Technologies for Energy and Operation Efficiency in Stainless Steel Production

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Linde India Limited
Industrial Gases Production and Supply

Production

- Cryogenic (Oxygen, Nitrogen, Argon)
- Absorption (Oxygen, Nitrogen)
- Steam Reformer, Electrolysis (Hydrogen)

Supply

- Gaseous via Pipeline
- Liquid via Tanker to Intermediate Onsite Storage and Vaporization
- Cylinder

The cost relates mainly to:

- Way and Size of Production
- Efficiency and Age of Production
- Electricity Price
- Purity Requirement
- Pressure Requirement
- Way and Distance of Supply

Solutions Provider
Burners and Injectors in an EAF
BGH Edelstahl Siegen, Germany

**Equipment**
- OXYGENJET
- CARBONJET
- LIMEJET

**Results**
- **Heat size**: +2 t
- **Electricity**: -45 kWh/t
- **Power on time**: -13 min.
- **Electrode**: -0.3 kg/t
- **Oxygen**: +16.8 Nm³/t
- **Natural gas**: +6.6 Nm³/t
- **Charge carbon**: -10.8 kg/t
- **Inject carbon**: +8 kg/t
- **Lime/dolo**: +6 kg/t
Burners and Injectors in an EAF
BGH Edelstahl Siegen, Germany

Aluminium granulates injected for chromium recovery, size 1-2 mm

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity (kWh/t)</td>
<td>525</td>
<td>475</td>
</tr>
<tr>
<td>Power-on-time (min.)</td>
<td>96</td>
<td>80</td>
</tr>
<tr>
<td>1600C to tapping (min.)</td>
<td>22</td>
<td>15</td>
</tr>
</tbody>
</table>

![Diagram showing aluminium granulates and chemical composition](image)
Oxyfuel Solutions
Energy Efficiency

1. No nitrogen in
2. No nitrogen out
3. Radiation
4. Lower flue-gas velocity
Dominant Heat Transfer Mechanisms

Convection

Radiation

Gas Radiation

O₂  N₂  H₂O  CO₂

CH₄ + 2O₂ + 8N₂  CO₂ + 2H₂O + 8N₂  CH₄ + 2O₂  CO₂ + 2H₂O

Air-fuel burner  Oxyfuel burner

Sum of the emission coefficients $\varepsilon_{\text{H}_2\text{O}}$ and $\varepsilon_{\text{CO}_2}$

Flue Gas Temperature [°C]

Emission Coefficient [-]

e.g. Oxygen/Natural gas

e.g. Air/Natural gas

Radiation

Convection

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140

0,000 0,100 0,200 0,300 0,400 0,500 0,600 0,700 0,800

ég Oxygen/Natural gas
ég Air/Natural gas
Conventional and Flameless Oxyfuel

**Conventional oxyfuel**

\[
\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + \text{HEAT}
\]

**Flameless oxyfuel**

\[
\text{CH}_4 + 2\text{O}_2 + \text{Hot furnace gases} \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} + \text{HEAT}
\]
The limitations of using an LCV fuel, can be overcome by using Oxyfuel combustion thus in case of combustion with LCV fuels, oxyfuel combustion is an absolute requirement.

- Partial replacement of air-fuel combustion of a high calorific value fuel gas by oxyfuel combustion of a low calorific value fuel gas can make great sense!
- The nitrogen component is reduced hence efficiency is increased.
- The flame by LCV fuel combusting with oxygen is stable and compact.
- The flame temperature by this configuration is around 1900 Deg C.
- The radiation heat transfer is restored by Oxyfuel in case of LCV fuels.
Beneficial Use of Low Calorific Fuels

By removing the ballast (N\textsubscript{2}) in the oxidant, by using oxyfuel instead of air-fuel combustion, a high ballast in the fuel (N\textsubscript{2}, CO\textsubscript{2}, H\textsubscript{2}O) can be accepted.

In-house gases such as Blast Furnace Gas, or Producer Gas, may then be used for high temperature applications, e.g. in ladle pre-heating and reheat furnaces.

High Calorific Fuels can then be saved (or used elsewhere) without any negative impact on the operation.
General Benefits of Oxyfuel in Vessel Preheating

Benefits from higher heating temperature of a steel-making vessel:

- No need to have too high temperature of the steel in the EAF/BOF/AOD
- 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
- Possibility to reach very high pre-heating temperatures when wanted
  (Example 1500°C for atomizing customer)

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

Added features in Flameless oxyfuel:

- Further improved heat distribution in vessel
- Ultra low NOx emissions
- Extended refractory lifetime due to higher and more even temperature distribution in vessel
Flameless Oxyfuel in Ladle Preheating
Results from Acerinox, Spain

Drying of refractory, 24 hours
— Final temperature of 1,175ºC
— Fuel consumption: 1,000 Nm³ NG
— Average thermal efficiency is 84%

Drying cycle of 12 hours
— Final temperature of 1,175ºC
— Fuel consumption: 759 Nm³ NG

From 900ºC to 1,175ºC
— Final temperature after 1 hour
— 325ºC outside temperature
— Fuel consumption: 111 Nm³ NG
Vessel Preheating with Flameless Oxyfuel

- Increased temperature uniformity in ladle/converter
- Decreased fuel consumption
- Lower NOx formation
- Increased heating capacity

Examples of installations of flameless oxyfuel for preheating

- Sandvik (Sweden) 90 t converters 1.4 MW
- Outokumpu, Avesta (Sweden) 90 t ladles 1.5 MW
- Acerinox (Spain) 90 t ladles 2.0 MW
- Ovako, Hofors (Sweden) 90 t ladles 1.4 MW
- Ovako, Smedjebacken (Sweden) 100 t ladles 1.5 MW
- Ovako, Imatra (Finland) 80 t ladles 1 MW
- Kanthal (Sweden) 5 t ladles 0.2 MW
- Outokumpu, Tornio (Finland) 90 t converters 2 MW
- Mahindra Sanyo (India) 50 t ladles 0.6 MW
- Bradken (Malaysia) 12 t ladles 0.4 MW
- SICSQ (Thailand) 65 t ladles 0.8 MW
Ferro Chrome Converter at Outokumpu, 2.5 MW Flameless Oxyfuel Used for Drying and Heating
Installations of REBOX Oxyfuel Solutions in Steel Reheating Have Resulted in:

- Capacity Increase by up to 50%
- Fuel Savings of up to 50% (some cases 65%)
- Reduction of CO₂ Emission by up to 50%
- Reduction of NOₓ Emission
- Improved temperature uniformity, max. +/- 10°C
- Decrease of Scaling Losses by up to 50%
136 REBOX® Oxyfuel Installations

Examples of Sites with Installations

ArcelorMittal, Galati (RO)
ArcelorMittal, Shelby (US)
Ascométal, Les Dunes (FR)
Ascométal, Fos-sur-Mer (FR)
Brach, Bremen (DE)
Buderus, Wetzlar (DE)
Dongbei Special Steel, Dalian (CN)
Ellwood City Forge, Ellwood City (US)
Evraz Steel, Claymont (US)
Jindal SAW, Nashik (IN)
Kalyani Carpenter Special Steels, Pune (IN)
Mahindra Sanyo Special Steel, Khopoli (IN)
Michigan Seamless Tube, South Lyon (US)
North American Forgemasters, New Castle (US)
Outokumpu, Avesta (SE)
Outokumpu, Degerfors (SE)
Outokumpu, Nyby (SE)
Outokumpu, Tornio (FI)
Ovako, Hofors (SE)
Ovako, Smedjebacken (SE)
POSOCO, Pohang (KR)
Salzgitter Flachstahl, Salzgitter (DE)
Sandvik Materials Technology, Sandviken (SE)
Scana Steel, Björneborg (SE)
SSAB, Borlänge (SE)
Tayo Rolls (Tata Group), Jamshedpur (IN)
ThyssenKrupp Steel, Bruckhausen (DE)
ThyssenKrupp Steel, Finnentrop (DE)
Timken, Canton (US)
Uddeholn Tooling, Hagfors (SE)
Usiminas, Cubatao (BR)
## Total Energy Requirement Comparison

<table>
<thead>
<tr>
<th></th>
<th>Air-fuel</th>
<th>Air-fuel with recuperator</th>
<th>REBOX® oxyfuel</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>155*</td>
</tr>
<tr>
<td>Flue-gas temperature</td>
<td>°C</td>
<td>1,200</td>
<td>850</td>
</tr>
<tr>
<td>Air preheating</td>
<td>°C</td>
<td>20</td>
<td>450</td>
</tr>
<tr>
<td>Thermal efficiency</td>
<td>%</td>
<td>42</td>
<td>60</td>
</tr>
<tr>
<td>Energy need</td>
<td>kWh/t</td>
<td>500</td>
<td>365</td>
</tr>
<tr>
<td>Energy need</td>
<td>GJ/t</td>
<td>1.8</td>
<td>1.33</td>
</tr>
<tr>
<td>Oxygen production</td>
<td>kWh/t</td>
<td></td>
<td>25</td>
</tr>
</tbody>
</table>

*after recuperation
Flameless Oxyfuel Increases Capacity Over Air-fuel and Conventional Oxyfuel

Comparison of total heating time at Ovako’s Hofors Works, Sweden, using different combustion technologies in Soaking Pit and Rotary Hearth Furnaces.
Linde’s first installation of flameless oxyfuel: Complete conversion of a Walking Beam Furnace at Outokumpu’s Degerfors mill, Sweden in 2003.

30% Capacity Increase
30% Fuel Savings
Walking Beam Furnace Converted into All Flameless Oxyfuel Operation

**Linde Gas Turn-key delivery**
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
REBOX® at Outokumpu, Degerfors

More Heating Capacity in Walking Beam Furnace

Stainless steel slabs 166 mm thick
Top fired with wall-mounted flameless oxyfuel burners
REBOX® installations at Outokumpu

Catenary furnace at Outokumpu, Avesta (Sweden).
Conversion into all flameless oxyfuel operation.

40 MW Flameless Oxyfuel; Capacity 150 tph
ArcelorMittal Shelby – Tubular Products, Ohio
Rotary Hearth Furnace

Before; Air-fuel

After; REBOX
REBOX® HLL
No Full Conversion, but More Capacity and Less Fuel Consumption

Continues using existing air-fuel burners

Minimum installation down time

Greater flexibility in operation techniques

Optimized in response to fluctuating fuel cost and productivity requirement

REBOX HLL at Outokumpu, Tornio (Finland)
REBOX® installations at Kalyani Carpenter Special Steels

Walking Beam Furnace for alloyed steel blooms; design capacity 30 tph
REBOX installation commissioned in February 2012

Solution: 1 pair of Flameless Oxyfuel Burners added; HLL at existing air-fuel burners
Fuel: Furnace Oil

Results:
✓ Only HLL: +20% throughput
✓ Oxyfuel burners & HLL: +30% throughput
✓ Fuel consumption (and CO₂) down by >20%

A second REBOX installation was made in a 40 tons Soaking Pit Furnace in mid 2013.

This successful installation has provided 65% fuel savings to KCSSL.
To whom so ever it may concern

This is to certify that Linde India has successfully installed and commissioned their 2nd REBOX oxyfuel system at our 35 ton capacity furnace oil fired soaking pit furnace in Mundwa Pune works.

The following equipment successfully installed by Linde India at our 3rd soaking pit furnace

- Five nos of Linde India REBOX oxyfuel burners.
- Automatic PLC based furnace control system for furnace operation.
- Oxygen flow train, and individual burner controls system.
- Individual burner oil control system and safety interlocking.

The following performance results were achieved as a result of the conversion of Linde India REBOX oxy-fuel Combustion technology in our Soaking pit furnace

- More accurate temperature control and improved temperature uniformity.
- Furnace oil consumption reduction 65 % has been achieved.
- Significant reductions in maintenance and plant operating costs.
- No deviation in special steel quality
- Substantial reduction in NOx emissions.
- Scale loss reduction better as compare to our previous air fuel combustion
- Overall flue gas volumes have been reduced by 75% when compared our furnace that was heaved using an air-fuel combustion system.

The above parameters are tested at our 3rd soaking pit furnace. We have found that Linde India REBOX oxyfuel system is an excellent solution for energy saving, increase production for a reheating furnace.

The Linde India REBOX system is now in operation since September 2013.

Thanks & regards

Nikhil Pasahuri
Vice President (Rolling mill/Finishing Shop)
Kalyani Carpenter Special steel Limited
REBOX® installations at Mahindra Sanyo Special Steel

Chamber Furnaces for alloyed steel blooms and billets; maximum batch size is 35 tons.

- REBOX installations in two furnaces commissioned in January 2014.
- Installations in two more furnaces commissioned in October 2014.
- Further installations in evaluation phase.

Solution: Flameless Oxyfuel
Fuel: Furnace Oil

Results:
- Fuel consumption down by >50%
- CO₂ emission reduced by >50%
- Scale losses down by >50%
- Heating and soaking times decreased; throughput increased
REBOX® installations at Mahindra Sanyo Special Steel

Reduction of Scale Losses

Before

After
REBOX® installations at Mahindra Sanyo Special Steel
REBOX® installations at Mahindra Sanyo Special Steel

50% Hot Charged and 50% Cold Charged

Average total oil per rolled ton

55% less oil!!!
REBOX HLL installation in a Rotary Hearth Furnace, rated 75 t/h but operating at 40-50 t/h due to the fuel used. The furnace is today running with ‘producer gas’ (CV at 1,250 kcal/m$^3$) as fuel in the heating zones and oil in the soaking zones. The purpose of the installation is to make it possible to stop using oil, and run with ‘producer gas' in all zones.
Jindal SAW, Nashik
REBOX® HLL
Reference measurements of temperature uniformity using Thermovision camera

Installation of measurement system for the ‘producer gas’
Some Additional REBOX® Installations in 2014

Sandvik, Sweden
Full conversion into REBOX flameless oxyfuel of 35 t/h LPG fired walking beam furnace.
The purpose of the installation is to reduce the fuel consumption by 35% and increase the temperature uniformity.
This is Linde’s third REBOX installation at Sandvik.
Commissioning successfully completed in August 2014.

Tayo Rolls (Tata Steel), Jamshedpur
Full conversion into REBOX flameless oxyfuel of an oil-fired 50 t bogie hearth furnace.
The purpose of the installation is to reduced the fuel consumption.
Commissioning successfully completed in December 2014.
Fuel consumption decreased by 55%.
REBOX® DST
For Wire Annealing

- Less Fuel Consumption
- Faster Production, Less Time
- Better & More Uniform Quality
- Less Scale Losses
## Some Technical Data from Linde’s DST Installations

<table>
<thead>
<tr>
<th>Category</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>45 to 72.5 tph</td>
</tr>
<tr>
<td>Length</td>
<td>30 to 35 m</td>
</tr>
<tr>
<td>Inside width</td>
<td>1.45 to 1.47 m</td>
</tr>
<tr>
<td>Fuel</td>
<td>LPG, gasified coal</td>
</tr>
<tr>
<td>Cooling</td>
<td>Water Spray</td>
</tr>
<tr>
<td>Wire Dimensions</td>
<td>4.5 to 20 mm</td>
</tr>
<tr>
<td>Coil Diameter</td>
<td>1,075 to 1,100 mm</td>
</tr>
<tr>
<td>Steel Grade</td>
<td>300 Series</td>
</tr>
<tr>
<td>Grain Size</td>
<td>ASTM &lt;6.5</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>up to 240 N/mm$^2$</td>
</tr>
<tr>
<td>Strength Variation</td>
<td>$&lt;\pm 10$ N/mm$^2$ within a coil</td>
</tr>
<tr>
<td>Temperature Uniformity</td>
<td>$\pm 3.5^\circ$C over width, $\pm 5^\circ$C over length</td>
</tr>
</tbody>
</table>
REBOX® DST
For Wire Annealing
REBOX® DST
For Wire Annealing
Outokumpu, Nyby, Sweden
REBOX DFI in Strip Annealing Line

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

Furnace throughput capacity increased by 50%,
from 23 to 35 tph
**Oxyfuel Solutions**
**Reduced CO₂ and NOₓ Emission Levels**

Fuel savings of up to 50%

Reduction of CO₂ emissions by up to 50%

A flue-gas volume that is
- 75-85% smaller
and having a
- CO₂ content of 95% (dry basis)

This small flue-gas stream with a high CO₂ content should be very suitable for cleaning, storage and sequestration.

**CO₂ emission directly proportional to fuel consumption**

**Air fuel**
- 70 mg NOₓ/MJ (as NO₂)
- 88 g NO₂/t
- 80 kg CO₂/t

**425 Nm³/t**

**Oxyfuel**
- 70 mg NOₓ/MJ (as NO₂)
- 66 g NO₂/t
- 57 kg CO₂/t

**70 Nm³/h**

**350 kWh/t**

**250 kWh/t**
Thank you very much for your kind attention

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