Big and Diffuse or Small and Sharp
State-of-the-Art Oxyfuel Based
Melting and Heating

Presentation at SCANMET III

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June 10, 2008
Oxyfuel Solutions
Energy Efficiency

- Low flue-gas losses due to low flue-gas volume
- Possible to use high flue-gas temp
- Radiating compounds, H₂O & CO₂
- Possible to use high power input
- Possible to use Low Calorific Fuels

8 Molecules of Nitrogen Ballast!
Hi JET

- Up to 5 MW burner with innovative mixed swirl flame technology.
- ‘Deep’ carbon injection into the liquid steel.
- Oxygen and natural gas consumption savings due to the shut-off of the oxygen and natural gas during injection mode.

OXYGENJET

- Up to 5 MW burner with innovative mixed swirl flame technology.
- Supersonic/coherent oxygen injection.
- Oxygen and natural gas consumption savings due to the shut-off of the oxygen and natural gas during injection mode.

CARBONJET

- Up to 5 MW burner.
- With innovative mixed swirl flame technology.
- Carbon/lime/dolo-lime injection.
- Oxygen and natural gas consumption savings due to the shut-off of the oxygen and natural gas during injection mode.

LIMEJET

18/06/20
Oxyfuel Combustion Technology

- Energy savings
- Increased production
- Lowered emission

Flameless – low NOₓ, high uniformity

Big & Diffuse

DFI – for ultra fast heating

Only <800°C

And the Newest: REBOX® HLL!
Flameless Oxyfuel
Uniform Heating and Reduced NO\textsubscript{x}

Combustion extended in time and space
- Volume combustion
- Spontaneous reaction above self ignition temp. (>750ºC from safety point of view)

Dilution of flame reduces flame temperature
- Flame temperature is even with no peaks which minimizes thermal NO\textsubscript{x}

Minimized temperature difference between flame and furnace walls
- Uniform heating of object

Dilution results in good stirring of the highly radiating CO\textsubscript{2} and H\textsubscript{2}O gases in furnace
- More even furnace temperature
- Convection transfer to object

Compact and powerful burner technology
Flameless Oxyfuel

Oxyfuel Staged Combustion with 5% Primary Oxygen

Flameless Oxyfuel
Flameless Oxyfuel
Ultra Low NO$_x$ Levels

<table>
<thead>
<tr>
<th>Type</th>
<th>NO$_x$ mg/MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Oxyfuel</td>
<td>~100-200</td>
</tr>
<tr>
<td>Staged Oxyfuel</td>
<td>70-100</td>
</tr>
<tr>
<td>Flameless Oxyfuel</td>
<td>&lt;25</td>
</tr>
</tbody>
</table>

Dilution reduces flame temperature and provides effective stirring of the highly radiating CO$_2$ and H$_2$O gases.
Flameless Oxyfuel has Lower Flame Temperature, but Same Energy Content

Flame mode

Flameless mode
Flameless Oxyfuel
Ultra Low NO\textsubscript{x} Despite Ingress Air

![Graph showing NO\textsubscript{x} emissions vs. oxygen concentration in chimney for different fuel types.](image)
Benefits of Oxyfuel in Vessel Preheating

Benefits from higher heating temperature of a steel-making vessel:
— No need to have too high tapping temperature from the EAF/BOF
— Shorter heating cycles for less number of vessels needed
— Only 75-80% flue gases due to less fuel and no nitrogen in combustion – smaller flue-gas system
— 50-55% lower fuel consumption compared to cold air fuel system

Simple, compact and low weight installation as compared to air-fuel system with recuperator or regenerative solution

Additional Benefits from Flameless oxyfuel:
— Further improved heat distribution in the vessel
— Ultra low NO$_x$ emissions
— Extended refractory lifetime due to a more even temperature distribution in vessel
Vessel Preheating with Flameless Oxyfuel

Vessel preheating using oxyfuel is common technology – using **Flameless Oxyfuel is a Milestone in Preheating**!

- Increased temperature uniformity in ladle
- Decreased fuel consumption
- Lower NO\textsubscript{X} formation
- Increased heating capacity

**Cases of flameless oxyfuel**

<table>
<thead>
<tr>
<th>Company</th>
<th>Type</th>
<th>Capacity</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandvik</td>
<td>90 t converters</td>
<td>1.4 MW</td>
<td></td>
</tr>
<tr>
<td>Outokumpu</td>
<td>90 t ladles</td>
<td>1.5 MW</td>
<td></td>
</tr>
<tr>
<td>Acerinox</td>
<td>90 t ladles</td>
<td>2.0 MW</td>
<td></td>
</tr>
<tr>
<td>OVA KO</td>
<td>90 t ladles</td>
<td>1.4 MW</td>
<td></td>
</tr>
<tr>
<td>Kanthal (1500\textdegree C)</td>
<td>5 t ladles</td>
<td>0.2 MW</td>
<td></td>
</tr>
<tr>
<td>Outokumpu</td>
<td>90 t converters</td>
<td>2.5 MW</td>
<td></td>
</tr>
</tbody>
</table>
REBOX® Oxyfuel Solutions
General Results from Installations

Fuel and CO₂ savings
Up to 50% reduction

Low NOₓ emission
Levels continuously below 70 mg/MJ

Less Scaling
Up to 0.4%-units reduction

Increased production capacity/flexibility
Up to 50% higher throughput

Car bottom furnace at SCANA Steel, all equipped with flameless oxyfuel
**Lower Fuel Consumption in a Reheating Furnace**

<table>
<thead>
<tr>
<th></th>
<th>Air fuel</th>
<th>AF w recu</th>
<th>REBOX®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enthalpy in steel</td>
<td>kWh/t</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Transmission losses</td>
<td>kWh/t</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Flue-gas enthalpy</td>
<td>kWh/t</td>
<td>290</td>
<td>140*</td>
</tr>
<tr>
<td>Flue-gas temperature</td>
<td>ºC</td>
<td>1200</td>
<td>850</td>
</tr>
<tr>
<td>Air preheating</td>
<td>ºC</td>
<td>20</td>
<td>450</td>
</tr>
<tr>
<td>Thermal efficiency</td>
<td>%</td>
<td>42</td>
<td>70</td>
</tr>
<tr>
<td><strong>Energy need</strong></td>
<td>kWh/t</td>
<td>500</td>
<td>350</td>
</tr>
<tr>
<td><strong>Energy need</strong></td>
<td>GJ/t</td>
<td>1.8</td>
<td>1.26</td>
</tr>
<tr>
<td>Oxygen production</td>
<td>kWh/t</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*after recuperation
Flameless Oxyfuel burners, Water-cooled & Ceramic

Ultra low NO$_x$ & Uniform heating
   — High flue gas circulation and lower flame temperature

Dual mode burner – standard and flameless

Separated jets – Supersonic

Powerful: 0.5-5 MW
   — Oil, coal or gaseous fuels

Easy retrofit & Compact rugged design
   — Quick release fittings
   — Simple dismounting
   — Integrated UV and pilot burner
   — Burner diameter 105 mm (w-c), 300 mm (ceramic)
   — Weight 10-20 kg (w-c)
REBOX® Oxyfuel Solutions
Retrofit Replacing Air-fuel

4 MW air-fuel installed, before REBOX®

2.5 MW Flameless Oxyfuel Installed
REBOX® Oxyfuel Solutions
Typical Installation

Flameless Oxyfuel Burner
REBOX® Oxyfuel Solutions
Typical Installation

Flameless Oxyfuel Burner
REBOX® Oxyfuel Solutions
Use of a Low Calorific Fuel

For Coke Oven Gas, Blast Furnace Top Gas, BOF Gas, and other in-house gases. Used individually or in different combinations.

Combusting Low Calorific in-house gases with oxygen provides the flame temperature needed in reheating and annealing operations.

With oxygen a fuel of 3.3 MJ/Nm³ (0.9 kWh/Nm³) is “upgraded” to be like a 7.7 MJ/Nm³ (2.1 kWh/Nm³) fuel combusted with air (i.e., roughly like conventional air-fuel combustion)
REBOX® Oxyfuel Solutions
Use of a Low Calorific Fuel

Burner design – Flameless Oxyfuel using a Low Calorific Fuel

➢ Separate Jet Flameless technology
➢ Ceramic self-cooled design
➢ Dual-fuel and mixed fuel capability
➢ Flame and Flameless mode for cold and hot furnace operation

Ø 300mm stone
For 400-600mm Wall
325 kW at 15 mBar BFG
LPG/NG injection possible
REBOX® Oxyfuel Solutions
Flameless vs. Conventional

Rotary hearth furnace at ArcelorMittal Shelby, all equipped with flameless oxyfuel

Total Heating Time at Ovako Hofors Works using different combustion technologies
Walking Beam Furnace at Outokumpu, Degerfors. Conversion into all flameless oxyfuel operation.

**Linde Turn-key delivery in 2003**
Combustion system with flameless burners, furnace upgrade, new flue gas system, flow train, control system

**Furnace data**
Dimensions: 27 m length, 5 m wide  
Fuel: LPG  
Stainless steel: all grades, 1,550 mm wide 140-300 mm thickness

**Performance Guarantee**
35% more throughput  
30% fuel savings (down to 0.97 GJ/ton cold charged)  
NOx emission <70mg/MJ (350 mg/m3)  
Revamped in 25 days

**Linde Turn-key delivery in 2005-2008**
Combustion system with flameless burners, furnace upgrade, new flue gas system, flow train, control system

**Furnace data**
Dimensions: 80-120 ton/furnace
Fuel: Natural gas
Bearing steel

**Performance**
50% more heating capacity
40% fuel savings (down to 1.15 GJ/ton cold charged)
NOx emission reduced by 40%
Scale formation reduced with 3 ton/1000 ton heated (0.3%)
Rotary hearth furnace at ArcelorMittal Shelby. Conversion into all flameless oxyfuel.

Linde Turn-key delivery in 2007
Combustion system with flameless burners, furnace upgrade, new flue gas system, flow train, control system

Furnace data
Dimension: 15 m diameter
Billet diameter: 76-222 mm
Fuel: natural Gas
Carbon steel:

Performance Guarantee
>33% more through put
50% fuel savings (from enrichment; 65% from air-fuel)
NO$_x$ emission <70 mg/MJ
Direct Flame Impingement (DFI) Technology

Firing Directly Onto a Moving Material

DFI Oxyfuel the local heat flux could be as high as 800-1000 kW/m²
Outokumpu Nyby Works, Sweden
DFI Oxyfuel installation in 2002 by Linde

4 MW installed power
120 oxyfuel flames, four burner rows
2 meter long unit at entry of strip annealing furnace

Furnace throughput capacity increased 50%, from 23 to 35 t/h
DFI Oxyfuel in Metal Coating Lines
ThyssenKrupp Steel at Finnentrop and Bruckhausen

3 m of recuperative zone removed to fit DFI
Compact DFI unit: L 2.8 x W 2.8 x H 1.2 meter
12 days line stop
DFI Oxyfuel in Metal Coating Lines
ThyssenKrupp Steel at Finnentrop and Bruckhausen

5 MW power input

- 80-90% thermal efficiency
- Totally 120 oxyfuel flames, in 4 burner rows
- Option for 2 more burner rows (+ 2 MW)
REBOX® DFI Oxyfuel
Example of Installation

Galvanizing lines at ThyssenKrupp Steel, Finntrop and Bruckhausen. DFI boosting.

Linde Turn-key deliveries in 2006 and 2007
Combustion system with Direct Flame Impingement in 4 Burner Row Units, flow train, control system

Furnace data
Dimensions: 2.8 m long
Fuel: Natural Gas
Carbon steel strip: all grades, 1,550 mm wide

Performance Guarantee
30% more throughput
10% fuel savings
Revamped in 4 days/furnace
“DFI is 3 solutions in one – more capacity, clean strip and no extension of line”

The alternative to DFI Oxyfuel at ThyssenKrupp Steel at Finnentrop was a 10-m extension of the furnace, but that would not have provided decreased fuel consumption and elimination of the cleaning section.
Here DFI for $\Delta T$ 200°C at max production rate (ton/h), but can be used for much higher $\Delta T$, for example 500°C
DFI oxyfuel could be used not only for strip heating relating to annealing and coating of different kinds.

- Agglomeration – for example, ignition of sinter beds and agglomeration of briquettes
- Iron-making
- To change material properties
- Press hardening
- Edge-heating
- Skid-marks removal
- ... ?

A technology that has 10 times the heat transfer than the one in use is waiting to be fully exploited!
Summary:
In the steel industry, flameless oxyfuel should be applied for heating in all types of furnaces and vessels, with temperatures above 800-900°C. Flameless oxyfuel leads to great benefits in terms of lower fuel consumption, decreased CO$_2$ and NO$_x$, and increased production capacity. The benefits of flameless oxyfuel have already been demonstrated in 30 installations. In general air-fuel is only viable below 800°C.

There are only two exceptions where flameless oxyfuel should not be used:
- Conventional oxyfuel in Electric Arc Furnaces
- DFI Oxyfuel applications

In addition to strip processing lines, where DFI Oxyfuel has shown great success, where else in the iron and steel making process chains could DFI Oxyfuel be applied?