

# Combustion and Gasification

JUAN OTERO DE BECERRA - HEAD OF COMBUSTION AND GASIFICATION DIVISION, CIEMAT - SPAIN

The CIEMAT Combustion and Gasification Division focuses on the development of systems that enable the clean, efficient use of solid fuels (coal, biomass, wastes) and future alternatives – Hydrogen – in a situation such as today's where it is increasingly clear that there is a need for a wide range of energy generation and storage systems, while still having to rely on a very significant share of the fossil fuels, for which zero emission solutions are being studied to mitigate their impact on climate change.

The combustion process is the oldest chemical process that human beings have used, first to heat themselves and later to obtain energy, without understanding in the beginning its chemical nature. Gasification processes began to emerge in the era of industrial development due to the need in certain processes to have a combustible or synthesis gas in order to obtain other products. Today the main application of both processes is to obtain clean energy from fossil fuels, biomass or waste, and there has been a revival of synthesis gas obtainment processes due to the rising prices of gas and oil.

The ideal combustion process is a process of total chemical oxidation of the fuel with the oxygen in air (21% O<sub>2</sub> and 79% N<sub>2</sub>), which gives rise to CO<sub>2</sub>, H<sub>2</sub>O, N<sub>2</sub> and O<sub>2</sub> with the release of energy in the form of heat. However, neither the fuel is ideal nor the reaction perfect and, consequently, many substances will be found in the combustion products, to a greater or lesser extent depending on the characteristics of the fuel and the operating conditions, in two different currents: one solid current of ash and slag as a result of the mineral matter that accompanies the fuel, and another gaseous current that, in addition to the above mentioned combustion products, may contain substances such as the following: SO<sub>x</sub>, NO<sub>x</sub>, CO, heavy metals, ash particles and unburned materials carried by the gaseous current, this being the one that contains most of the fuel's energy in the form of heat. This thermal energy is transferred to a fluid which, in a thermodynamic cycle, is transformed into work and the work into electric energy. Technically and colloquially speaking, the

**THE CIEMAT, THROUGH THE CURRENT COMBUSTION AND GASIFICATION DIVISION, HAS BEEN WORKING ON COMBUSTION PROCESSES SINCE 1980 AND IS A PIONEER IN SPAIN IN THE APPLICATION OF THE FLUIDIZED BED COMBUSTION TECHNOLOGY**

term Thermal Power Plant is applied to those installations that employ fossil fuels (coal, fuel-oil, gas), biomass or wastes and convert their chemical energy into heat for direct use or transformation into electric energy.

This is valid for all fuels, with modifications in the contents and compositions of the currents depending on the fuel formulation, reaction kinetics and operating conditions, and this gives rise to specific designs of burners, furnaces and recovery boilers.

The gasification process is a much more complex process than combustion that involves processes of volatilization, partial oxidation and chemical conversion between the obtained products themselves, with the fuel proper and in some cases with the presence of catalysts that drive and move the reactions in the desired direction. The gasifying agent can be air, oxygen and water vapor, making up a complex system. The gasification process is endothermic and needs to be supplied with energy; therefore, if no energy is available, it is necessary to reach total oxidation of a fraction of the fuel, with release of the energy required for the development of the rest of the endothermic

processes. Just as in the case of combustion processes, contaminants are produced that will need to be treated before using the obtained gas.

Fuels are present in solid form (coal, biomass, waste), liquid form (oil and liquid byproducts) or gas form (natural gas, from gasification or from waste methanation processes), and each one acts differently in the aforementioned oxidation reactions:

- Solid fuels are burned in three phases: heating and volatilization, oxidation of the volatilized compounds in vapor phase, and oxidation of the non-volatilized compounds at operating temperatures. Part of the heat generated in the oxidation process is used to maintain the volatilization until it is complete. The second stage, which occurs in vapor phase, is much faster than the third, which is a heterogeneous reaction between a gaseous phase and another solid phase.
- Liquid fuels burn in a vapor phase and, therefore, part of the reaction heat is used to vaporize the fuel.
- Gaseous fuels are directly burned.

Gasification processes start with solid fuels and include the stages of heating and volatilization, partial oxidation of the fuels (a fraction can reach total oxidation) and interactions between the gasifying gas, the volatilization products and the non-volatilized compounds at operating temperatures. This requires that the design of each installation always be tailored to the fuel to be used.

The CIEMAT, through the current Combustion and Gasification Division, has been working on combustion processes since 1980 and is a pioneer in Spain in the

application of the Fluidized Bed Combustion technology, resulting in the most comprehensive experimental installation (with Fluidized Bed technologies) in Spain at the pilot plant level. At present, its installations include a 5 KWt bubbling fluidized bed (LFB) at the laboratory level in Madrid, and the pilot plants currently located in the CIEMAT Center in Soria (CEDER), where various installations are located: 0.5 MWt grate boiler, 100 KWt LFB, 1 MWt LFB, both mere combustors, 3 MWt LFB equipped with steam boiler, 0.5 MWt circulating fluidized bed (LFC), which can operate under conditions of combustion or gasification using air as oxidizing agent or air and/or O<sub>2</sub>, CO<sub>2</sub> and water vapor mixtures as gasifying agent. In addition, in the CEDER there are several biomass boilers in operation to supply energy to its buildings and that are simultaneously used for studies. Activity in this field is currently being carried out in the CIEMAT through the Combustion and Gasification Division and

## **HYDROGEN, AS AN ENERGY VECTOR, PRESENTS ITS HIGHEST ENERGY PERFORMANCE ON CONVERTING ITS ELECTROCHEMICAL ENERGY INTO DIRECT ELECTRIC ENERGY**

the CEDER Center (Soria), working together in all the above mentioned installations.

Some important aspects for the development of combustion and gasification technologies concern the development of tools for modeling. For this purpose, the Numeric Modeling Unit of the Combustion and Gasification Division uses numeric solutions of conservation of mass, quantity of movement, energy and chemical species equations, together with chemical kinetics models. These simulations take into consideration all the spatial-temporal scales in

order to study simplified scenarios that will elucidate the physical-chemical mechanisms that govern combustion or gasification phenomena. In the case of modeling realistic plants, this technique is not viable because of the high computational costs and, therefore, models are introduced that reflect the impact of the smaller scales (unresolved) on the largest ones (resolved). Typically, these models simplify and lower the cost of simulation of reactive turbulent flows.

Another very important aspect concerns the purification, treatment and reforming of gases, in addition to those strictly related to combustion and gasification. The Energy Recovery Unit of the Combustion and Gasification Division is in charge of all these tasks.

Hydrogen, as an energy vector, presents its highest energy performance on converting its electrochemical energy into direct electric energy. In this field, the Fuel Cells and Systems Integration Unit of the

CIEMAT, in coordination with the CSIC, is actively working on the development of components for the different types of fuel cells and on the development of systems to enable the integration of the fuel cells into hydrogen generation systems (gasification, gas reforming, wind energy and electrolysis, etc.) and the end electric power consumers (electric power grid or isolated systems).

A fluidized bed is a chemical reactor where the reactions – in our case combustion or gasification – take place on a suspended bed of inert material (sand) with very special characteristics, the most important of which are homogeneity, the capacity to easily control the operating temperature at a much lower thermal level than that of other technologies and the possibility of adding reactives and products that reduce and/or eliminate the formation of contaminants.

Since the early 1980s, clean coal technologies have been under development which are based on the implementation of systems of new low NO<sub>x</sub> burners and gas purification in conventional power plants, the use of Fluidized Bed technologies (in Spain: La Pereda, Escatron) and Gasification integrated into Combined Cycles of coal and oil byproducts (in Spain: Elcogas). In addition, there are now combined cycle plants that burn natural gas with higher energy performance and fewer problems of contaminant formation, which have gradually replaced the coal installations. In recent years, the use of biomass as a renewable source has become increasingly relevant in both combustion and gasification processes.

The rising prices of oil, the limited reserves and the new problems associated with climate change have required a new look at fossil fuels, and especially coal, because according to all estimates they will still have to be taken into consideration, since they will be needed in the energy mix to be able to supply, at least in a 50-year timeframe, the worldwide energy demand.

For this to be possible, a step beyond what has been the clean coal technology (elimination of contaminant emissions – NO<sub>x</sub>, SO<sub>x</sub>, particles, heavy metals) must be taken: prevent the main product of combustion, CO<sub>2</sub>, one of the precursors of so-

called Climate Change with its very high levels of accumulation due to the mass use of fossil fuels.

In the distribution of greenhouse gases, carbon dioxide (CO<sub>2</sub>) accounts for 77% of total emissions of these gases, methane (CH<sub>4</sub>) for 14%, nitrous oxide (N<sub>2</sub>O) for 8%, and the remaining 1% comes from other gases. As for their source, 61.4% comes from the energy sector, 3.4% from industrial processes, 18.2% is contributed by land use changes, and agriculture accounts for 13.5% and wastes 3.6% of total emissions.

The United States and Europe have invested heavily in the development of technology for CO<sub>2</sub> capture in large combustion installations, focusing on the ones that use coal.

For this purpose, three courses of action are proposed:

- Pre-combustion processes: applicable to gasification processes in which the synthesis gases of coal gasification are treated and reformed, converting them into H<sub>2</sub> and CO<sub>2</sub> to separate the CO<sub>2</sub> before energy conversion of the gas. In Spain, this initiative is being developed by Elcogas with a 20 MWt plant, a project in which the CIEMAT is participating together with other institutions such as CSIC and the University of Castilla la Mancha.
- Post-combustion processes: Based on the purification and separation of the CO<sub>2</sub> of the combustion gases in conventional installations. The CIEMAT is participating in these processes with the study and evaluation of adsorbents. Other developments in Spain are those carried out in INCAR (CSIC) in Carbonation-Decarbonation processes.
- Oxy-combustion processes involve the separation of oxygen from air and combustion with high purity oxygen to obtain combustion gases with more than 80% CO<sub>2</sub>. Spain has been a pioneer in this field; in 2004 the CIEMAT developed an Experimental Platform in El Bierzo for the development of oxy-combustion processes, taking the first steps towards what is today, governed by the State Foundation Ciudad de la Energía (CIUDEN), the most complete and most important experimental platform in the world for CO<sub>2</sub> capture in oxy-combus-

tion processes. It is equipped with a 20 MWt pulverized coal-fired boiler, a 30 MWt circulating fluidized bed, a 3 MWt biomass gasifier, and gas treatment and CO<sub>2</sub> purification and compression systems. These installations are due to begin operating in late 2010 and the two boilers in mid-2011.

In this respect, the EU has decisively backed the initiative to demonstrate the viability of thermal power plants with a capacity for industrial-scale capture and storage, including the social acceptance of the technology. The first step has been the call for proposals of the European Commission's Directorate General of Energy and Transport to award grants to a series of CO<sub>2</sub> Combustion and Storage (CAC) demonstration projects, in the framework of the Economic Recovery Program that the EU has undertaken in the field of energy.

The six selected projects include the Spanish initiative headed by Endesa, CIUDEN and Foster Wheeler, with a 180 million euro grant. This is the only Spanish project, and the only one of the selected projects, that deals with the oxycombustion technology in a circulating fluidized bed, and it covers everything from the development being carried out in the Technology Development Platform for CO<sub>2</sub> Capture that CIUDEN is building in Cubillos del Sil (Leon) and the one for CO<sub>2</sub> Storage that is still in the project phase, to the design, construction and startup of a 300 MWe demonstration plant, which will include geological capture and storage. The Ministry of Industry, Tourism and Trade has agreed with CIUDEN and Endesa to set up a company that will take on the design, construction and operating tasks of the plant, which will be located in the Thermal Power Plant of Compostilla. During the first 20 years of plant operation, the plant will stop the emission of 18 million tons of CO<sub>2</sub>, which will be stored in a safe deep geological repository, in accordance with the European Union regulation published on June 5th and that is being transposed to Spanish legislation.

The CO<sub>2</sub> Geological Storage Program and the Socio-Technical Research Center of Barcelona, both pertaining to the CIEMAT, are participating in the experimental and research work that will make it possible to safely build this repository.