Flameless Pressurized Oxy-combustion Technology

A new way of burning at close to zero emissions

Workshop a Carbonia, Centro Ricerche Sotacarbo
27 novembre 2014
Mitigazione dei cambiamenti climatici: il ruolo delle tecnologie «Carbon Capture and Storage»
Itea’s Milestones

- The **Sofinter Group is leader in combustion technology** and fully owns a Research Company on combustion operating one of the biggest test rig in Europe

- Due to the rising environmental concerns on combustion emissions the **Sofinter Group decided in 2002 to invest in a spin off, ITEA**, dedicated to the development of a whole new way of burning: the flameless.

- **In 2004 a new pilot plant with the significant capacity of 5 MWth has been built by Itea at Research Company branch facility**

- Itea, through the testing activity at the plant, has registered important patents on processes and equipment **making the flameless combustion technology an industrial product ready to be marketed**

- **In 2009 a larger plant (15 MWth) has been built in Singapore; the long term operational campaigns done in then Singapore plant gave to Itea the operational experience needed to make the flameless combustion technology a product ready to be marketed in a number of industrial applications**
Itea’s Registered Patents Application

• **WO2004/094904**: METHOD AND PLANT FOR THE TREATMENT OF MATERIALS IN PARTICULAR WASTE MATERIALS AND REFUSE

• **WO2005/108867**: HIGH-EFFICIENCY COMBUSTORS WITH REDUCED ENVIRONMENTAL IMPACT AND PROCESSES FOR POWER GENERATION DERIVABLE THEREFROM

• **WO2008/080561**: PROCESS FOR THE PURIFICATION OF COMBUSTION FUMES

• **WO2009/071230**: COMBUSTION PROCESS

• **WO2009/071238**: COMBUSTION PROCESS

• **WO2009/071239**: COMBUSTION PROCESS

• **WO2011/012516**: STEAM GENERATOR

* **WO2014/016235** COMBUSTION PROCESS FOR FUEL CONTAINING VANADIUM COMPOUND

* **WO2014/016237** COMBUSTION PROCESS FOR FUEL CONTAINING VANADIUM COMPOUND
Isotherm Block Diagram

- **Oxidation reactor**
- **Fumes quencher**
- **Energy recovery**
- **Neutralization/condensation** (as option)
- **Co2 recovery**

- **Combustion fumes**
- **Fumes loop**
- **Cool gas**

- **Oxygen**
- **Fuel/Waste**

- **Vitrified Slag**
- **Steam/Power**
Isotherm Pwr®

Flameless Pressurized Oxy-combustion

5 MWth Pilot Unit - Aerial View
in operation since 2004

120 ft X 60 ft

Blower
Small
Compact
Simple
(few unit operation)

Fully automated
Easy to operate

At Ansaldo CCA Test Rigg Gioia del Colle (BA) Italy

Boiler
Fumes: Water Condensation

Fumes Neutralization

Reactor
Feeding set
Itea Flameless Combustion

Traditional “flame” combustion
“chaotic”
non locally controllable

Itea «Flameless combustion »
MILD, flameless, « volume combustion»
volume expanded - controllable

Cool Zone
Flame Front: Peak Temperatures

High Uniform Temperature
# Industrial Waste Treatment: Overall Emissions

## Flue Gas Emissions

<table>
<thead>
<tr>
<th>Noxious Gas:</th>
<th>EU 2000/76</th>
<th>Isotherm PWR® at stack</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>50 mg/m³, peak value 200</td>
<td>&lt; 1 mg/m³</td>
</tr>
<tr>
<td>NOx</td>
<td>200 mg/m³, peak value 400</td>
<td>&lt; 100 mg/m³</td>
</tr>
<tr>
<td>SOx</td>
<td>50 mg/m³, peak value 200</td>
<td>&lt; 30 mg/m³</td>
</tr>
<tr>
<td>TOC</td>
<td>10 mg/m³, peak value 20</td>
<td>&lt;0.05 mg/m³</td>
</tr>
<tr>
<td>HCl</td>
<td>10 mg/m³, peak value 60</td>
<td>&lt; 0.1 mg/m³</td>
</tr>
<tr>
<td>PAH</td>
<td>0,1 mg/m³</td>
<td>&lt;0.0001mg/m³</td>
</tr>
<tr>
<td>Dust (total)</td>
<td>10 mg/m³, peak value 30</td>
<td>&lt; 1 mg/m³</td>
</tr>
<tr>
<td>PM 2.5</td>
<td>Not yet regulated (Industrial avg. 1.000 – 5.000 µg/m³)</td>
<td>&lt;10 µg/m³</td>
</tr>
<tr>
<td>Dioxin, Furans</td>
<td>0,1 ng/m³</td>
<td>&lt;0.0001 ng/m³</td>
</tr>
<tr>
<td>Heavy metals</td>
<td>0,5 mg/m³</td>
<td>&lt; 0.1 mg/m³</td>
</tr>
<tr>
<td>SOOT / Organic Carbon</td>
<td>Not yet regulated</td>
<td>Zero</td>
</tr>
</tbody>
</table>

(1) Performances already attained at combustor outlet.
The product of the combustion: Inert Slag

heavy and fly ashes melting

Ashes quantitative melting and coalescence is unique to Isotherm process.

- Quantitative Melting
- Liquid phase triggers slag coalescence
- Molten slag drained at combustor bottom

- Molten slag quenched in a water bath
- Vitreous Granular
- Zero Residual Carbon
- Impervious to Heavy Metal Leaching
- Fully inert
Ashes: Vitreous vs. Heavy

Heavy ashes in traditional combustion

Vitreous Ashes of Itea process
Itea’s Approach To Combustion

**TRADITIONAL APPROACH TO COMBUSTION**

Flame combustion
- Chaotic process/non controllable
- Formation of dangerous products during combustion
- Expensive/complex fumes treatment lines
- Heavy and Fly ashes with questionable disposal
- Plants with limited rangeability
- Low CO₂ concentration in outlet fumes

**ITEA APPROACH**

Flameless oxy-combustion
- High and uniform temperature
- Total absence of dangerous products during combustion
- Simple fumes treatment
- Incombustible ashes reduced to vitrified inert slugs
- High plant rangeability (10 => 100%)
- High CO₂ concentration in outlet fumes
- Flexible fuel
Key Success Factor of Isotherm Pwr

A new way of burning at close to zero emission

- The **lowest emissions** rank that known combustion technologies can guarantee.
- The ashes are reduced to totally inert vitrified slags.
- 96% of introduced heat (LHV) is recovered.
- High rangeability of the combustion process (from 10% to 100%)
- Extended acceptance of water content in the fuel
- Ease in commercial CO2 recovery for different utilizations (Industry, Eor, sequestration)
- Capacity to burn simultaneously different kinds of waste and fuels
- Compact relatively small plant highly automated
- Competitive capex.
Industrial Application And Development Stage

- Industrial waste treatment and Landfill remediation → Already commercial
- Municipal waste treatment → Already commercial
- Oil and Gas → Different stages depending on application
- Coal power plants with/without CCS → FEED stage for large pilot and demonstration plant
<table>
<thead>
<tr>
<th>Year Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007 - 2010</td>
<td>Experimental campaigns (with Enel)</td>
</tr>
<tr>
<td>2009 - 2010</td>
<td>50 MWt front end design (with Enel)</td>
</tr>
<tr>
<td>2011 - 2012</td>
<td>350 MWe net front end design (with Enel)</td>
</tr>
<tr>
<td>2013 - 2014</td>
<td>30 bar pilot in USA (with MIT)</td>
</tr>
</tbody>
</table>

Next step: a technology demonstration facility (50 to 100 MWth)
Established Performances

On the basis of the experience already done:

. The technology can treat standard coal and/or low ranking coal, with the same emission results

. Coal can be fed as grinded (not pulverized) slurry with water: slurry logistic avoids coal dust pollution

. Coal ashes disposed as vitrified zero-Carbon inert pearls; therefore can be used as recycled material

. A plant based on this technology can easily follow daily cycling requirements of the grid
Background for Economics Comparison

This technology is subject to comparison with both:

. competing CCS technologies
. current state of art of SC coal fired power plants (in non-CCS set up)

Considering:
. 550 MWe net Super Critical coal power station baseline
. Figures relevant to overall hardware installed
. Standard methods (DOE-NETL) - LCOE
. Key indexes: CAPEX (capital expenditure), LCOE (Levelized Cost of energy)
## CCS Technologies Competitive Positioning

**Base Line: SC Power Station**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>unit</th>
<th>Non-CCS</th>
<th>CCS</th>
<th>CCS ready</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SC base line</td>
<td>SC + amine</td>
<td>IGCC (1)</td>
</tr>
<tr>
<td>Power in</td>
<td>MWth</td>
<td>1345</td>
<td>1880</td>
<td>1770</td>
</tr>
<tr>
<td>Gross Power</td>
<td>MWe</td>
<td>580</td>
<td>661</td>
<td>786</td>
</tr>
<tr>
<td>Net Power</td>
<td>MWe</td>
<td>550</td>
<td>550</td>
<td>550</td>
</tr>
<tr>
<td>Efficiency</td>
<td>%</td>
<td>40.9</td>
<td>29.3</td>
<td>31.0</td>
</tr>
<tr>
<td>Capital</td>
<td>M€</td>
<td>936</td>
<td>1693</td>
<td>2403</td>
</tr>
<tr>
<td>CAPEX</td>
<td>€/kWnet</td>
<td>1700</td>
<td>3078</td>
<td>4370</td>
</tr>
<tr>
<td>LCOE</td>
<td>€/MWh</td>
<td>76</td>
<td>133</td>
<td>140</td>
</tr>
<tr>
<td>LCOE with low rank coal (-35% coal cost)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Location in Europe

Quality coal

Elaborated according to std methods (DOE-NETL)

(1) Recent advance 0.16 kWh/kg O2 applied to all Oxy-combustion technologies

(2) FPOC only performs low rank coals, with efficiency and economic figures equivalent to quality coals
## Competitive Positioning Key Figures

<table>
<thead>
<tr>
<th></th>
<th>Super Critical</th>
<th>Super Critical</th>
<th>Pressurized Oxyfuel – Flameless</th>
<th>Pressurized Oxyfuel-Flameless</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>(non CCS)</td>
<td>CCS with amine</td>
<td>(Itea-Enel study)</td>
<td>Improved</td>
</tr>
<tr>
<td><strong>Net Power</strong></td>
<td>550</td>
<td>550</td>
<td>550</td>
<td>550</td>
</tr>
<tr>
<td><strong>Efficiency (LHV)</strong></td>
<td>40,9</td>
<td>29,3</td>
<td>36,2</td>
<td>38,6</td>
</tr>
<tr>
<td><strong>Capex €/KW</strong></td>
<td>1700</td>
<td>3078</td>
<td>3700</td>
<td>2710</td>
</tr>
<tr>
<td><strong>LCOE €/MWh</strong></td>
<td>76</td>
<td>133</td>
<td>104</td>
<td>91</td>
</tr>
</tbody>
</table>

MIT modelling and economics analysis confirms that Itea-Enel LCOE is pretty close to DOE target (+35% vs Super Critical) for advanced CCS Technologies.
Comments on CCS Situation

ITEA Vision

• At the present technologies development state, all CCS technologies are not economically convenient in comparison with non-CCS state of art power units

• It is likely that the laws regulations will impose a gradual increase, percentage wise, of by-produced CO2 to be stored, though schedule and entity of such obligation is not predictable because of political influence

• The uncertainty about perspective is the major cause for the difficulties in CCS development (together with environmental worries about sequestration)
We intend as «ready for CCS» a coal power plant, based on flameless oxy-combustion, that produces fumes, ultra low emission level, constituted by concentrated CO\(_2\) delivered to the atmosphere.

Such plant can be retrofitted with modular units for compression and storage of CO\(_2\), in accordance with the entity of CO\(_2\) permitted emissions.

The LCOE of such a plant corresponding to the LCOE presented before with cost deduction of the non compressed and stored CO\(_2\) portion.
## Flameless Ready for CCS Economics

### Key Figures

<table>
<thead>
<tr>
<th></th>
<th>Super Critical (non CCS)</th>
<th>Pressurized Oxyfuel – Flameless (Itea-Enel study)</th>
<th>Pressurized Oxyfuel- Flameless Improved</th>
<th>Pressurized Oxyfuel- Flameless Ready for CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Power</td>
<td>550</td>
<td>550</td>
<td>550</td>
<td>613</td>
</tr>
<tr>
<td>Efficiency (LHV)</td>
<td>40,9</td>
<td>36,2</td>
<td>38,6</td>
<td>42,9</td>
</tr>
<tr>
<td>Capex €/KW</td>
<td>1700</td>
<td>3700</td>
<td>2710</td>
<td>1974</td>
</tr>
<tr>
<td>LCOE €/MWh</td>
<td>76</td>
<td>104</td>
<td>91</td>
<td>75</td>
</tr>
<tr>
<td>Low rank Coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCOE €/MWh (-35% coal cost)</td>
<td></td>
<td>94</td>
<td>82</td>
<td>68</td>
</tr>
</tbody>
</table>

Low rank coal capability, with performance retention is unique to Flameless Technology
Thank you for your kind attention
Highlights on key Improvements to be validated at 50 - 100 Mwt demonstration unit

. Efficiency improvement (LHV basis) from 36,2 % to 38,6 %

. CAPEX reduction from 3700 to 2710 €/KWe net

. Levelized Cost Of Energy, CCS set up, from 104 to 91 €/MWh (with quality coal)