Electrification of reheating furnaces: state of the art and future research needs

INFUB14, Algarve, 3rd april 2024

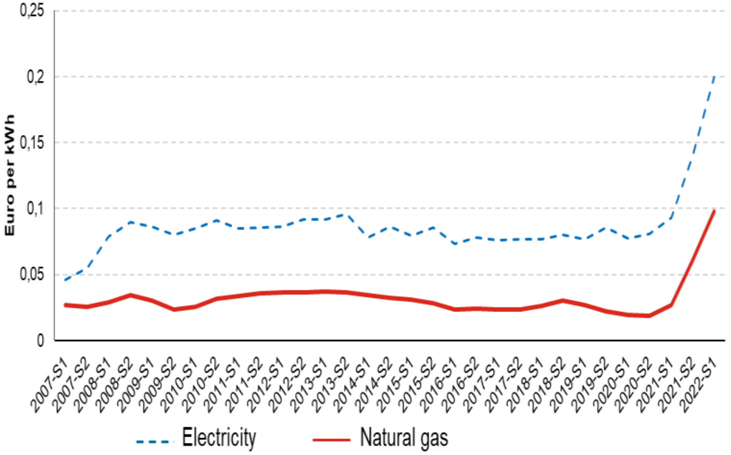
Gustav Häggström

Researcher at Swerim in Luleå, Sweden

gustav.haggstrom@swerim.se

Introduction and motivation

- Large focus on emission reduction of the ore in steel industry
  - Increased and necessary focus on downstream possibilities
    - 6-8 % of total energy use (About 100-130 TWh/year)
- Electrification as a means for decarbonisation
  - Direct and indirect



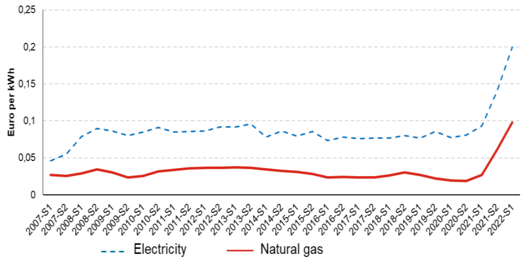
Eurostat – prices of natural gas and electricity in EU27 2007-2022 (large consumers)

Introduction and motivation

- Direct electrical heating was developed, but less common due to price considerations
    - Typically for applications <1000 °C
- Option at higher temperatures exist and varying TRL

Motivation

- Give an overview and state-of art of electrical heating and its matureness for the reheating furnaces



Eurostat – prices of natural gas and electricity in EU27 2007-2022 (large consumers)

Method

Article and report reviews

- 20 articles, 13 RFCS and 6 HEU reports, technology provider reports and webpages, state of the art documents

→ TRL, efficiency, productivity, CAPEX, OPEX, CO_2 emissions

Research & Development drivers:

- Profitability and legislative limits of SO_2, NO_x, and GHG emissions

What is the main topics that will be covered in this presentation

- Electric heating
- Electrofuels

Method

Comparison

- Total effiency from electrical power to heat in steel slabs
- TRL for the different technology options
- Challenges and advantages
    - Retrofitting possibilities
- Role in energy and electrical system

SoA: Electrofuels in reheating furnaces

dissHEAT

Fuel	η_{syn} (LHV)	η_{tot} ($50\ \% < \eta_{tot} < 75\ \%$)
Hydrogen (H_2)	~50-70 %	~25-53 %
Ammonia (NH_3)	~55-65 %	~28-49 %
Methane (CH_4)	~49-65	25-49 %

$$\eta_{electricity} \geq \eta_{combustion} > \eta_{electrofuel}$$

Easy to implement, but likely expensive

"Process efficiency simulation for key process parameters in biological methanogenesis"
"Current and future role of Haber–Bosch ammonia in a carbon-free energy landscape"
"Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-to-gas and power-to-liquids: A review"

SoA: Electrofuels in reheating furnace

Technology/ measure	TRL	Challenges	Advantages
Combustion of Electrofuels	8-9	• Availability of hydrogen and gas infrastructure • Efficiency • Challenging temperature control • NO_x emissions	• High TRL • Flexible in terms of feedstock type and geometry • Fuel flexible • Easy transition from fossil-based heating • Not dependent on local energy infrastructure

SoA: Developments in electrical heating

Electrical heating

- Resistive heating
  - Direct
  - Radiative
  - Convective
- Inductive heating
- Plasma heating
- Rotodynamic heating

Technology	Heat recovery/ Efficiency	Heat transfer/ productivity
Combustion	Low to high	Moderate
Resistive heating	High to very high	Low
Direct resistive heating	Moderate to very high	Very high
Inductive heating	Low to high	High

Generally requires a new furnace installation

SoA: Resistive heating

dissHEAT

Radiant resistance heating

- Common for smaller scale applications
- Limitations to geometry and location in furnace
  - Low surface power density > long furnaces
  - Top and wall mounting due to oxide scale
  - Physical durability
- Kanthal has a fully electric WBF since 30 years

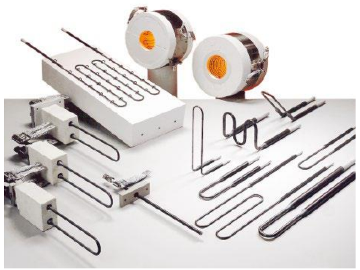
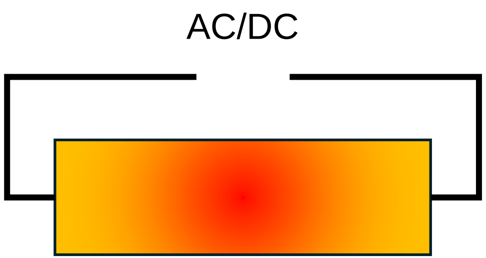


Image: Kanthal

Direct resistance heating

- Industrialized up to 1000 C
- Very rapid heating
- Electrical connection issues and power supply



$$\eta_{total} \sim >90\ \%$$

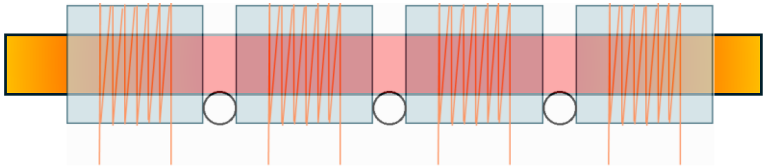
SoA: Resistive heating

Technology	TRL	Challenges	Advantages
Radiative resistance heating	9	• Low power density • Durability, especially in tough environments	• High TRL • High efficiency • Flexible in terms of feedstock type and geometry • No particulate or gaseous emissions • Atmosphere control • Precise temperature control
Direct resistive heating	4	• Sensitive to feedstock type and geometry • Electrical contact • Low TRL	• High efficiency • Very rapid heating possible • Compact • Precise temperature control • Rapid start and stop • No particulate or gaseous emissions

SoA: Induction heating

- Mature technology
- Electromagnetic power transfer
- High power density and fast heating rates
- Cooling water losses

$$\eta_{total} \sim 50\text{-}60\ \%$$



Technology	TRL	Challenges	Advantages
Induction heating	9	• Sensitive to feedstock type and geometry • Challenging temperature control	• Rapid heating • Low space requirements • Rapid start and stop • No particulate or gaseous emissions

SoA: Plasma heating

dissHEAT

- Under development for conditions relevant to reheating furnaces
- High power density > retrofitting opportunities
- Loss of sensible heat due to temperature requirements on plasma carrier gas (recirculated gases)

BFI

CRM GROUP

RINA

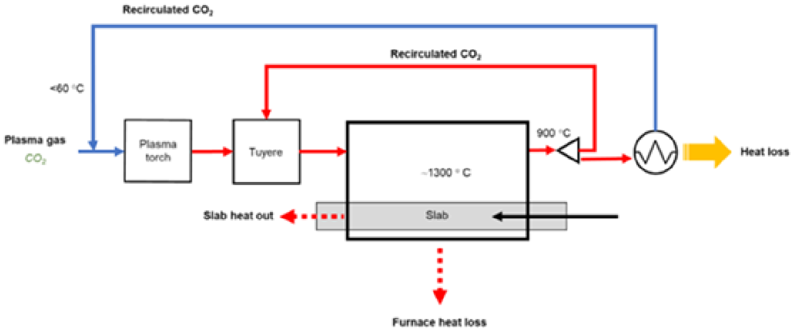
RWTH AACHEN UNIVERSITY

SWERIM

European Commission

Research Fund for Coal & Steel

Image: Scanarc



SoA: Plasma heating

- High thermal efficiency (~ 70-95 %)
  - Total efficiency around 60 %
- Flexible to different types and geometry of steel slabs

Technology	TRL	Challenges	Advantages
Plasma heating	5-6	• Low total efficiency • Maintenance costs • NOx formation • Challenging temperature control	• Rapid start and stop • Compact • Flexible in terms of feedstock type and geometry

SoA: Rotodynamic heating

- Turbomachinery with 100 % internal losses into heat
  - Potential for high thermal efficiency
  - Theoretical temperatures up to 1700 °C
- Under development for higher temperatures
  - Currently at 900 °C
- Potential to reheat hot gases > high total efficiency

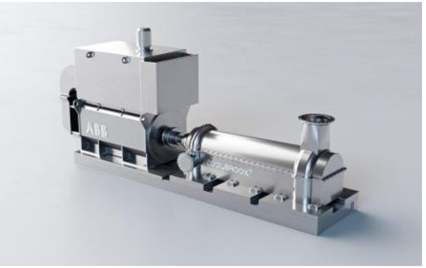


Image: Coolbrook Oy

Technology	TRL	Challenges	Advantages
Rotodynamic heating	4-5 (6)	• Low TRL • Sensitive to dust	• Rapid heating • Retrofitting possible

Discussion

- The topic of decarbonization using electrification is diverse with many local and regional challenges
- The electrification of heating processes inevitably exposes the industry to the electrical energy market and its volatitliy
    - Causing indirect effects on an industrial site in terms of
- Waste heat integration and sector coupling

Future research

- Evaluate technologies at lower TRL in larger scales
- System integration for electrification of furnaces
    - Direct and indirect, including the combinations of combustion and electrical heating
        - Top and bottom end temperature range
    - Focusing on total energy use, costs and emission reduction potential (CO_2, NOx, etc.)
- Technology options for existing furnaces and greenfield installations

Conclusions

- Large variety of electrical heating solutions are available
  - No single technology better, very dependent on site opportunities and power infrastructure/electricity sources
- Aim of GHG emission reduction must consider the system level effects

More research needed:

- Emerging electrical heating options
- Hybrid heating options
- System integration on a plant level and energy system level scale
  - Focusing on installations in new sites and the retrofitting potential.

Thank you for the attention!

Stay informed

www.dissheat.eu