
# Research developments during the last 20 years and todays BAT and State of Art.

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# Topic classification

| Number | Name | Main Partner |
|---|---|---|
| 1 | Heating and burner technology; alternative heating methods; electrical heating | BFI |
| **2** | **Modelling of entire furnace, model based predictive control (level 2)** | **RINA** |
| 3 | Measurement and sensors, measurement-based furnace control (level 1); standards, regulations | RWTH |
| 4 | Materials in the furnace and product quality | CRM |
| 5 | Heat transfer, heat recovery, productivity, economy | SWE |

# Topic 2 Scope

**Topic 2 covers the models used in simulation of reheating furnaces.**

Simulations can regard:

- Whole furnace
    - furnace zone model
    - concentrated parameters model
- Burners
    - Computational Fluid Dynamics (CFD)
    - Combustion simulation

**The aims is to improve the regulation and control of the furnace**

This can be achieved by simulating scenarios in advance and the testing of new procedure before application to industrial facilities.

This can also lead to reduction of fuel consumption and the development of more efficient technologies, such as low NOx burners.

# Main KPIs

Over the past **25 years**, the main KPIs reported for furnace measurement technologies have been as follows:

- **Energy consumption (e.g. GJ/t):** Fuel consumption decrease through design of ideal heating curves and through use of dynamic temperature control (model based).
- **Furnace productivity (e.g. in t/h):** Reducing energy consumption, better production planning and early detection of anomalies can increase the process efficiency. This can increase furnace productivity.
- **Scale loss (e.g. g/m²):** Early detection of anomalies, predictive diagnosis preventing failures occurrence and avoiding failures propagation (not quantified) and reduction of unplanned machines shut-downs can reduce scale loss

# Overview state of the art technologies

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- Computational fluid dynamic model of burner and combustion
- Furnace Model

# Computational fluid dynamic model of burner and combustion

| Topic | Description |
|---|---|
| Description | Simulation of burners and furnaces in model to investigate heat and pollutant production. |
| Technical description | CAD software for building the model, CFD software to perform the simulation through several approaches (e.g. RANS), Detailed kinetic schemes to simulate combustion process, machine learning techniques to investigate combustion process |
| Achieved environmental benefit | Simulation of innovative burners can lead to reduction of fuel consumption and to a lower pollutant production |
| Technical limitations | No limitations in the sector, but kinetic schemes reliability can be improved |
| Economics | CAD software: CAPEX ~ 3.000 - 20.000€,<br>CFD software: CAPEX ~ 20.000 - 60.000€<br>Some opensource and/or freeware software exist, for both kind of software, but they are less efficient |
| Case studies | walking beam furnace No. 304 at SSAB (Tunnplat AB, Borlänge) |
| Reference literature | B. Lindblad, "Performance of reheating furnaces equipped with highly preheated air combustion technology (HPAC)," European Commission, Directorate-General for Research and Innovation, 2005.<br>CLEAN-gas, 2018. [Online]. Available: https://cordis.europa.eu/project/id/643134.<br>VADEMECOM, "VADEMECOM," 2022. [Online]. Available: https://cordis.europa.eu/project/id/714605. |

# Furnace Model

| Topic | Description |
| --- | --- |
| Description | Simulation thermal simulation of zone of the furnace and heating curve of the product. |
| Technical description | Zone model, Statistical model, Machine learning model, Dynamic furnace model for predictive control |
| Achieved environmental benefit | Simulation of whole furnace can lead to better scheduling, more stable and efficient productivity and problem detection in advance |
| Technical limitations | No limitations in the sector, but great amount of data required for statistical and machine learning model |
| Economics | Most of economic expenses are due to data collecting |
| Driving force for implementation | Data availability |

# Furnace Model

| Topic | Description |
|---|---|
| Case studies | • Thyssen Krupp Steel AG in Bochum (Germany)<br>• hot strip mill at SSAB Tunnplat AB Works in Borlänge<br>• Acciai Speciali Terni Walking Beam furnace |
| Reference literature | R. Klima, M. Arribas, E. Moosavi, D. Zander, V. Santisteban, B. Leden, F. Vode, A. Arnaiz, F. Peñalba and M. Torkar, "Quality improvement by metallurgical optimised stock temperature evolution in the reheating furnace including microstructure feedback from the rolling mill (OPTHEAT)," 2011.<br>Jäckel, M. Lubrano and B. Dahm, "Rules-based systems for improved monitoring and guidance of reheating furnaces," 2006.<br>J. S. Stubbs, G. Quintiliani and F. Sanfilippo, "Integration of reheating furnaces with rolling conditions at roughing mill (Improheat)," 2002<br>S. J. Wilcox, J. Ward and G. Andrews, "Real-time intelligent diagnostics and optimisation of reheating furnace performance," 2010<br>J. . Niska, C. Steimer, J. Broughton, A. Queck, C.-K. Tan and V. M. Santisteban Mendive, "Advanced measurements and dynamic modelling for improved furnace operation and control (DYNAMO)," 2017 |

# Emerging technologies for future developments

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- What BAT and promising technology is relevant for future technological development.
- What are the current technology gaps in these technologies

# Emerging technologies for future developments

- ✓ Use of machine learning, joining of statistical models and physical models
- ✓ Aspen Plus and plant simulators for simulation of $CO_2$ capture*

**F. Z. Y. S. W. H. S. Y. L. Zhang, "CO2 capture from reheating furnace based on the sensible heat of continuous casting slabs," International Journal of Energy Research, 2018.*

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# Summary of technical measures used to improve performance of reheating furnace

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# Summary of technical measures used to improve performance of reheating furnace

| Measure/technology | Description |
| --- | --- |
| **Furnace design optimization** | Minimizing the loss of heat due to furnace design, or optimizing placement of burners and flow patterns etc. |
| **Regenerative burner** | Regenerative burners consist of two burners which are operated alternately, and which contain beds of refractory or ceramic materials. While one burner is in operation, the heat of the exhaust gas is absorbed by the refractory or ceramic materials of the other burner and then used to preheat the combustion air. |
| **Recuperative burner** | Recuperative burners employ different types of recuperators to directly recover heat from the exhaust gases, which are then used to preheat the combustion air. |
| **100% oxyfuel** | Combustion air is fully replaced by oxygen |
| **oxygen enrichment** | Combustion air is partially replaced by oxygen |
| **Oxygen lancing** | Instead of adding oxygen into the combustion air stream of each burner as done with traditional oxygen enrichment, oxygen is injected at high velocity at a short distance from the burner, allowing the oxygen to be diluted by furnace fumes before it takes part in the combustion |
| **Flameless combustion** | Flameless combustion is achieved by injecting fuel and combustion air separately into the combustion chamber of the furnace at high velocity to suppress flame formation and reduce the formation of thermal NOx while creating a more uniform heat distribution throughout the chamber. Can be used in combination with oxy-fuel combustion. |

# Summary of technical measures used to improve performance of reheating furnace

| Measure/technology | Description |
|---|---|
| **Pulse fired burner** | The heat input to the furnace is controlled by the firing duration of the burners or by the sequential start of the individual burners instead of adjusting combustion air and fuel flows. |
| **Flue gas recirculation** | Partial recirculation of the flue-gas to the combustion chamber to replace part of the fresh combustion air, with the dual effect of limiting the O2 content for nitrogen oxidation and reducing the combustion temperature, thus limiting NOx generation. |
| **Optimized skid design** | The design of skids in reheating furnaces is optimised to minimise skid marks on the feedstock using skid riders, skid shifting or a skid mark compensation device |
| **Heat recovery from skids** | Steam produced when cooling the skids supporting the feedstock in the reheating furnaces is extracted and used in other processes of the plant. |

# Summary of technical measures used to improve performance of reheating furnace

| Measure/technology | Description |
|---|---|
| **Heat conservation during transfer of feedstock** | Insulated covers are used between continuous caster and the reheating furnace, and between the roughing mill and the finishing mill. |
| **Hot/direct charging** | Continuous-cast steel products are directly charged hot into the reheating furnaces or directly transferred to the rolling mill in hot conditions |
| **Organic Rankine cycle** | Low-grade heat from the exhaust gases of hot rolling reheating furnaces is converted into electricity using high-molecular-weight fluids |
| **Furnace automation and control** | The heating process is optimised by using a computer system controlling in real time key parameters such as furnace and feedstock temperature, the air to fuel ratio and the furnace pressure |

For more info:

# Thank you for your attention

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