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The Oxy-combustion burner development for the CO_2 pilot at Lacq

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Abstract

Steam demand is increasing for Oil & Gas projects, and in particular oil sands and extra-heavy oils thermal recovery schemes. Use of oil residues and bitumen can be a cost-effective solution for natural gas substitution in SAGD (Steam Assisted Gravity Drainage). However, use of such fuels gives rise to higher specific GHG emissions.
Oxy-combustion technology is an elegant solution to this problem since oxygen allows complete combustion of very high viscosity and heavy fuels, and because it provides a concentrated CO_2 stream, for easier Carbon Capture and Storage (CCS).
Air Liquide has acquired over the last two decades extensive industrial experience of full oxy-combustion for the glass, metals, cement and waste treatment industries. This expertise and extensive scientific knowledge have been used to develop an innovative oxy-burner technology, specific to steam and power production applications.
This oxy-burner technology presents novel and differentiating features, which will be described in this paper. In particular, it features a direct oxygen injection into the burner, without external mixing of oxygen with the flue gas recycle, which provides additional flue gas recycle rate flexibility, and enables a safe handling of the oxygen.
Air Liquide has demonstrated the performance of this oxy-burner concept through downscaled (1 MW) oxy-combustion tests in a dedicated cold-wall test-rig with flue gas recycle.
Total will retrofit the air-fired boiler at its Lacq CO_2 Project (SW of France) with an intermediate size of this oxy-burner technology (four 8 MW oxy-burners).
The paper presents:

- the innovative oxy-burner technology, its challenges and novelties,
- a description of the Air Liquide 1 MW oxy-combustion test rig and the test results obtained over a wide range of flue gas recycle rates,
- the integration of the oxy-combustion system into Total's existing 30 MWth boiler.

Keywords: Type your keywords here, separated by semicolons ; oxycombustion; oxyburner; carbon capture; Lacq;

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1. Introduction

Steam demand is increasing for Oil & Gas projects, and in particular oil sands and extra-heavy oils thermal recovery schemes. Use of oil residues and bitumen can be a cost-effective solution for natural gas substitution in SAGD (Steam Assisted Gravity Drainage). However, use of such fuels gives rise to higher specific GHG emissions.

Oxy-combustion technology is an elegant solution as oxygen allows complete combustion of very high viscosity and heavy fuels, providing intrinsically a concentrated CO_2 stream, for easier Carbon Capture and Storage.

Over the last two decades Air Liquide has acquired extensive industrial experience of full oxy-combustion for the glass, metals, cement and waste treatment industries. This extensive expertise and scientific knowledge have been used to develop an innovative oxy-burner technology, specific to steam and power production applications.

Total and Air Liquide have conducted from 2003 to 2005 a feasibility study and laboratory experiments on oxy-combustion of natural gas and different heavy oil residues applied to large steam boilers associated with CO_2 capture, with funding from the French National Agency ADEME.

Total launched end 2006 an integrated CCS project in the Lacq gas treatment complex in the South-West of France. An existing boiler built in 1957 within the utilities facilities is being retrofitted to oxygen firing for the combustion of commercial gas. The 30 MW_{th} oxyboiler will produce 40t/h of steam (60 bar and 450°C) which will be used as heating medium or for power generation within the Lacq complex.

The pilot plant will emit up to 120,000 tons of CO_2 over a 2-year period. The CO_2 stream will then be treated, compressed and transported via a pipeline to the depleted gas field of Rousse, 30 kilometers away, where it is to be injected into a deep carbonate reservoir. Currently, the ASU is under construction, the boiler being modified and start-up is scheduled beginning 2009. The plant will be fully integrated into the existing facilities and it is designed to comply with the safety standards of Total Exploration & Production. Air Liquide is an industrial partner to this project, and is supplying the Air Separation Unit (ASU), four 8 MW oxy-burners and the Flue Gas Dryer.

Such an industrial pilot plant is a necessary step to ensure that the CCS solution will be technologically and economically optimized through representative upscaling (learning from operation), reliable on both short and long terms, energy efficient, environmentally effective, recognized within a legal framework and accepted by the public.

The major expected outcomes of the Lacq pilot plant are:

- to demonstrate, at reduced scale, the whole integrated chain of oxy-combustion for CCS, through capture, transport, injection and storage,
- to gain feedback on technical feasibility, operability and reliability of CCS steam production scheme,
- to design and carry out the retrofit and operation of a CO_2 capture 30 MWth oxycombustion gas boiler,
- to develop and apply geological storage qualification methodologies, monitoring and verification techniques in a real operational situation,
- to prepare future larger scale long term storage projects.

2. Oxy-burner technology: its challenges and novelties

Oxygen flames are characterized by quick kinetics when compared to air. This results in a rapid and dense heat release of chemical energy from the fuel, in the form of short and intense flames. Industrial applications such as glass and metallurgy have built on these characteristics of oxy-combustion for increased productivity and temperature increase.

Because of the aforementioned characteristics, the use of oxygen can be of great interest for difficult fuels, ensuring stable and complete combustion. These difficult fuels require either long residence times in the combustion zone, or blending with “easier” fuels, which would reduce viscosity and introduce higher volatile content. Examples of difficult fuels are bitumen, residues, petcoke, emulsions, etc.

For the high-temperature applications, oxy-combustion is usually implemented in furnaces, whose walls are mainly covered by refractory material. This implies high wall temperature and a considerable level of back-radiation, which facilitates at the same time flame stability and complete combustion.

Boiler application implies on the other hand completely different conditions to the oxy-burner design, as the combustion chamber is covered by steel water-walls, with high heat transfer rate and relatively cold surfaces:

- Heat transfer distribution within the boiler towards the water-walls has to be controlled, both in its peak values in order to avoid departure of nucleate boiling (DNB) inside the water tubes, and also in its overall distribution, in order to avoid excessive kurtosis and skewness in this heat transfer profile.
- Higher adiabatic temperature of oxygen flames must be correctly managed. This temperature is 2757°C for methane, while in air it would be 1937°C.
- Flue gas composed mainly of CO_2 and H_2O, due to the absence of nitrogen ballast, implies different properties when compared to an air flame: higher emissivity, but also a shielding effect if used wisely.
- Cold water-walls enclosing the combustion chamber imply the need of a good mixing of fuel and oxidant for ensuring complete combustion, especially for difficult fuels.
- Safe operation and safety procedures, allowing the use of the oxy-combustion technology within stringent environments such as Oil & Gas plants.

The developed oxy-burner technology addresses these issues, while taking advantage of the characteristics of oxygen flames for difficult fuels. Schematically, such as shown in the Figure 1, the burner concept can be considered a core oxygen flame, surrounded by a screen of flue gas recycle.

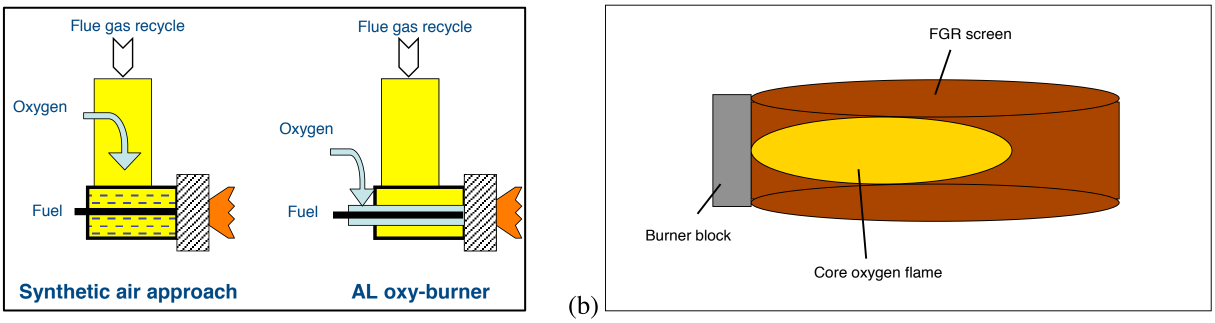
(a)  (b)

Figure 1. (a) Principle of internal fluid arrangement and (b) flame configuration principle with proposed oxy-burner.

A first novel feature in this oxy-burner concept is that there is no external mixing of oxygen with the flue gas recycle, the whole stream of oxygen is injected through the burner. This has three main advantages:

- Improved operating safety, allowing a dedicated circuit for pure oxygen all along distribution system.
- Additional flexibility to adjust the flue gas recycle rate, this variable being a key parameter to retrofit existing combustion chamber designs (such as Lacq boiler).
- Benefit from above listed oxy-combustion advantages (flame stability, ability to cope with difficult fuels, high turndown ratio), while dealing with the constraints related to the boiler application.

At the same time, this oxy-burner design allows more flexibility since it provides a stable air-combustion mode in which air is injected through the recycle duct, and is used for start-up, transient phases and fallback operation.

This oxy-burner concept has been developed for several years along different test campaigns on different types of fuels, including even residues from oil industry.

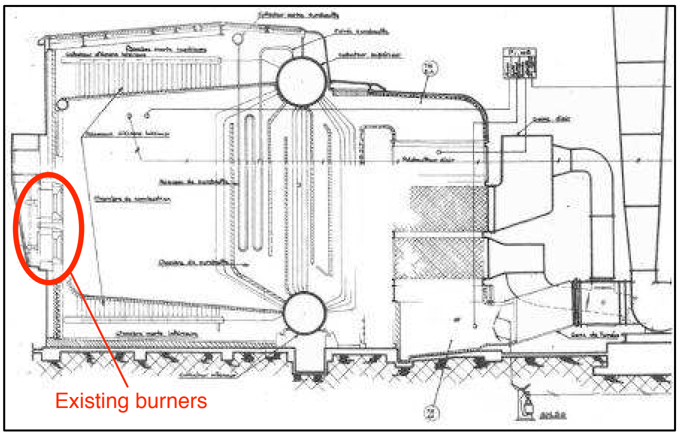


Figure 2. Lacq CH2 boiler to be retrofitted.

The oxyburners to be implemented in the Lacq CCS Project have been designed to deliver 8 MWth each, to replace the four existing horizontal air-fired burners, in the existing CH2 boiler (see Figure 2). This imposed the geometry arrangement of the four burners and of the combustion chamber itself, particularly the chamber length, in front of the burners, before the frontal water wall.

3. The oxy-burner development at the 1MW test rig

The oxy-burner development path which has been decided for the Lacq CCS project is: a) to downscale the real size design (8 MWth), b) to refine the downscaled design and to validate it experimentally in a dedicated test rig, and c) to upscale it again to the definitive real size 8 MWth design to be manufactured.

A test rig was therefore designed for the experimental validation. It provided answers concerning the following points:

- Characterization of heat transfer from the flame and of the effect of variable flue gas recycle rate on heat transfer, on complete combustion and on flame stability within a cold-wall environment.
- Study of mixing parameters, which would have a strong influence on flame length.
- Validation of the oxy-combustion principle to obtain very high CO_2 concentration in the flue gas.
- Feasibility of stable and safe operation.

3.1. The experimental set-up

Following these considerations, the combustion chamber design has been chosen to be of cylindrical geometry with one horizontal oxy-burner (see Figure 3), providing a comparable chamber confinement to that of Lacq boiler, which is translated into similar design ratios for power over chamber volume and power over surface. More chamber length has been allowed to study the effect of mixing parameters on the oxy-flame length. The oxy-burner is placed in the centre of one of the sides of the cylinder, and the flue gas exits at the opposite side. The lateral walls are composed of five separated cooling water loops as carbon steel coils, ensuring heat extraction from the flame. Cooling water flow is controlled and measured on each coil, and its inlet and outlet temperatures are also measured, which enables the calculation of heat transfer to each of the five coils along the chamber axis.

The different flows into the oxy-burner (fuel, oxygen, flue gas recycle) are controlled and measured.

Instrumentation inside the chamber includes, at four positions in between the water-wall coils:

- Thin foil flexible heat flux sensors, placed along the boiler axis, consisting of a thermoelectric panel laminated between flexible heterogeneous plastic layers, giving a local measure of total heat flux. They are regularly calibrated at the proper temperatures on an adapted black body.
- Thermocouples, which are introduced at variable depths inside the chamber.
- Peepholes, capable of hosting sampling and metering probes.

Figure 3. 1 MWth oxy-combustion test rig at Air Liquide's CRCD.

At the outlet of the chamber, flue gas composition is continuously measured. The flue gas coming out of the chamber is further cooled within a cross-flow heat exchanger against a variable flow of air, and goes through a variable-speed fan. This flue gas flow is measured and divided into two streams, one to a stack while the other is recycled to the oxy-burner, after being measured as well. Pressure profile along the circuit is monitored to ensure a slightly positive level within the chamber during the test campaigns.

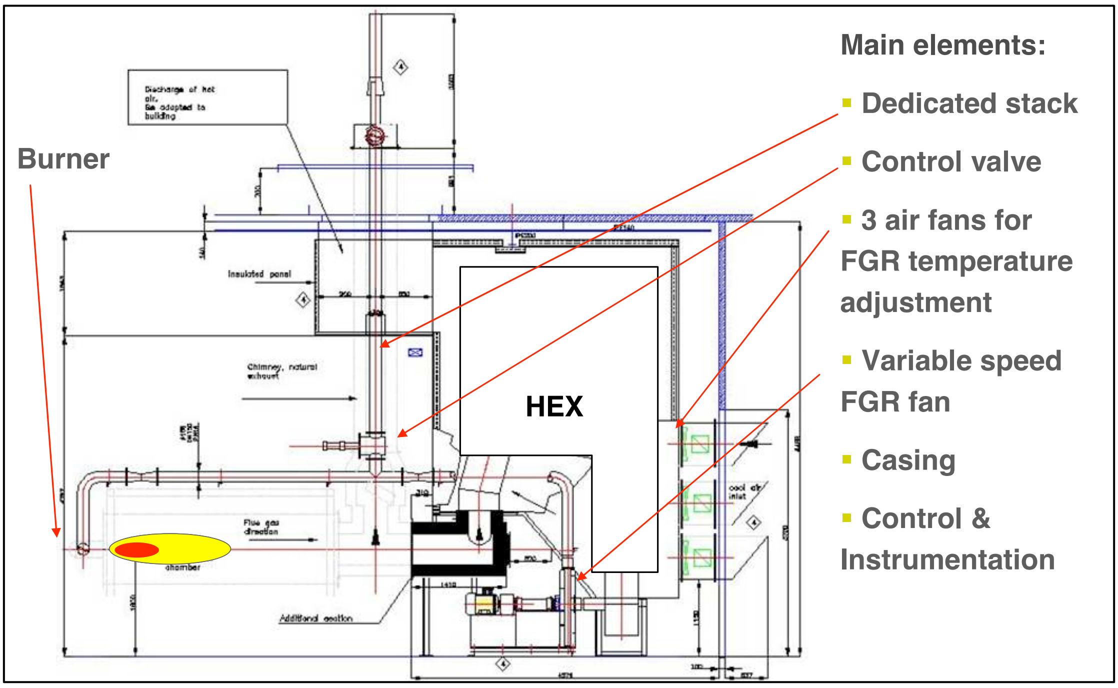


Figure 4. Arrangement of the 1 MWth oxy-combustion test rig.

An important element to this chamber is that it is not thoroughly sealed. Air in-leakage reduction into the combustion chamber is mainly performed by control of the pressure level. This control is mainly performed through the variable speed recycle loop fan and the flue gas control valve to the stack (see Figure 4).

All measured data are recorded thanks to an acquisition station, and coherent heat and mass balances have been performed and cross-checked on these data.

Several oxy-combustion test campaigns have been carried out with commercial natural gas as fuel, at different operating conditions, including variation of flue gas recycle rate. Oxygen supply has been provided from commercial liquid purity (99,5 % vol). Flue gas recycle rate is defined here as flue gas volume recycled to the burner over flue gas volume to the stack.

3.2. Results

The oxy-combustion concept has been validated as a means to obtain CO_2-enriched flue gas. Excess O_2 was controlled at 2% vol. on a wet basis at the boiler exit. High CO_2 concentration (94 % vol. on a dry basis) has been systematically achieved during the various test campaigns when maintaining a slightly positive pressure in the chamber.

These excellent results have been obtained in the test rig through the proper monitoring of the pressure at level, at the chamber outlet, slightly positive. This brings the important conclusion that control of pressure in the system is a key element in reducing air inleakages into the system. These air inleakages are one of the main sources of dilution of CO_2 in the oxy-combustion flue gas.

As expected for oxy-combustion, an important turndown ratio has been demonstrated on the test rig configuration, attaining values as low as 10%.

Tests have also shown that variation of flue gas recycle rate has a considerable effect on the flame properties. Heat transfer distribution to the water walls can be readily managed, in addition to the temperature levels of hot gas in contact to the water walls (Figure 5).

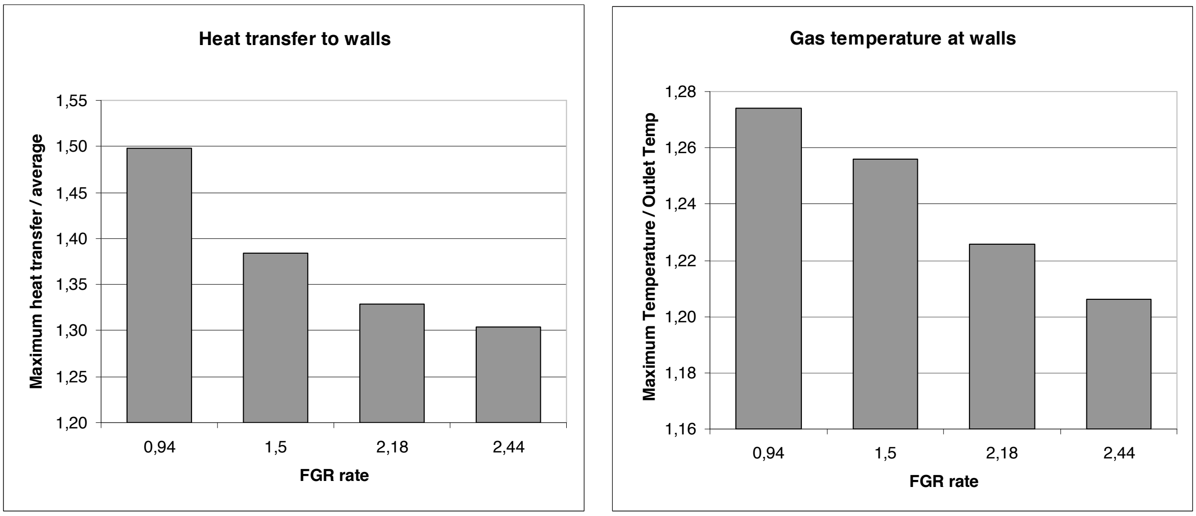


Figure 5. (a) Measured effect of FGR rate on heat transfer to water walls, (b) on flue gas temperature at walls.

In Table 1, the main parameters describing the heat flux measurements distribution for each flue gas recycle rate are shown. The negative values for kurtosis excess ($\gamma_2 = \frac{\mu_4}{\sigma^4} - 3$) indicate the desired smooth shape with round peak and wider "shoulders", which should avoid high stress and lack of homogeneity in heat transfer distribution. This negative value becomes more important with higher flue gas recycle rates, confirming the intuition of a thermal tempering of the flame. μ_i indicates the moment of i degree about the mean and σ is the standard deviation.

The skewness ($\gamma_1 = \frac{\mu_3}{\sigma^3}$) in Table 2 indicates the asymmetry of the heat flux transfer distribution. With lower flue gas recycle rate, this distribution is asymmetric towards the burner root, while with increasing flue gas recycle, it becomes more symmetric and its peak moves towards the end of the flame.

FGR rate	Maximum/average	Excess kurtosis	Skewness
0,94	1,50	- 0,86	- 0,13
1,5	1,38	- 0,80	- 0,01
2,18	1,33	- 0,84	0,02
2,44	1,30	- 1,11	0,04

Table 1. Parameters of the measured distribution of heat transfer to the water walls.

4. The oxy-burner upscaling at Lacq's boiler

The optimized downscaled 1 MW oxy-burner design (including validated improvements with the experimental rig), has been upscaled to 8 MWth to fulfill all the requirements of the Lacq CCS Project.

The interaction between the four different oxy-burners and the interaction of the multiple burners oxy-combustion system and the boiler itself has been addressed specifically by separate experiences and computer simulation, allowing the supply of an adapted design for the Lacq boiler.

4.1. The oxy-burner upscaling to 8 MW

The oxy-burner upscaling takes into account the following constraints linked to the CCS project:

- existing boiler geometry, including replaced burner size, burner arrangement and flame length,

- slight operating overpressure in the boiler and sizing of the flue gas recycle and air fans, which favors a low pressure drop in flue gas recycle or air injections,
- the low-pressure Air Separation Unit design for energy optimization, which allows a low pressure drop in oxygen lines and injections.

The burner auxiliaries (igniter, flame detector and actuators) have been integrated to the design and its compatibility with the oxy-burner concept has been validated with the downscaled prototype.

Figure 6. 3D view of actual 8 MW oxy-burner.

4.2. Validation of operating mode.

There is not yet an existing code for oxy-boiler operation. Engineers and operators from Total and Air Liquide adapted their procedures to the characteristics and features of the oxy-burner design within a safe and reliable oxy-boiler. They delivered an operating mode and the instrumentation and control requirements, which have been implemented in the detailed design of the fluid distribution system and the boiler retrofit.

This operating mode was thoroughly rehearsed at the 1 MW test rig, validating its feasibility and the satisfactory flame characteristics at every transient phase. In particular, the fallback air-fired mode has been validated, both from the points of view of flame stability and flue gas composition.

4.3. The integration into the existing boiler.

Further to this, the four oxy-burners have to be physically integrated to the existing boiler at the Lacq site:

- Fixation into the existing burner openings and refractory walls.
- Sealing the interfaces between the burner and the boiler, in order to avoid any leakage.
- Mounting and supporting the burners, arranging individual flue gas recycle entry points.

Figure 7. Lacq boiler front wall after dismounting existing air-fired burners.

Another capability of the oxy-burners installed at Lacq is that of being bi-fuel. With the change of a central injection element, the burners are able to burn liquid fuel and/or gaseous fuel with the same level of performance.

5. Conclusions

The oxy-combustion concept has been experimentally validated as a solution to obtain high CO_2 concentration in the flue gas facilitating the CO_2 capture. The feasibility of oxy-combustion within a boiler environment has been demonstrated for a large spectrum of operating conditions. Tests have also shown the importance of pressure control to avoid air inleakages (and associated CO_2 dilution) into the system.

The proposed oxy-burner concept, implementing a separate injection of oxygen and flue gas recycle, enables oxy-combustion in boilers with high oxygen content in a safe manner regarding oxygen handling and boiler integrity. The feasibility of this high oxygen content has been experimentally validated in a boiler configuration.

The characteristics of this oxy-burner have been experimentally validated:

- variable flue gas recycle rate for revamping applications,
- oxygen flame stability, even with difficult fuels,
- high turndown ratio,
- air mode for transient operation,
- fuel flexibility for gas & liquid fuels.

Air Liquide and Total are presently implementing the industrial demonstration of this advanced oxy-burner design within the Total Lacq Gas plant, as an integrated pilot of the complete oxy-combustion for CCS chain. Start-up of the retrofitted oxy-boiler is scheduled early 2009.

6. Bibliography

1. Nicolas Aimard, Marc Lescanne, Gérard Mouronval, Claude Prébendé. “The CO_2 pilot at Lacq: an integrated oxy-combustion CO_2 capture and geological storage project in the South West of France”. IPTC SPE Conference, Dubaï (UAE), 4-6 December 2007.

2. Nicolas Aimard, Claude Prébendé, Denis Cieutat, Ivan Sanchez-Molinero, Rémi Tsiava. “The CO_2 pilot at Lacq: an integrated oxy-combustion CO_2 capture and geological storage project”. 3rd IEA-GHG Oxyfuel Workshop, Yokohama (Japan), 4-6 March 2008.

3. Nicolas Aimard, Claude Prébendé, Denis Cieutat, Ivan Sanchez-Molinero, Rémi Tsiava. “The integrated CO_2 pilot in the SW of France (oxy-combustion and geological storage): A potential answer to CO_2 mitigation in bitumen production”. ITOHOS SPE Symposium, Calgary (Canada), 20-23 October 2008.

4. Bloch, K. “Dealing with deceptive failure modes”. Hydrocarbon Processing”, July 2003, p. 67.