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Fast and reliable temperature measurement at end of melting cycle in EAF

CoreTemp product description

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Summary

- In modern mini-mill setups, the EAF is considered primarily as a melting unit. Under these conditions, problem-free tapping is key to achieve efficient operations. Uncertainties on input material quality and thermal efficiency of the furnace introduce large variations on the progress of individual melting cycles. An accurate and reliable temperature measurement is therefore needed to determine the appropriate end point for each single heat.
- Current automatic lances use disposable probes to determine temperature of steel bath. These single dip measurement systems are however not accurate enough to guarantee problem-free tapping at all times. Erratic temperature profiles and significant fractions of residual solid scrap near the end of the production cycle are observed despite considerable safety margins being applied. A next generation of temperature measurement techniques is needed to further improve operational performance of EAF.
- A new, optical fiber based, measuring system has been developed, capable of delivering accurate temperature readings every 20 seconds. Black body radiation from inside the liquid steel pool in the EAF is transmitted through a shielded optical fiber onto a light emission detector where Planck's law is applied. A semi-continuous temperature profile can now be established to help accurately define the desired end point of the melting cycle.
- Modern EAF steelmakers can benefit in several ways from the newly developed technique. With increased sampling frequency overheated production cycles and tap hole blockages are more easily avoided. Prolonged deep foamy slag conditions increase efficiency of the furnace. Both effects lower energy and consumables cost while increasing productivity. For a typical high powered, high productivity EAF it is estimated that approximately 3,2 USD per ton of liquid steel can be saved on each heat.

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In modern mini-mill setups, accurate end temperature control is key to achieve efficient operational performance of the EAF

Modern mini-mill philosophy:

- EAF is primarily a melting unit
- Final temperature control and alloying is done during secondary metallurgy

- Key to successful operational performance is **accurate determination of end point of melting cycle**

Problem-free tapping is guaranteed by:

- Sufficiently high temperature of liquid steel (superheat)
- Low fraction of residual solid scrap at time of tap hole opening

Accurate and reliable temperature measurement is needed to determine appropriate end point

Large variations in the progress of individual heats are **inherent to the EAF process**:

- **Uncertainties on raw material quality** (especially for scrap based furnaces) leading to inaccurate mass and energy balances

- **Process scatter on thermal efficiency** of furnace caused by varying:
  - Scrap quality
  - Slag foaming conditions
  - Hot heel conditions
  - State of the furnace (skulls)
  - Residual solid scrap
  - Loading of the furnace

Current automatic lances use disposable probes for temperature measurement of liquid steel bath at end of heat cycle

- **Equipment description**:
  - Mechanical automated lancing system fitted with disposable thermocouple on probe holder at tip of lance
  - Temperature measurement is done by dipping the probe in liquid steel
- **Points of concern** of current automatic lancing systems:
  - Low measurement frequency (60 seconds between dips)
  - High risk of failure (disposable probe can hit piece of scrap during dip)
  - Lance operator is present at dangerous area in EAF plant near slag door (fits probe to lance system)

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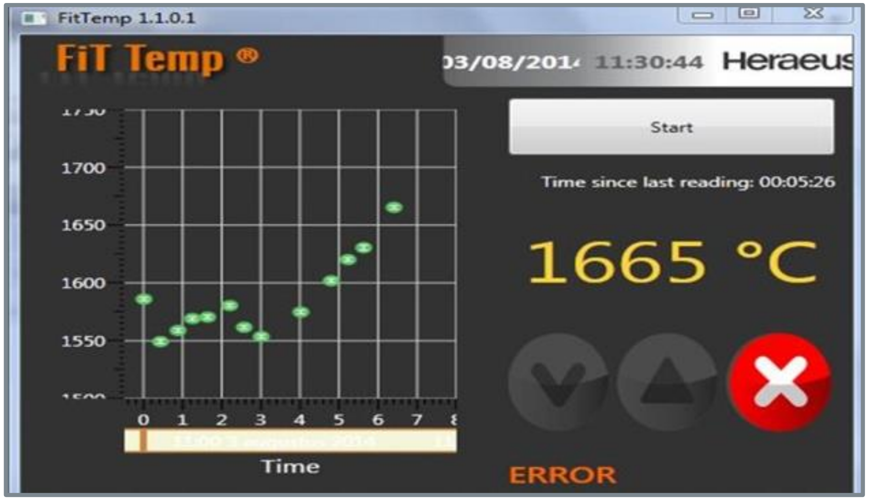
Erratic temperature profiles and significant amounts of residual solid scrap are observed at end of melting in spite of safety margins



- **Standard operating procedure**:
  - Target end point of production cycle is fixed at 20 °C above ideal conditions to avoid freezing in the EBT area during tapping of liquid steel
- **Frequently observed issues**:
  - Large fraction of superheated cycles due to sharp increase of liquid steel temperature right before tapping
  - Significant amounts of residual solid scrap present in the EBT area after tapping, especially when tap to tap times are shorter than 40 mins
  - First dip measurement 4 mins before tapping of liquid steel breaks deep foamy slag conditions (lowers furnace efficiency)

Low frequency of current measuring systems is unable to fully capture erratic temperature profile at end of production cycle in EAF

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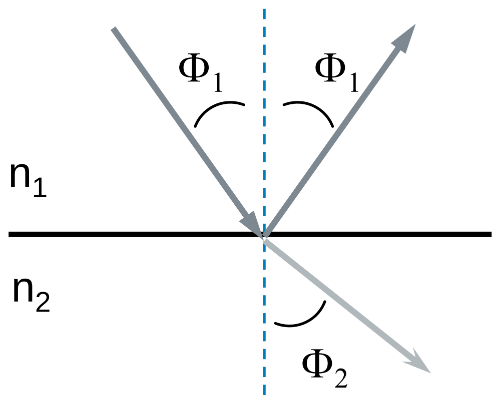
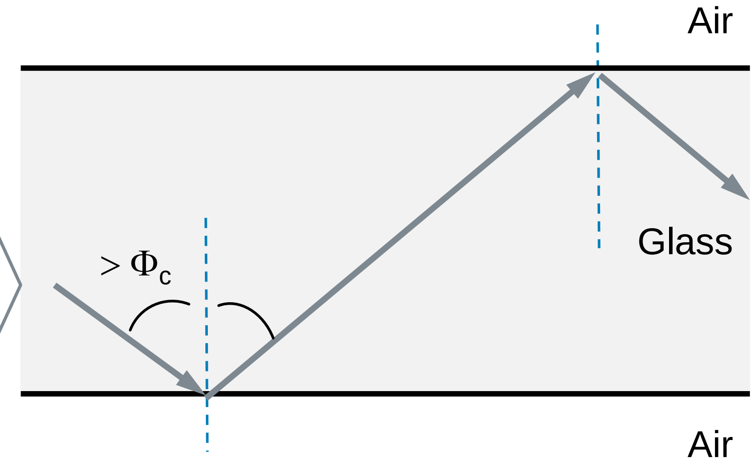
Black body radiation inside liquid steel can be transmitted to a light emission detector through internal refraction in an optical fiber

Law of refraction (Snell's law)



- Mathematical formulation of Snell's law : $n_1 \sin \Phi_1 = n_2 \sin \Phi_2$
- Internal refraction when $n_1 < n_2$ or $\Phi_2 > \Phi_1$
- Total internal reflection when $\Phi_2 = 90°$ or $\Phi_1 > \Phi_C = \arcsin(n_2 / n_1)$

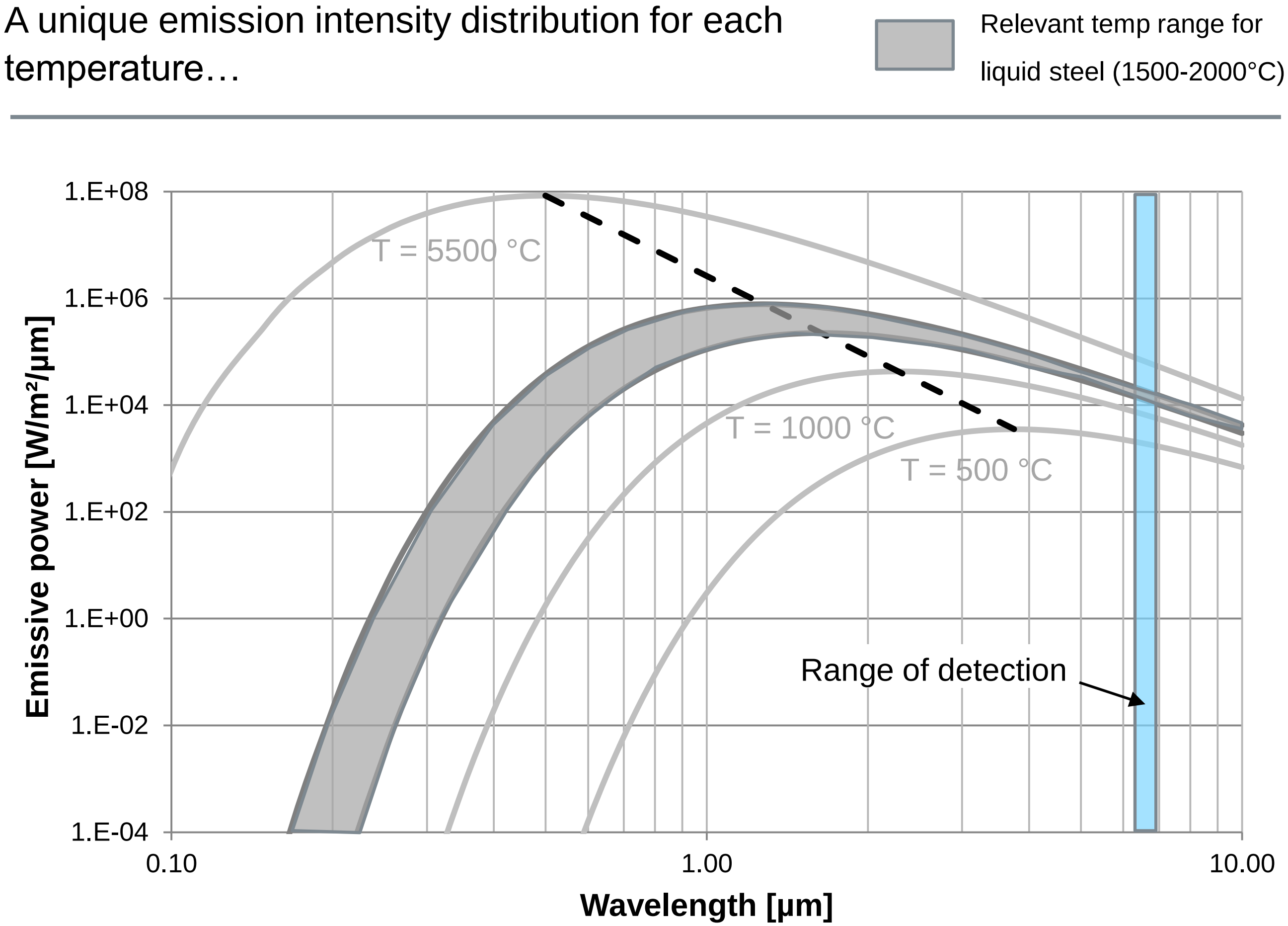
Transport of light through fiber



- $\Phi_C = \arcsin(n_{Air} / n_{Glass}) \cong 42°$

Temperature is determined by applying Planck's law of radiation to the measured emitted light intensity

A unique emission intensity distribution for each temperature…



… makes an accurate measurement possible

- Emission intensity is determined at 1,550 nm (chosen for minimal signal attenuation in fiber)
- Planck's law states that for a given fiber cross section and exposure time a unique temperature corresponds to the measured emitted light intensity

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New optical temperature measurements offer several clear advantages over current standard sampling techniques

	Description	Advantage
1 **Increased sampling frequency**	• More accurate temperature profile at end of melting cycle • Increased availability versus standard measuring systems	• Superheated production cycles can be avoided through better operational control of furnace • Decreased energy consumption in EAF due to lower tapping temperature
2 **Limited impact on foamy slag conditions**	• Temperature measurement without opening slag door • Foamy slag conditions can be maintained until the end of melting cycle	• Increased energy efficiency of furnace during final phase of melting • Decreased costs in EAF for energy and consumables from improved operational performance
3 **Residual solid scrap assessment**	• Accurate temperature profile allows for assessment of remaining fraction of solid scrap at end of power-on time	• Strongly increased accuracy in predicting liquid steel temperature in ladle after tap • Lower occurrence of freezing in EBT zone during tapping of liquid steel

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For a typical high powered, high productivity EAF a conservative estimate of 3,2 USD per ton of savings can be made

Value in use levers			Key assumption
Value in use of optical temperature measurement in EAF	1 Decreased energy consumption by **avoiding superheated cycles**	1,0	• Increased frequency of temperature measurements allows for better furnace control near end of melting cycle • Avoiding superheated production cycles lowers tapping temperature by 10°C on average
	2 Improvement of energy related KPI's through **increased efficiency** of furnace	1,5	• Optical temperature measurement allows for 2 additional minutes of power-on time under deep slag foaming conditions • Thermal arc efficiency is increased by 30% vs non deep slag foaming conditions
	3 Lower production losses due to **avoiding tap hole blockages**	0,7	• Semi-continuous temperature profile allows for assessment of residual solid scrap at end of melting cycle • Avoiding blockages of tap hole reduces average tap-to-tap time by 0,5 mins

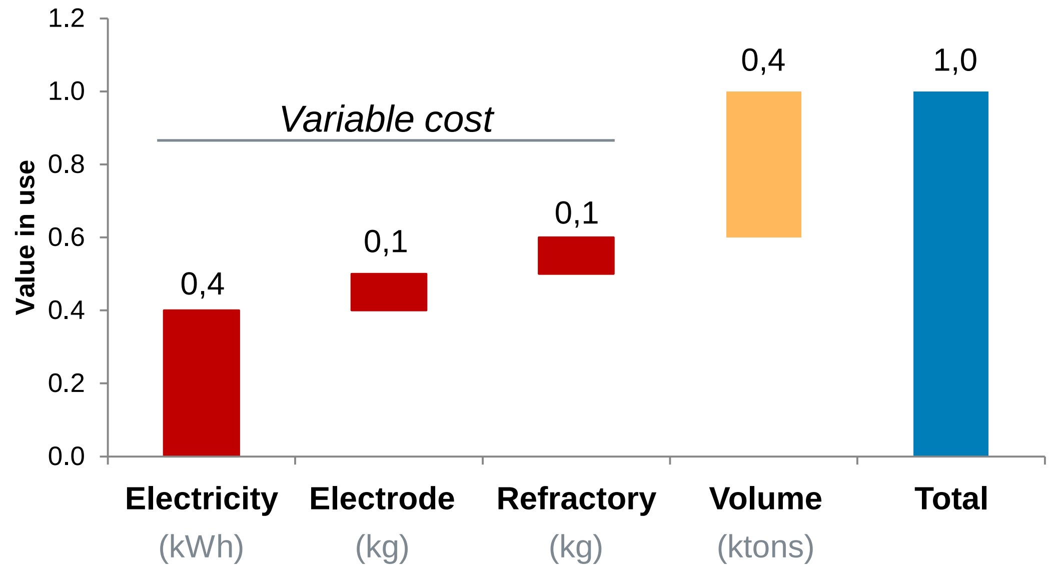
Lowering average tapping temperature by 10°C decreases cost base by 1,0 USD per ton liquid steel

Standard high power EAF operation

- Electricity consumption: 330 kWh / t
- Tap-to-tap time:
  - Power on: 30 min
  - Power off: 7 min
- Factor costs
  - Electricity: 0,09 USD / kWh
  - Electrode: 5600 USD / t
  - Refractories: 600 USD / t
  - Fixed cost: 30 USD / t

Lowering average tap temperature by 10 °C shortens TTT time by 28 seconds

USD / t



	Electricity (kWh)	Electrode (kg)	Refractory (kg)	Volume (ktons)
Delta :	-4,2	-0,02	-0,1	+19

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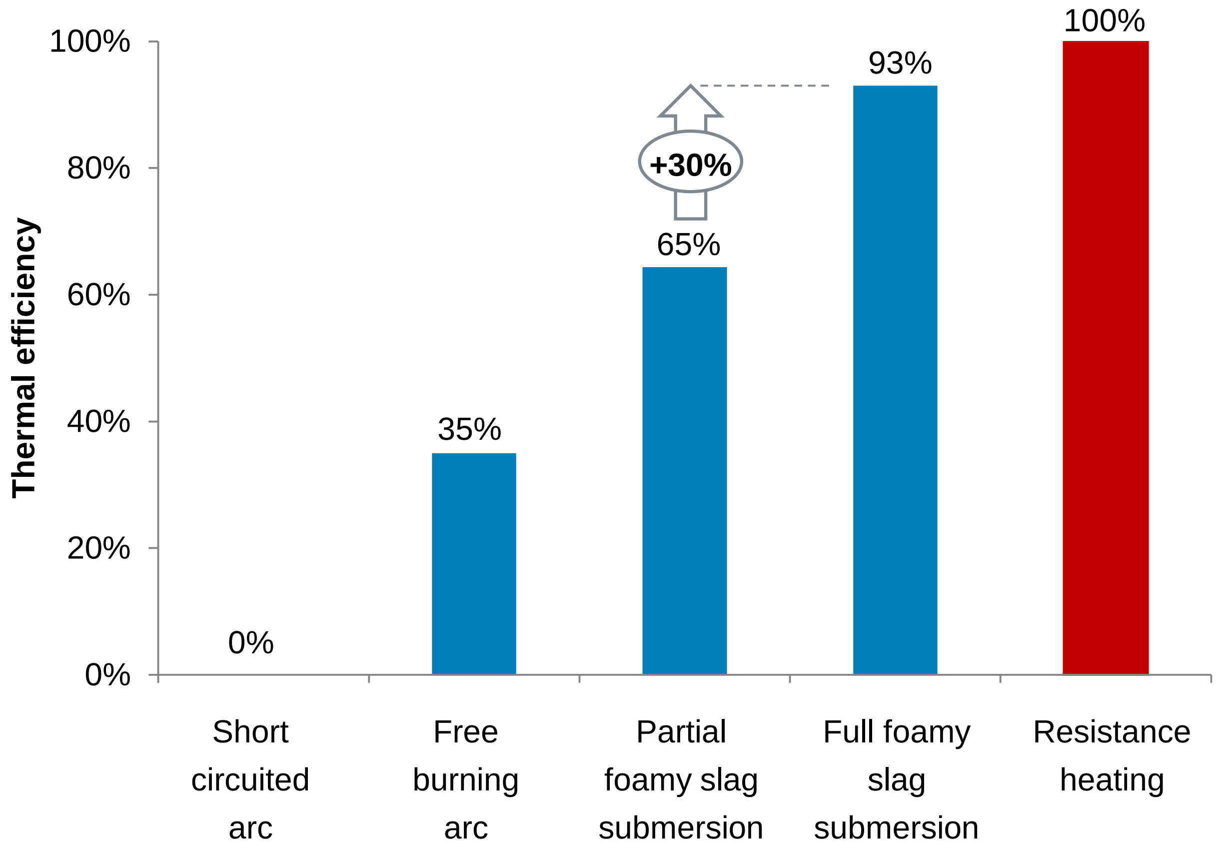
Energy transfer from arc to steel bath is ~30 % more efficient under deep foamy slag conditions than under partial arc coverage

Electric energy transfer efficiency strongly depends on slag foaming conditions



Source: Ameling et al, 1986

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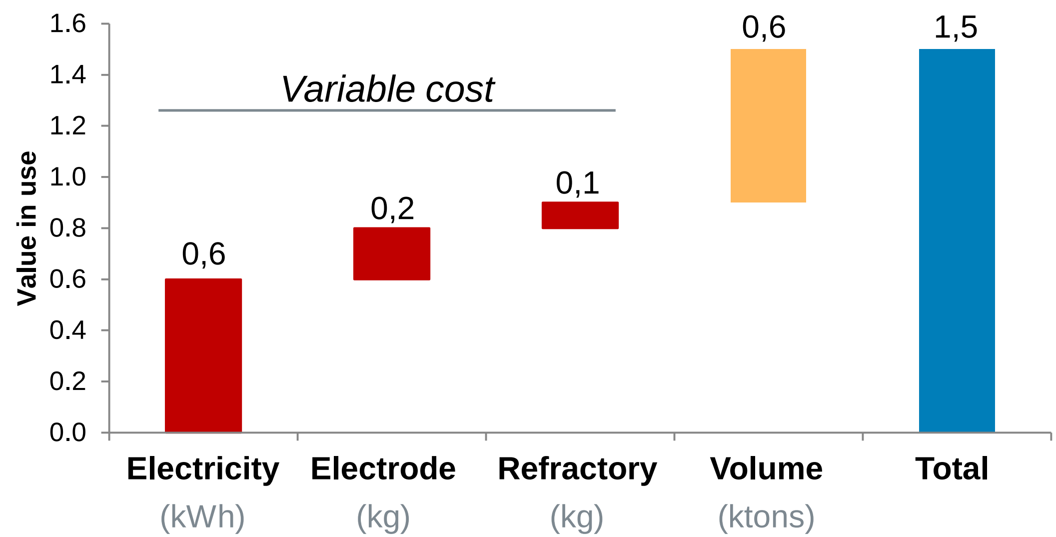
Increased furnace efficiency during end of melting cycle yields additional 1,5 USD per ton of liquid steel

Standard high power EAF operation

- Electricity consumption: 330 kWh / t
- Tap-to-tap time:
  - Power on: 30 min
  - Power off: 7 min
- Factor costs
  - Electricity: 0,09 USD / kWh
  - Electrode: 5600 USD / t
  - Refractories: 600 USD / t
  - Fixed cost: 30 USD / t

Increasing deep foamy slag conditions by 2 minutes reduces TTT by 47 seconds through higher furnace efficiency

USD / t



Delta :	-7,0	-0,03	-0,1	+32

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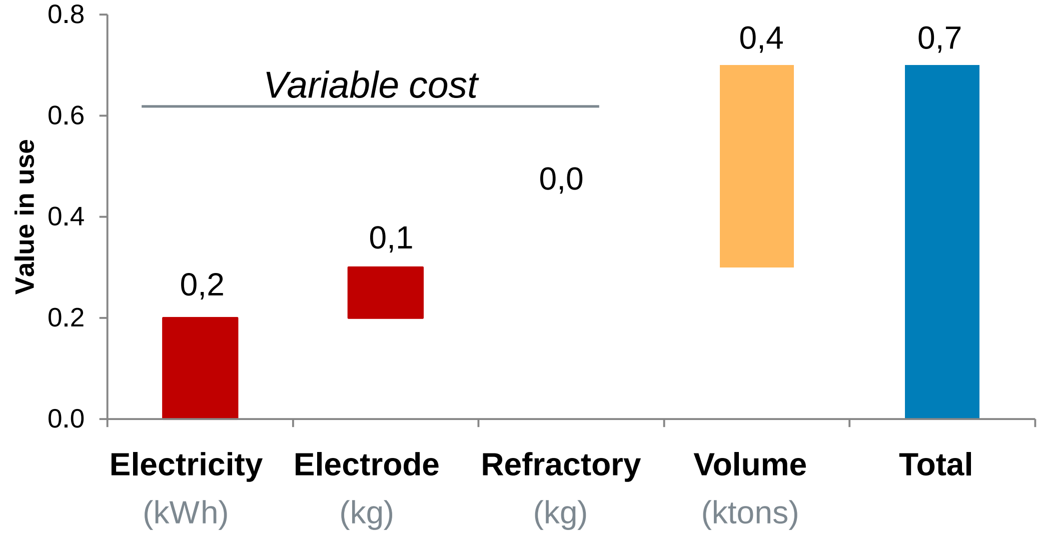
Avoiding production losses by tap hole blockages and related costs yields additional 0,7 USD per ton of liquid steel

Standard high power EAF operation

- Electricity consumption: 330 kWh / t
- Tap-to-tap time:
  - Power on: 30 min
  - Power off: 7 min
- Factor costs
  - Electricity: 0,09 USD / kWh
  - Electrode: 5600 USD / t
  - Refractories: 600 USD / t
  - Fixed cost: 30 USD / t

Tap hole blockages typically add 30 seconds to the average TTT of high powered EAF

USD / t



Delta :	-2,0	-0,01	-0,1	+20