THERMAL CONVERSION PROCESSES UNIT:

RESEARCH COMPETENCES AND FACILITIES

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1. TECHNOLOGICAL AND RESEARCH COMPETENCES

The Thermal Conversion Processes Unit is a research group of the Centre for Development of Renewable Energies (CEDER), dependent on CIEMAT, with a great experience in combustion and gasification of biomass and waste for producing energy.

Currently, the Thermal Conversion Processes Unit has a wide number of research facilities in CEDER-CIEMAT, located in Soria (Spain). These facilities, unique in Spain, are integrated by combustion and gasification plants of different technologies and powers (from 10 to 1000 kW_{th}), which allow to perform a wide range of test runs and studies in the field of energy valorisation of biomass and waste, measurement of combustion emissions, characterization and cleaning of gasification gas and study of deposit formation.

The research activities of the group are:

- Assessment of commercial combustion devices (boilers and stoves) using standard biofuels, to obtain impartial information on behaviour, emissions, efficiencies and problems related to ashes.
- Study of the combustion process of different types of biomass and waste in well-characterized combustion devices, comparing results with those obtained with standard biofuels. These results support the development of new biofuels to be used in the domestic or industrial sectors and the writing of biofuels quality standards. This activity also provides information for the further design and development of new technologies or the improvement of existing combustion devices.
- Combustion emissions measurement, so that the fulfilment of thresholds established by national and international emission regulations can be evaluated. This activity supports the decision of using alternative types of biomass or waste as energy source in different existing or new facilities.
- Study of deposit formation in heat exchangers in medium and large power plants, using a deposit sampling probe developed by the Unit. This allows

getting deposit samplings from heat exchanger surfaces, without shutting down installations, with the corresponding economic benefit. The analysis of the samplings provides information on the deposit structure and quantity and the possibility of reducing it for increasing efficiency.

- Study of the gasification process of different types of biomass and waste, optimizing the operating parameters and using different gasifying agents for obtaining a gas of the best possible quality. This activity contributes to the evaluation of the feasibility of the energy use of a fuel through gasification and to the optimization of the process.
- Characterization of gasification gas, measuring the main components (H_2, CO, CO_2, CH_4, C_2s, C_3s, benzene, toluene and H_2O) and pollutants (NH_3, HCl, HF, particles and tars). These results provide relevant information regarding the need of cleaning and upgrading of the gasification gas for the final use (burner, engine, gas turbine, production of syngas, etc.). Taking into account the obtained results, the best way of using the produced gas is established.
- Study of the gasification gas cleaning process, using different stages and optimizing the sorbents and operating conditions in each case. This will facilitate criteria for designing the gas cleaning plant in an industrial application, taking into account the desired use of the gas.

For the development of all these research activities, the Unit has several research facilities and analysers that are described in the following chapter.

2. RESEARCH FACILITIES

The Thermal Conversion Processes Unit, located in CEDER and dependent on CIEMAT, focuses its research activities in combustion and gasification of biomass and waste for producing energy in a sustainable way.

Several research facilities of different technologies and powers allow performing these activities and are available for carrying out test-runs in the framework of research projects or technical services to private or public companies:

2.1. COMBUSTION FACILITIES

A. 1 MW_{th} bubbling fluidized bed combustion plant

Bubbling fluidized bed combustion plant with 1 MW_{th} capacity, consisting on a furnace of 1 m inner diameter and 4 m height. Temperature control is achieved through several heat exchangers inside the bed and an external air-exhaust gases exchanger, heating several buildings connected to the plant through a pipe net.

Three hoppers are available for feeding simultaneously several kinds of biomass or waste and inert materials or inorganic sorbents. The main hopper is adapted to all kind of woody and herbaceous biomass, feeding in the range 100-350 kg/h. The fuel inlet to the furnace is performed by a screw conveyor 50 cm above the air distribution plate.

A propane burner provides the installation initial heating up to the solid fuel ignition temperature.

Two possibilities for removing particles from exhaust gases are available: a bag filter or a combination of an electrostatic precipitator and a bag filter.

A centralized control system allow the online measurement and saving of all operating parameters, such as temperatures, pressures, heat transfer and flow of biomass, air and water. An online measurement of O_2, CO_2, CO, NO_x, SO_2, TOC and TSP is carried out in the exhaust gases, being also possible to measure other specific gases (NH_3, HCl, CH_4, NO, NO_2, N_2O, etc.) and to perform discontinuous isokinetic samplings for determining particle concentration.

1 MW_{th} bubbling fluidized bed combustion plant.

Electrostatic precipitator and bag filter.

B. 500 kW_{th} commercial moving grate boiler

Commercial moving grate boiler with a capacity of 500 kW_{th}, with continuous ash removal and heat exchanger cleaning, which produces hot water for heating several buildings connected to the plant through a pipe net.

Two hoppers adapted to all kind of woody and herbaceous biomass are available for feeding simultaneously several kind of biomass or waste in the range 50-200 kg/h. The fuel inlet to the furnace is performed by a screw conveyor in an extreme of the combustion chamber and the grate movement transports fuel and ashes through the furnace up to the screw conveyor that carry ashes to the ashbin.

Two fans introduce primary and secondary combustion air below the grate and into the combustion chamber.

The coarse particles in exhaust gases are removed by a multicyclone at the outlet of the boiler.

A centralized control system allows the online measurement and saving of all operating parameters, such as temperatures, pressures, heat transfer and flow of biomass, air and water. An online measurement of O_2, CO_2, CO, NO_x, SO_2, TOC and TSP is carried out in the exhaust gases, being also possible to measure other specific gases (NH_3, HCl, CH_4, NO, NO_2, N_2O, etc.) and to perform discontinuous isokinetic samplings for determining particle concentration.

500 kW_{th} commercial moving grate boiler

C. 160 kW_{th} cyclonic combustion plant

Cyclonic combustion plant with a thermal capacity of 160 kW_{th}.

The combustion chamber is divided into two parts: a cylindrical section thermally isolated and a cone-shaped region where heat is transferred to water. In the cylindrical region fuel is burnt in suspension, while in the cone section the combustion of the volatile compounds, CO and particles takes place. At the outlet, a multicyclone removes coarse particles from exhaust gases and afterwards fine particles are eliminated in a bag filter.

The feeding system consists on a hopper with a bridge breaker and a screw conveyor with a capacity of up to 40 kg/h.

The control system allows the control and operation of the plant. Temperatures and flows are also measured and saved. An online measurement of O_2, CO_2, CO, NO_x, SO_2 and TOC is carried out in the exhaust gases, being also possible to measure other specific gases (NH_3, HCl, CH_4, NO, NO_2, N_2O, etc.) and to perform discontinuous isokinetic samplings for determining particle concentration.

D. 40 kW_{th} commercial moving grate boiler

Commercial moving grate boiler with a capacity of up to 40 kW_{th}, depending on the fuel, with continuous ash removal and heat exchanger cleaning.

Two hoppers of different sizes are available for short or long test-runs. The fuel inlet to the furnace is performed by a screw conveyor in an extreme of the combustion chamber and the grate movement transports fuel and ashes through the furnace up to the screw conveyor that carry ashes to the ashbin.

A control system allows the online measurement and saving of all operating parameters, such as temperatures, heat transfer and flow of air and water. An online measurement of O_2, CO_2, CO, NO_x, SO_2, TOC and TSP is carried out in the exhaust gases, being also possible to measure other specific gases (NH_3, HCl, CH_4, NO, NO_2, N_2O, etc.) and to perform discontinuous isokinetic samplings for determining particle concentration.

40 kW_{th} commercial moving grate boiler

E. 25 kW_{th} commercial condensing biomass boiler

Commercial condensing biomass boiler with a thermal capacity of 25 kW_{th}, with the possibility of working in automatic modulation mode or at five different fixed power levels. The boiler is able to work under condensing or non-condensing conditions.

Fuel is fed from below into the burner, which has a patented cleaning system. Ashes fell into the ash bin, from where are manually remove in the experimental boiler, in order to facilitate the sampling of ashes, avoiding the mixing of ashes from different test-runs.

The heat exchanger has a special spiral design with a really high yield, so that the exhaust gases are at a very low temperature in any operating conditions (40-70ºC). The tubes of the boiler are automatically clean with a water jet.

A control system allows the online measurement and saving of all operating parameters, such as: temperatures, pressures, heat transfer and flow of air, exhaust gases and water. An online measurement of O_2, CO_2, CO, NO_x, SO_2 and TOC (also specific gases such as NH_3, HCl, CH_4, NO, NO_2, N_2O, etc.) is carried out in the exhaust gases, being also possible to perform discontinuous isokinetic samplings for determining particle concentration.

25 kW_{th} commercial condensing biomass boiler

F. 10 kW_{th} commercial pellet and olive stone stove

Commercial pellet and olive stone stove with a nominal thermal capacity of 10 kW_{th}, with the possibility of working in automatic modulation mode or at four different fixed power levels. It has the possibility of delivering hot air to three different rooms. The stove has an integrated hopper with capacity of up to one day consumption of fuel.

Fuel is fed from above and the stove has a system for automatic ashes removal from the burner, which allows the operation with fuels with moderate ash content. It also incorporates a heat exchanger cleaning system manually actuated.

A control system allows the online measurement and saving of all operating parameters, such as: temperatures, pressures and flow of air and exhaust gases. An online measurement of O_2, CO_2, CO, NO_x, SO_2 and TOC (also specific gases such as NH_3, HCl, CH_4, NO, NO_2, N_2O, etc.) is carried out in the exhaust gases, being also possible to perform discontinuous isokinetic samplings for determining particle concentration.

10 kW_{th} commercial pellet and olive stone stove

G. Test stands for small domestic boilers and stoves

There are several test stands in the Unit facilities for installing domestic boilers and stoves to be tested in the laboratory. Therefore, the installation of a stove with a thermal capacity up to 20 kW_{th} and two boilers with a power range 15-50 kW_{th} is possible in order to study the behaviour of such devices with different fuels under controlled operating conditions, following a protocol based in the existing standards (EN 303-5, EN 14785, EN 16510 and Eco-Design).

The required instruments for measuring all the operating parameters (temperatures; air, exhaust gases and water flows; heat transfer; pressures) and a central data acquisition system is available for the stove and the boilers installed in these test stands.

The characterization of exhaust gases could be performed with the equipment described in the following section.

H. Combustion gas analysers

A set of different gas analysers provides the typical combustion emissions characterization of exhaust gases from the combustion testing plants located at CEDER-CIEMAT. The following analysers are included:

- NDIR (Non Dispersive Infrared Detector) for determining CO, CO_2, NO and SO_2.
- Paramagnetic for determining O_2.
- Ultraviolet for determining SO_2.
- FID (Flame Ionisation Detector) for determining TOC.

The system includes a NO_2 catalytic converter, so that NO_2 present in the exhaust gases is transformed into NO. Thus, the value of NO provided by the analyser is currently NO_x (NO + NO_2, expressed as NO).

FID is an analyser that operates at high temperature and uses H_2 as fuel and compressed air as oxidizer for determining the quantity of organic carbon in the gas sample. An aliquot of the sample is introduced into this analyser after the filters. The rest of the gas sample is transported to a cooler, where the temperature is reduce close to 0ºC, condensing water. The cold dried gas sample is analysed in the other devices mentioned above.

A portable FTIR analyser for measuring the concentration of the following combustion gas components H_2O, CO_2, O_2 (ZrO_2 integrated probe), CO, NO, NO_2, N_2O, NH_3, HCl, SO_2, HF, CH_4, C_2H_4, C_2H_6, C_3H_8, C_6H_{14} and CH_2O is available.

The analyser consists of a portable sampling unit (with the pump and a ZrO_2 probe for measuring the O_2 content) and the analyser, which incorporates a Fourier Transform Infrared Spectrometer (FTIR). The sample is kept at 180ºC from the stack until the analyser, which allows the determination of all the components in gaseous phase, avoiding their condensation.

The system is connected to a laptop with software that provides the concentration of all the gaseous compounds above mentioned, after comparing the spectra of the gas sample with the spectra of all the components of the library.

Portable FTIR analyser

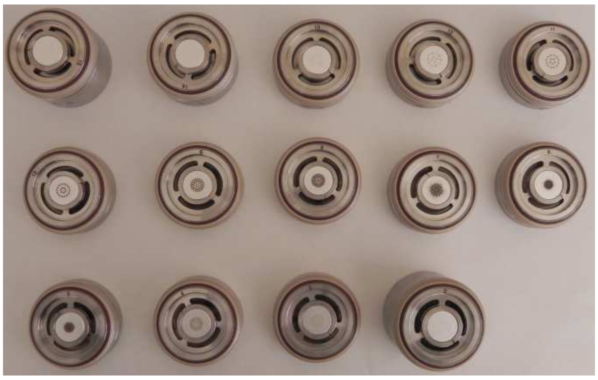
A portable FID (Flame Ionisation Detector) is also available for providing the Total Organic Carbon (TOC) present in the combustion gas. It keeps the gas temperature at 180ºC, avoiding condensation.

Portable FID analyser

An <u>isokinetic sampling probe</u> is available for determining particle concentration (main stream) and HCl and SO_x (side streams) simultaneously, following the standards EN 13284, EN 1911 and EN 14791, respectively.

An <u>Electrical Low Pressure Impactor (ELPI)</u> with 14 stages allows the determination of the concentration and size distribution of particles in the exhaust gases.

Portable ELPI analyzer.

ELPI: 14 stages and detail of the substrate gathered in one stage.

2.2. GASIFICATION FACILITIES

A. 500 KW_{th} circulating fluidized bed gasification plant

Gasification plant with a thermal capacity of 500 kW_{th}, consisting of an atmospheric circulating fluidized bed gasifier (300 mm inner diameter and 8.5 m height) and a gas cleaning plant. The gasifier works in autothermal mode, after its preheating with a propane burner.

The feeding system is airtight and consists of two hoppers and two screw conveyors. Moreover an additional hopper is connected to the gasifier for introducing the bed inert material continuously during the process, if needed.

The ashes removal from the bed is carried out by a refrigerated screw conveyor continuously, if necessary.

Solid recirculation is performed through a cyclone, a return pipe and a solid valve, all of them isolated.

The gas cleaning plant consists of several separate stages: another cyclone, a heat exchanger, a bag filter, low temperature scrubbers and a torch. The gases cleaning could be performed following all the stages or only the ones to be studied.

A centralized control system allows the online measurement and saving of all operating parameters, such as temperatures, pressures and flow of biomass, air and gas. An online measurement of O_2, CO, H_2, CO_2, CH_4 and SH_2, among other gaseous components, is carried out in the gasification gas (several sampling points). The tar sampling in the gas is performed based on the technical specification CEN/TS 15439 and the concentrations of each component are determined in the laboratory.

Gasification gas cleaning plant

B. 150 KW_{th} bubbling fluidized bed gasification plant

Bubbling fluidized bed gasification plant with a thermal capacity of 150 kW_{th}. The gasifier, of 300 mm inner diameter, is pre-heated with a propane burner at the startup of the plant, but afterwards the process is autothermal, without any external heat source. A fan introduces air uniformly through the distribution plate, but other gasifying agents, such as water steam or oxygen, are possible.

The feeding system is airtight and consists of two hoppers and two screw conveyors. Moreover an additional hopper is connected to the gasifier for introducing the bed inert material continuously during the process, if needed.

The ashes removal from the bed is carried out by a refrigerated screw conveyor continuously, if necessary.

At the outlet of the gasifier, the gasification gas enters a cyclone, which remove the coarse particles. The gas without particles flows through a pipe with two sample points. Finally, the gas generated in the process is burnt in a torch.

A centralized control system allows the online measurement and saving of all operating parameters, such as temperatures, pressures and flow of biomass, air and gas. An online measurement of O_2, CO, H_2, CO_2, CH_4 and SH_2, among other gaseous components, is carried out in the exhaust gases. The tar sampling in the gas is performed based on the technical specification CEN/TS 15439 and the concentrations of each component are determined in the laboratory.

150 kW_{th} bubbling fluidized bed gasification plant

C. Gasification gas analyzers

A transportable device with the following gas analyzers configured with the appropriate ranges for measuring gasification gas is available:

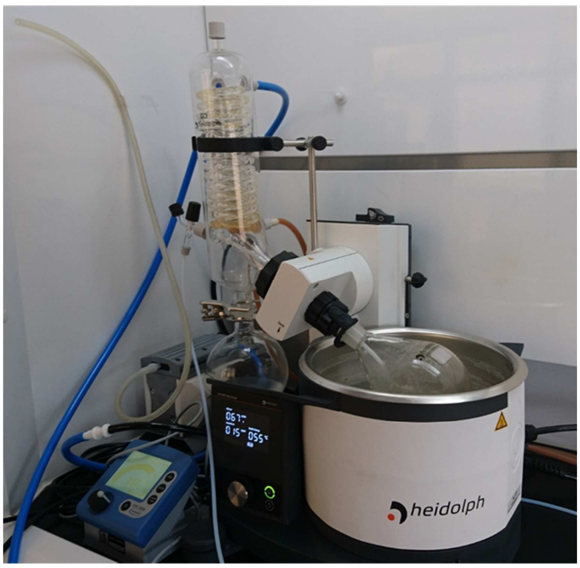
- NDIR for determining CO, CH_4 and CO_2.
- Thermal conductivity analyzer for H_2.
- Paramagnetic analyzer for O_2.
- Laser analyzer for SH_2.

- FTIR for determining H_2O, CO_2, CO, NH_3, HF, CH_4, C_2H_4, C_2H_6, C_2H_2, benzene and toluene (available at the end of 2020).

Moreover, a <u>portable FID analyzer</u> is available for determining TOC in the gas.

The <u>tar sampling</u> in the gas is performed based on the technical specification CEN/TS 15439 and the concentration of each component is determined in the laboratory. Furthermore, gravimetric tars are also determined with a <u>rotary evaporator</u>, following the same technical specification.

Tar sampling system



Rotary evaporator for gravimetric tars determination