Integration of the capture unit with the power generation: technology advances in oxy-combustion plants

Luca Mancuso\textsuperscript{a,1*}, Noemi Ferrari\textsuperscript{a}, Vince White\textsuperscript{b}, John Davison\textsuperscript{c}

\textsuperscript{a} Foster Wheeler, Via Caboto 1, 20094 Corsico, Italy
\textsuperscript{b} Air Products PLC, Hersham Place Technology Park, Molesey Road, Walton-on-Thames, Surrey, KT12 4RZ, UK
\textsuperscript{c} IEA Greenhouse Gas R&D Programme, The Orchard Business Centre, Stoke Orchard, Cheltenham, Gloucestershire, GL52 7RZ, UK

The International Energy Agency Greenhouse Gas R&D programme has contracted Foster Wheeler to perform a study that evaluates, technically and economically, coal-fired power plants with leading carbon dioxide capture technologies. This paper presents an up-to-date assessment of the oxy-combustion alternative, included in the study, based on Air Products’ proprietary technology for the carbon dioxide purification and compression unit. This work outlines the most recent technology advances, focusing on the integration of the capture unit with the power plant, mainly in the area of the thermal heat recovery, pollutant control and quality of the produced carbon dioxide. This study is currently under execution and is expected to be completed ahead of the conference.

Keywords: Oxy-combustion; CO\textsubscript{2} purification, CFB, PC, Sour compression, Integration

1. Introduction

Oxy-combustion of fossil fuels and carbon dioxide purification and compression is one of the leading technologies that can enable governments to move to a low-carbon economy.

Although the technologies are relatively new on the market, recently there have been significant technological advances in the design of these power plant types, aimed at reducing the energy penalty of the capture process and improving the net electrical efficiency of the plant.

Furthermore, the successful operation of key demonstration projects, like the Foster Wheeler’s oxy-CFB (circulating fluidized bed) boiler at CIUDEN and Air Products’ proprietary technology at Vattenfall AB’s research and development facility in Schwarze Pumpe, provided valuable feedback for the next technology scale-up and operation at large scale.

In addition to the above, one of the key challenges in reducing capital cost and in the development of commercial projects is the deep integration of the capture unit with the power plant, mainly in the area of the thermal heat recovery, pollutant control and quality of the produced carbon dioxide.

\* Corresponding author. Tel.: +39-02-4486-2670; fax: +39-02-4486-3045.
\textit{E-mail address:} luca_mancuso@fwceu.com.
Foster Wheeler is carrying out a study for the International Energy Agency Greenhouse Gas R&D programme (IEAGHG), to provide an up-to-date assessment of the performance and costs of coal-fired power plants with leading carbon dioxide (CO\textsubscript{2}) capture processes, investigating the most recent technological improvements.

This paper presents the results of a techno-economic assessment of the oxy-combustion alternative, included in the study, with a downstream carbon dioxide purification and compression unit. The assessment is made in close cooperation with Air Products, to include their most recent technology updates of their proprietary carbon dioxide capture, purification and compression system. New concepts of integration of the capture unit with the power plant for efficiency optimization and sensitivity to different capture rates and CO\textsubscript{2} purities are also presented.

2. Plant configuration

The oxy-combustion power plant is based on state-of-the-art boiler and steam generation equipment. To use existing, proven boiler technology, flue gas must be recycled and used for fuel transportation and inert dilution to moderate the peak temperature in the furnace. The boiler is equipped with electrostatic precipitators. The amount of SO\textsubscript{2} being fed to the CO\textsubscript{2} purification section is controlled in the flue gas desulphurization (FGD) unit, installed on the primary recycle to the boiler. Installing the FGD on the primary recycle enables the sulphur concentration in the furnace to be reduced below the figure at which excessive gas-gas tube corrosion occurs, without the investment cost related to a full-size FGD based on the entire flue gas flowrate.

SO\textsubscript{x} and NO\textsubscript{x} are removed from gaseous CO\textsubscript{2} during compression as sulphuric acid and nitric acid in aqueous solutions. Acid-free flue gases, after a temperature swing absorption unit, are fed to the auto-refrigerated inert gas removal section, where excess oxygen, along with argon and nitrogen present in the oxygen feed and air leakages, is mostly separated from the condensing CO\textsubscript{2} and vented. Using a standard configuration with two CO\textsubscript{2} flash separators leads to CO\textsubscript{2} purities of around 95-98%. An additional distillation column should be installed to comply with maximum allowed oxygen content of 100 ppmv, achieving CO\textsubscript{2} purity up to 99.9%. A low pressure air separation unit (ASU) provides the low-pressure oxygen required by the combustion.

Thermal integration within the process unit and the steam cycle is optimized in order to increase the power plant net electrical efficiency, also avoiding excessive capital cost increase. Boiler feed water and condensate are pre-heated against flue gases in the boiler cold end and against compressed CO\textsubscript{2} in the purification unit, reducing steam extraction from the steam turbine. Integration with the ASU is also considered.

3. Air Products’ Sour Compression

One of the most interesting technological advances in the oxy-combustion plant scheme is the CO\textsubscript{2} compression and purification unit based on Air Products’ solution, defined as a sour compression process, which removes SO\textsubscript{x} and NO\textsubscript{x} from the CO\textsubscript{2}-rich feed stream during compression.

In a standard configuration, the flue gas product from the power boiler is scrubbed with water in the direct contact cooler, condensing water vapor present in the flue gas, and removing residual ash particles and highly soluble HCl and SO\textsubscript{3} before further compression and purification. Very little SO\textsubscript{2} and NO\textsubscript{x} is removed in this water scrubbing process, resulting in a CO\textsubscript{2} purity lower than required to prevent corrosion and comply with possible regulations or with the stringent requirements for applications such as enhanced oil recovery.

The sour compression process removes SO\textsubscript{2} as H\textsubscript{2}SO\textsubscript{4} and NO and NO\textsubscript{2} as HNO\textsubscript{3} by controlling the acid formation in two stages of water scrubbing after compression, as shown in Figure 1. Any mercury compounds present in the CO\textsubscript{2}-rich flue gases are also removed as mercuric nitrate. After compression to 15 bar a holdup of a few seconds is added to the process, by the use of a contacting column to allow time for all of the SO\textsubscript{2} to be removed as H\textsubscript{2}SO\textsubscript{4}. The SO\textsubscript{2}-free CO\textsubscript{2} stream is then compressed before being dried and inert gas is removed, up to the level required to ensure the selected capture rate, e.g. 35 bar is required for a capture rate of 90%. This point is considered the ideal location to remove the NO and NO\textsubscript{2} from the process, adding another few seconds of holdup to the process. Around 90% of the NO\textsubscript{x} and all of the SO\textsubscript{2} can be removed in this way from the CO\textsubscript{2} before inert gas removal.
The optimum configuration, in terms of overall plant efficiency and costs, is presented in this work, also assessing both integrally geared intercooled compressors for the lowest electricity consumption and axial compressor to minimize the number of trains and recovering heat for boiler feed water pre-heating.

Figure 1. Air Products’ Sour Compression scheme

4. High CO₂ capture rate

The configuration of the auto-refrigerated inert gas removal section depends on the required capture rate and final CO₂ purity. As a base configuration, the CO₂ purification and compression unit is designed for capturing 90% of the CO₂ entering in the unit.

Higher CO₂ capture rate, up to 98%, is achievable with the Air Products scheme by installing a series of PRISM® membrane modules, recovering CO₂ from the vent stream and recycling it back to the process. An additional bonus is that oxygen is also recovered in the membrane and recycled back to the boiler, reducing the amount of oxygen required from the ASU, thus resulting in a smaller ASU and reduced power requirements.

Both configurations are assessed and presented in this work, focusing on the integration with the power plant.

5. Conventional PC and CFB boiler technologies

The present work is an update of the review of performance and costs of an oxy-combusted power plant, made in the past for a previous IEAGHG report (2005/9) and based on the use of a pulverised coal boiler technology. However, this work also presents the main features of a CFB boiler technology, particularly suited for oxy-firing conditions because of its fuel flexibility and temperature control (which allows reduction of the amount of recycled flue gas), as well as inherent sulphur capture characteristic, which avoid the installation of the downstream flue gas desulphurization equipment. Finally Foster Wheeler’s Flexi-Burn® CFB technology is also presented, which allows the operation under conventional air-fired combustion or oxy-combustion conditions, thus improving the operational flexibility of the plant.