI, size, percentage of aggregates, etc.).

Biomass combustion plants

Feeding a boiler with solid fuel require:

- a storage silo
- a fuel material handling system
- a fuel control and metering system
- a adiabatic combustion chamber for the oxidation-reduction process
- a flue gas treatment line

We will not dwell here on aspects related to storage, handling and feeding, even if of fundamental importance for the quality of the final plant. We want to highline on combustion aspects and emission treatment.
We can outline the typical steps of solid biomass combustion process as follows:

1. Heating and drying
2. Pyrolysis and releasing volatile compounds
3. Combustion in the gas phase
4. Secondary combustion of carbon residual
5. Drain the ashes

It is important to emphasize that the main parameter so that byproducts and pollutants are limited, is the quality and stability of the combustion. This parameter, in general, depends on the

level of control and stability that the boiler and the plant can maintain on the same reaction, or by the quality of the design of the boiler and by the use of proper fuel to the installation characteristics. The pollutants that are produced may be treated with a special line of flue gas treatment.
The main controls that a solid biomass combustion system must be able to carry out finely, to manage the quality of combustion reaction, are:

- **The amount and distribution of oxygen** present during the reaction: this parameter affects the stability of the temperatures, the creation of carbon monoxide, the efficiency and the production of specific pollutants.
- **The quantity and the fuel supply mode**. This control depends on the presence of an automatic feeding system and is crucial for a correct ignition, for the stabilization of the combustion system, for controlling the supply of heat (by choking the loads), and for a correct temperature control.
- **The flue gas recirculation**, which allows the control of temperatures and results in a reduction of emissions of nitrogen oxides, affecting in a direct manner on the kinetics of the oxidation reaction. This allows to reduce the upstream contaminant concentration.

On a main plant level, also, it is good to consider:

- **The presence of accumulators**, giving / accepting their reserves of thermal energy, facilitate the management of peaks / falls of heat demand and thus enabling them to “smooth out” sudden violent changes in the combustion. Such variations in fact, in addition to decreasing the average efficiency of the plant, would contribute to higher pollutant productions.
- Last, but not least important, the **aspect of maintenance**: both for the part of combustion that, for the part of the abatement systems, must be planned maintenance and, in certain cases, preventive one must be guaranteed.

By-products and pollutants of wood combustion

Generally it is accepted that the wood is a clean and environmentally friendly fuel. In fact we can agree with the fact that it is neutral in terms of CO_2 production, as well as sustainable (although some clarifications must be kept in mind, as the need to provide a suitable growth cycle and consumption and a “sourcing fuel” in areas adjacent to the plant).
Despite the high quality, also this form of fuel generates by-products and wastes (pollutants and not) dangerous for the environment and for human. For convenience, we divide them into:

- Ash
- Solid particles and condensable compounds
- Compounds in the gaseous phase

Ashes

The management of biomass ash is regulated differently ofr each country by internal environmental law and regulation. In Italy, for example, the management of the ashes follow Part IV of Legislative Decree no. 152/2006 (environmental regulations), which classifies them as “non-hazardous special waste ‘in the category inorganic waste from thermal processes.

As such, the landfill is only the last viable choice for their disposal; there are in fact simplified

procedures that allow for the recovery of the ashes.
In fact, limited to the ash from combustion of virgin wood, under D.M 186/2006, there is the possibility of by-product recovery. In addition, implementing the EEC Regulation 2092/91, the Italian State allows the use of this waste, or better, by-product, as fertilizer and soil conditioner for organic farming (Legislative Decree no. 220/95).

The solid particles and the condensable compounds

Regarding the solid particles, it is good to remember that the combustion of biomass is a major source of inhalable particulate with size smaller than 10 microns (PM_{10}). For the purposes of what follows, we will call these particles as aerosol, in virtue of the fact that are inhalable and, in a relatively short time, may enter the tissues (and from tissue into blood) of animals and humans.

These particles can be divided into:

- primary aerosols: emitted directly by combustion
- secondary aerosols: in the atmosphere resulting from the recombination of the primary molecules.

The literature attributes the formation of the **primary aerosols** to three phenomena:

- The minerals present in the fuel lead to the formation of inorganic fly ash, mainly consisting of salts and oxides. In normal combustion regime (optimal phase) and in modern and

automatic systems, they represent the majority of the emissions of solid particles.

- A combustion that takes place in poor conditions, or in excess of air, it is characterized by a lowering of temperatures and this is incomplete. This can lead to the formation of condensable organic compounds (COC) in the emissions. During uncontrolled burning, the COC may outnumbering inorganic fly ash.
- A combustion that takes place must be “rich”, with local or partial lack of oxygen (choked flame), leading to soot or elemental carbon (carbon black) formation. In addition the formation of VOC and PAH, tarry compounds (TAR) and CO take place.

The **secondary aerosols**, however, are derived from the recombination of VOC into the atmosphere and carbonaceous compounds. Note that, contrary to what one may expect, the secondary aerosols (SOA Secondary Organic Aerosols – SIA Secondary Inorganic Aerosol) contribute significantly to the formation of inhalable particulate matter in the atmosphere and, due to an effect of reflection and self-heating, they contribute to the amplification of light pollution and air heating.
It is important to emphasize that the toxicity levels of above classes of pollutants are quite different from each other.
To this, must be added that since the pollutant categories that “emerge” in non-optimal combustion regimes, even the behavior of the most used abatement systems tends to deteriorate and not be uniform during such working conditions.

The compounds in the gaseous phase

In addition to the above, each combustion reaction, typically, produces certain categories of molecules in the gaseous state:

- Carbon monoxide (CO)
- Carbon dioxide and water vapor (products of combustion)

In particular, the combustion of wood biomass, in the aspect of the gaseous pollutants, is relatively harmless. They are however to be noted emissions of acid gases, which usually have limited concentrations, but may vary substantially depending on the actual type of biomass into use. Among them we can find gas acids:

- Nitrogen oxides (NOx)
- Sulfur oxides (SOx)

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