Celox® - Celox SLAC®

The masters when it comes to control techniques

Electro-Nite
Steel making and steel refining are characterized through various oxidation and reduction processes coinciding with changes in liquid steel's oxygen activity. Production cost, yield and steel purity widely depend on comprehensive and reliable oxygen control.

Continued improvement in product performance and unmatched quality monitoring has made the Heraeus Electro-Nite Celox® precision oxygen sensor the world industrial standard to monitor and control both, steel and slag oxygen activity in primary and secondary liquid steel production.

**Celox® oxygen control in liquid steel**

Fig. 1: The Celox® sensor after an oxygen measurement

Fig. 2: The Celox® Principle

**PRINCIPLE**

An integrated electrochemical cell provides a characteristic voltage dependent on the liquid steel's oxygen activity by referring it to an approved oxygen standard ($p_{O_{2\text{air}}}$) within the cell. The generated Electro-Motive Force (EMF or cell voltage in mV) has a direct correlation to the liquid steel's oxygen partial pressure ($p_{O_{2\text{steel}}}$).

$$EMF = \frac{R \cdot T}{n \cdot F} \ln \frac{p_{O_{2\text{steel}}}}{p_{O_{2\text{air}}}}$$

(Nernst's law, $R$ is the gas constant, $n$ the number of transit electrons per standard reaction $O_2 = 2O$, and $F$ the constant of Faraday).
**OXYGEN MEASUREMENT**

At a given temperature (T in K), simultaneously measured by Celox\textsuperscript{\textregistered}, the oxygen activity in liquid steel can be taken from the generated EMF. \( E = \text{EMF (mV)} + 24 \).

\[
\log a_O = 1.36 + 0.0059 \cdot (E + 0.54 \cdot (T - 1823) + 0.0002 \cdot E \cdot (T - 1823))
\]

For unalloyed/low alloyed steel and thus Raoult’s activity factor \( f(O) = 1 \), the oxygen activity is practically same value as the dissolved oxygen content in ppm.

The oxygen measurement stands as the basis for downstream correlations to carbon and aluminium.

**CARBON CALCULATION**

In primary steelmaking, based on the reaction \( 2C + O_2 = 2CO \) and assuming that CO pressure equals the atmospheric pressure, carbon calculates to:

\[
\log \% C = f_1 + f_2/T + f_3 \cdot \log a_O
\]

with \( T \) in °C and \( a_O \) in ppm

**ALUMINIUM CALCULATION**

Based on the deoxidation reaction \( 2Al + 3O = Al_2O_3 \) in secondary metallurgy, dissolved aluminium may be calculated (assumption: reaction product is pure alumina, Raoult’s alumina activity = 1):

\[
\%Al = f(E, T) \quad \text{with } E = \text{EMF (mV)} + 24 \quad \text{and } T \text{ in Kelvin}
\]

The sharp correlation of aluminium to oxygen may be used to:

- calculate deoxidizer additions during furnace tap based on the Celox\textsuperscript{\textregistered} measurement during tapping
- calculate first aluminium addition in ladle metallurgy
- calculate trim aluminium addition to final specification

**Fig. 3:** \( a_O \text{(ppm)} = f \text{ (EMF in mV)} \)

Correlation oxygen activity \( a_O \) – Electro-Motive-Force (EMF)

for various metal temperatures, \( T \) in °C.

**Fig. 4:** % Carbon as function of measured oxygen

**Fig. 5:** Aluminium – oxygen correlation at 1873 K
**BENEFITS**

Celox is a sensor providing a measurement in some seconds. There is not any other method to provide readings of oxygen activity/dissolved oxygen in liquid steel. During secondary metallurgical refining of liquid steel in the ladle Celox allows for real aluminium readings rather than "fake results" through spectrometer measurement. Aluminium trim problems are thus avoided.

**CELOX VENDORS**

- Celox standard for measurements over 10 ppm dissolved/active oxygen.
- Celox Al for aluminium measurements in Al killed steels (incl. Celox standard range).
- Celox Ti for aluminium control in IF steels.
- Celox EAF for oxygen measurements with specific lance and hardware in EAF applications.

Celox versions come in thermocouple calibrations S, R, and B and various cardboard lengths.

**STANDARD OPERATION PROCEDURES**

- Store in a dry place.
- Preventive maintenance of cable and lance.
- Fix to contact and immerse 30 to 40 cm into steel avoiding damage on slag crusts.
- Stop electrode operation (EAF) and minimize gas stirring (ladle).

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**Celox SLAC** application in metallurgical slags

Celox SLAC controls ferrous ladle slag in terms of its FeO or FeO-MnO contents. The cell is built like the Celox sensor, but exposes an open zirconia thimble to pick-up slag during immersion. Celox SLAC goes together with standard Celox hardware and instrumentation. The sensor does not comprise a thermocouple, as not needed in slag chemistry.

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**Fig. 6: Oxygen measurement in ladle slag**
**BENEFITS**
- Provides a FeO or a FeO-MnO reading within a few seconds.
- Allows an instant decision to add slag modifiers.
- Predicts aluminium and sulfur fade; predicts reoxidation from slag and thus judges cleanliness.
- Replaces expensive and sophisticated X-ray analysis.
- Plays its advantages not just in speed, but as well in accuracy, especially in the low FeO-range.
- Eliminates erratic results from poor magnetic metal separation in sample preparation.

**APPLICATION**
Celox SLAC™ is used like a common Celox® sensor, however has to be immersed through liquid slag into steel to get the reading.
- select an “eye” with liquid slag on the ladle slag surface.
- make sure there is not any turbulence around the Celox SLAC™ sensor head; it would wash away the slag film surrounding the sensor's zirconia thimble and result in an erratic reading.
- immerse in a similar way as a Celox® sensor through liquid slag at a depth of about 10 cm into steel.

**A PROPER CELOX® LANCE**
Figs. 7 and 8 show the lance details of manual and autolance. All components may be ordered separately.
In autolance application telescopic cardboard tubes help to keep long exchange intervals.

![Conventional Hand Lance Diagram]

![AutoLance Diagram]

**Fig. 7: Celox manual immersion lance**

**Fig. 8: Celox quick connecting system for autolance (QCL)**

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More information on Celox® and Celox SLAC™ applications can be taken from our dedicated product files "Celox®/Celox SLAC™ applications in modern steelmaking".