Fuel Flexible Self-Recuperative Burners for Radiant Tube Heating Systems

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ESTEP - H_2 for Green Steel meets A Circular Economy driven by the European Steel

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FlexHeat2Anneal thyssenkrupp WS IOB Institut für Industrieofenbau und Wärmetechnik RWTH AACHEN UNIVERSITY

Introduction

Objectives

Flexible use of H_2 as fuel in radiant heating tubes of annealing lines for steel strip

- Investigation of the use of hydrogen in existing radiant tube systems
- Development and demonstration of innovative, fuel-flexible and energy-efficient FLOX radiant tube systems with lowest NOx emissions

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Partners

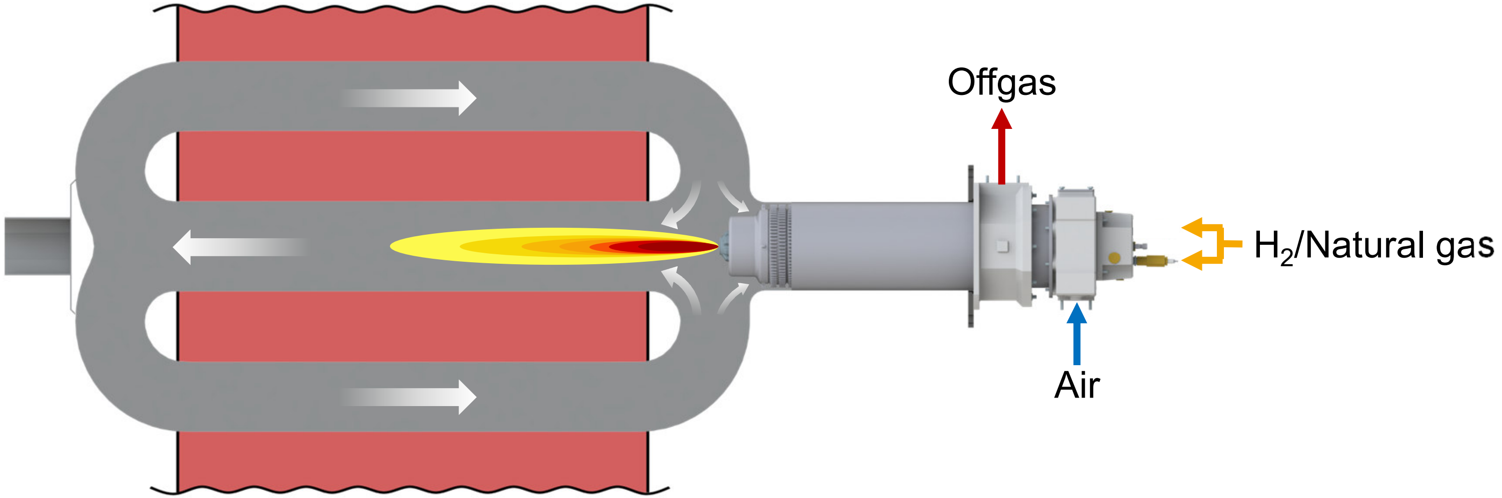
- Thyssenkrupp Rasselstein GmbH
- WS Wärmeprozesstechnik GmbH
- IOB RWTH Aachen

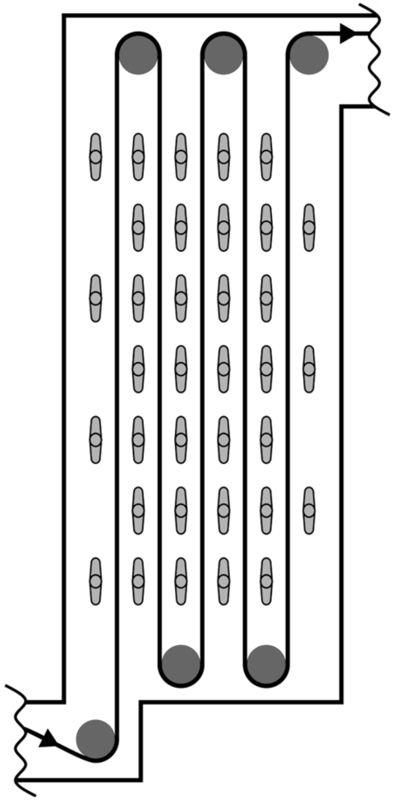
Framework

- 7th Energy Research Programme of the Federal Government
- Call for funding „Hydrogen Technology Offensive“
- Project duration: 04/2022 - 03/2025 (3 years)

Radiant tubes and self-recuperative burners

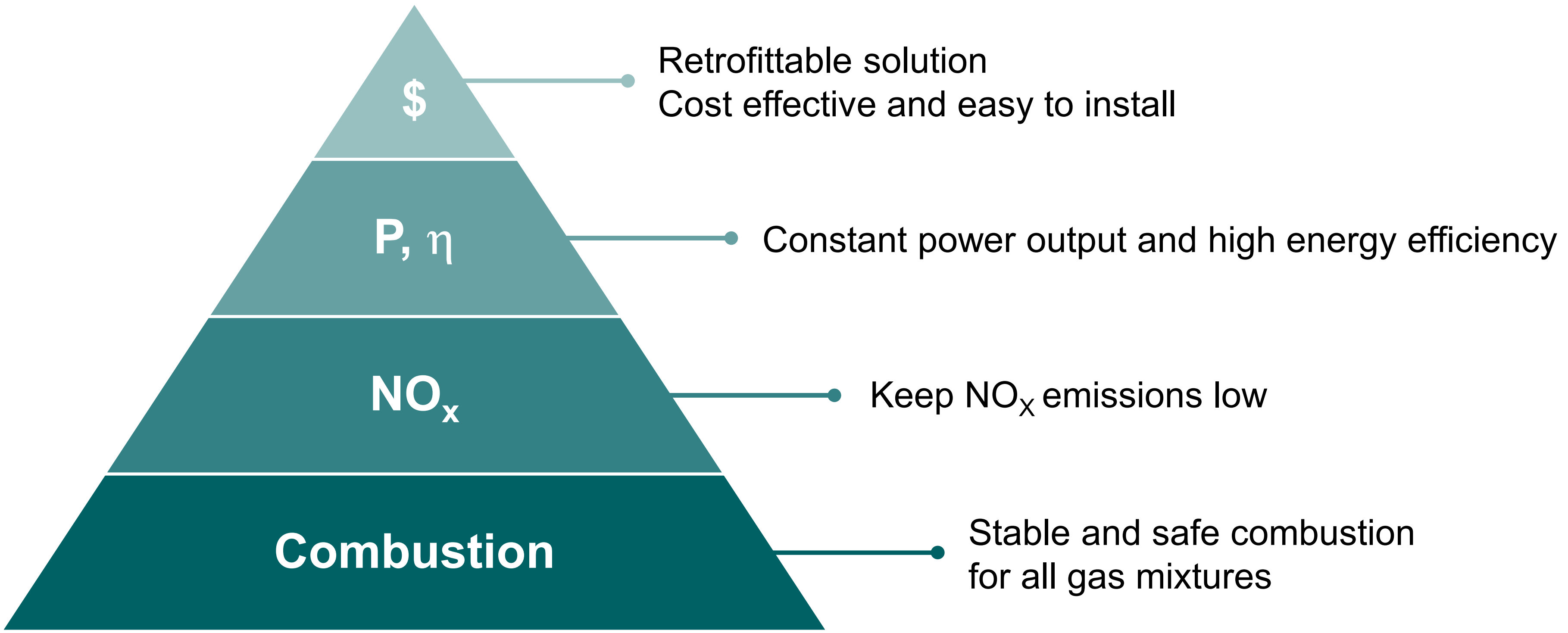
- Rekumat® M 250 from WS Wärmeprozesstechnik (P = 140 kW)
- Radiant tube burner systems previously optimised for natural gas or steel plant gases
- Annual CO_2 emissions of a selected CAL: approx. 16,000 ton_{CO2}/y





Introduction: Requirements for the new system

From 0 to 100 vol% hydrogen in natural gas without manual adjustment of the system



Background: Gas properties of NG and H_2

Characteristic	Unit	100 % H-Gas*	100 % H_2
GCV	kWh/m³	10,091	2,995
Density	kg/m³	0,7402	0,0899
Wobbe-Index	kWh/m³	13,31	11,34
Min. oxygen requirement	$m^3_{O_2}/m^3_{Gas}$	2,02	0,50
Min. air requirement	m^3_{air}/m^3_{Gas}	9,63	2,38
Min. flue gas (moist, air combustion)	m³/kWh	**1,05**	↓ 8.5% **0,96**
Lam. burning velocity in air**	m/s	**0,39**	↑ 435% **2,09**
Adiabatic temperature in air	°C	**2057**	↑ 9.2 % **2247**
Spec. CO_2 emissions	g_{CO_2}/kWh	198	0

* Composition of Russian H-Gas as specified in the DVGW G260 worksheet; ** reference: https://doi.org/10.1016/j.proci.2018.09.029

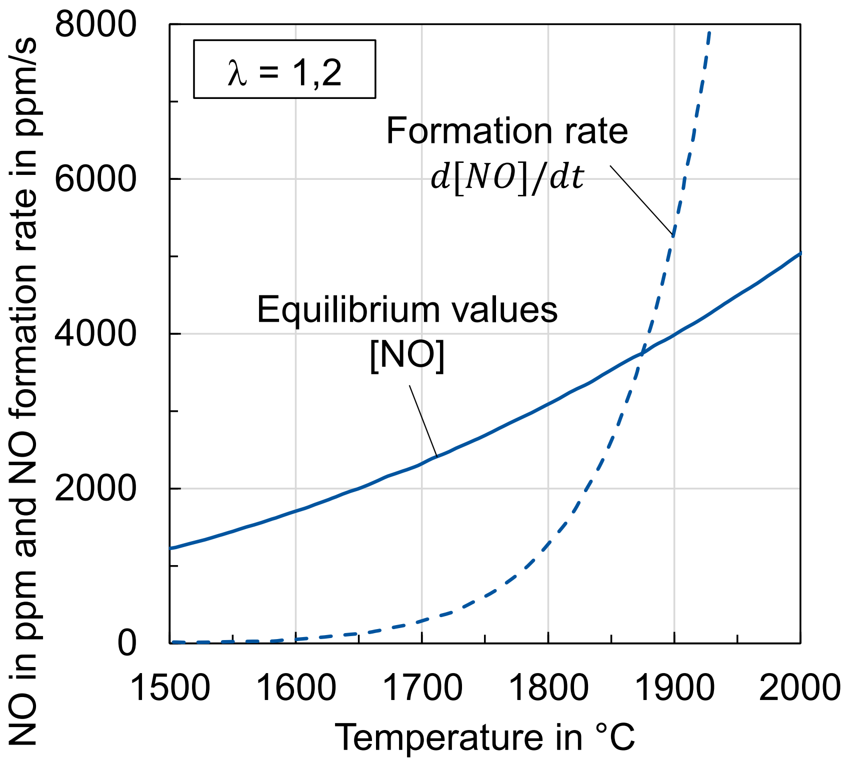
Thermal NO formation according to Zeldovich

$$\frac{d[NO]}{dt} = 2 \cdot k_{NO} \cdot [N_2] \cdot [O]$$

Reaction speed

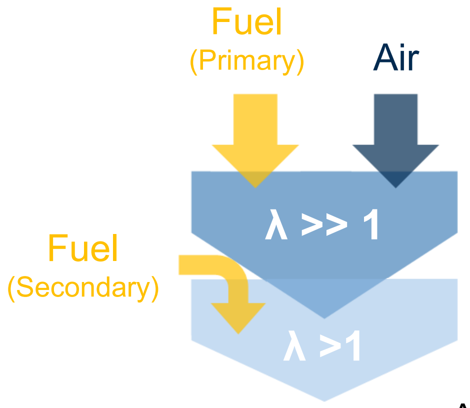
$$k_{NO} = 7.6 \cdot 10^{13} \exp(-\frac{316000}{RT})$$

➡ NO formation is strongly temperature-dependent



Investigated NO_x primary reduction measures

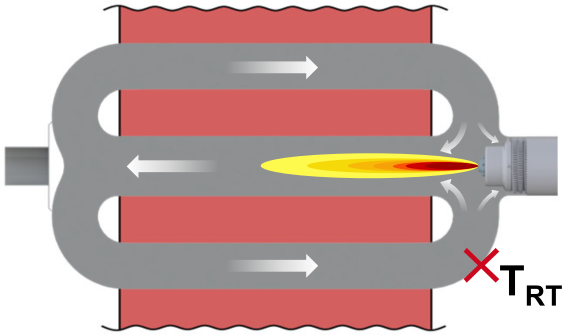
Fuel staging



Air ratio

$$\lambda = \frac{l}{l_{min}}$$

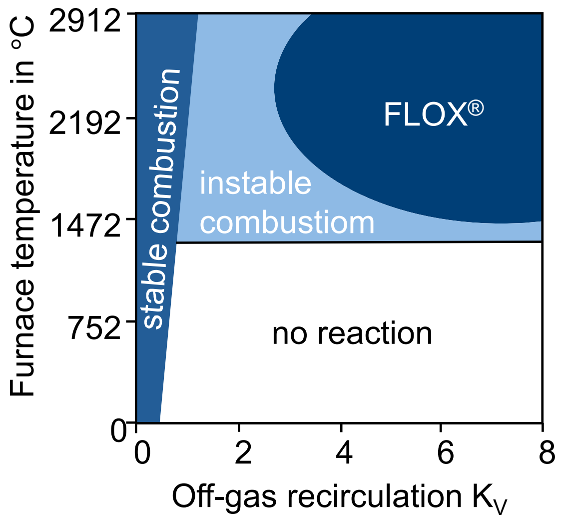
Off-gas recirculation



Recirculation rate

$$\bar{r} = \frac{\dot{m}_{off-gas}}{\dot{m}_{fuel} + \dot{m}_{combustion\ air}}$$

Flameless combustion



➡ Reduction of peak combustion temperatures

Experimental set-up

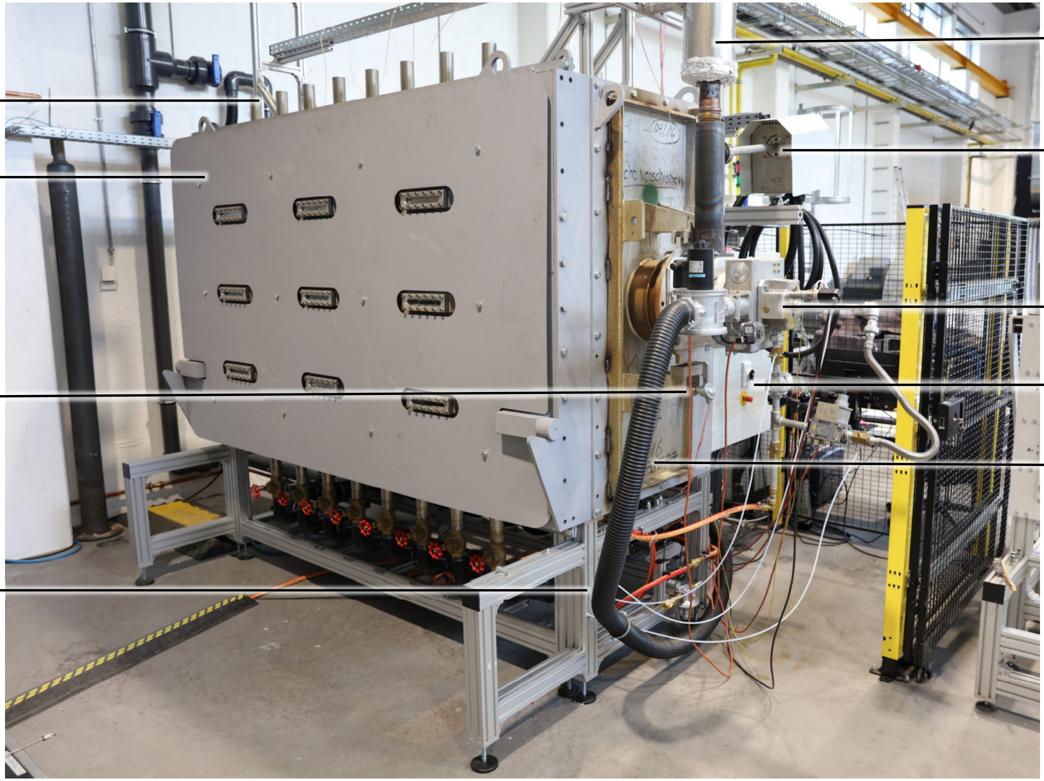
Lab-scale furnace

Air cooling tubes x16

Removable lid

T_{RT}

Combustion air supply



Off-gas duct

Wet off-gas analysis CO, CO_2, H_2O, O_2, NO, NO_2, $T_{Off\text{-}gas}$

Self-recuperative burner

Control cabinet

Exchangable radiant tube

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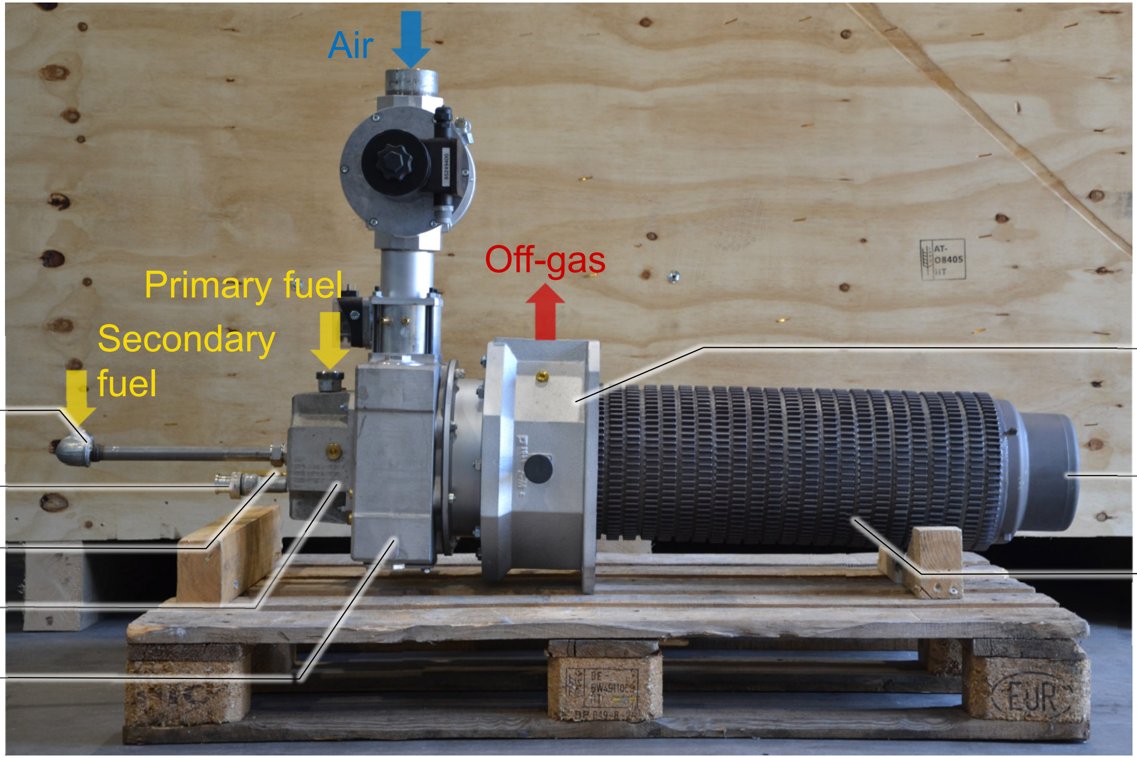
Experimental set-up

Retrofitted self-recuperative burner



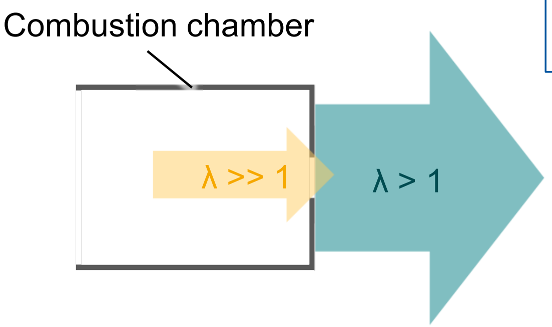
Experimental set-up

Parameter studies

Operating mode 1:
Flame with fuel staging

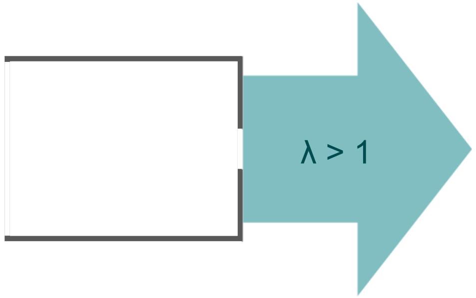
Air ratio

$$\lambda = \frac{l}{l_{min}}$$



Operation mode	Flame with fuel staging
Volume flow distribution in %	50/50

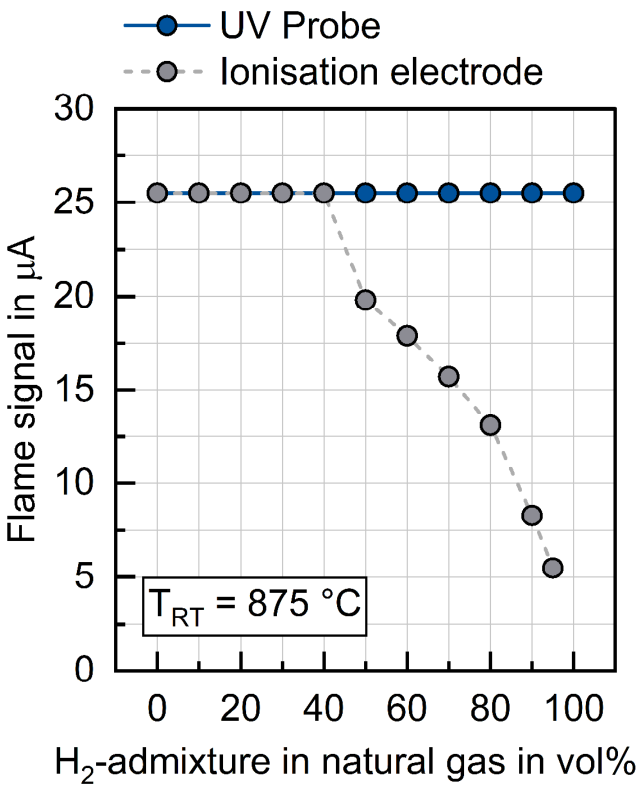
Operating mode 2:
Flameless

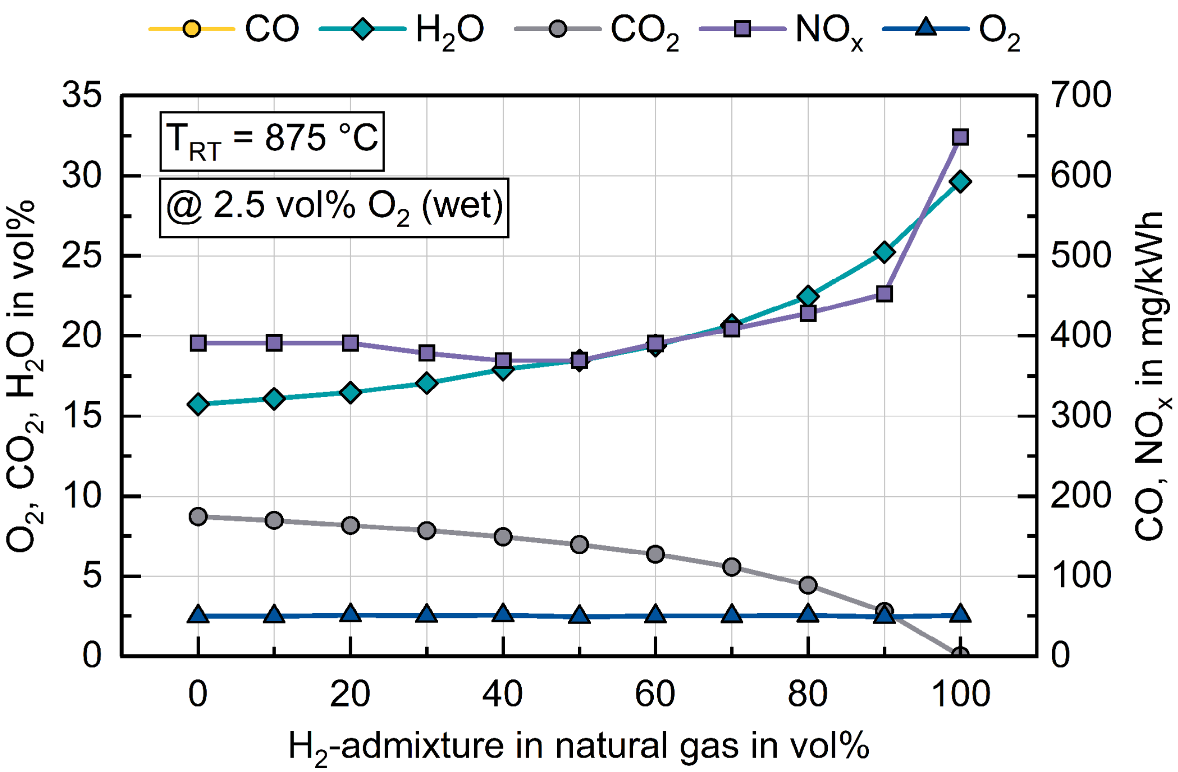


Operation mode	Flameless
Volume flow distribution in %	100

Results: Hydrogen enrichment in the state-of-the-art burner

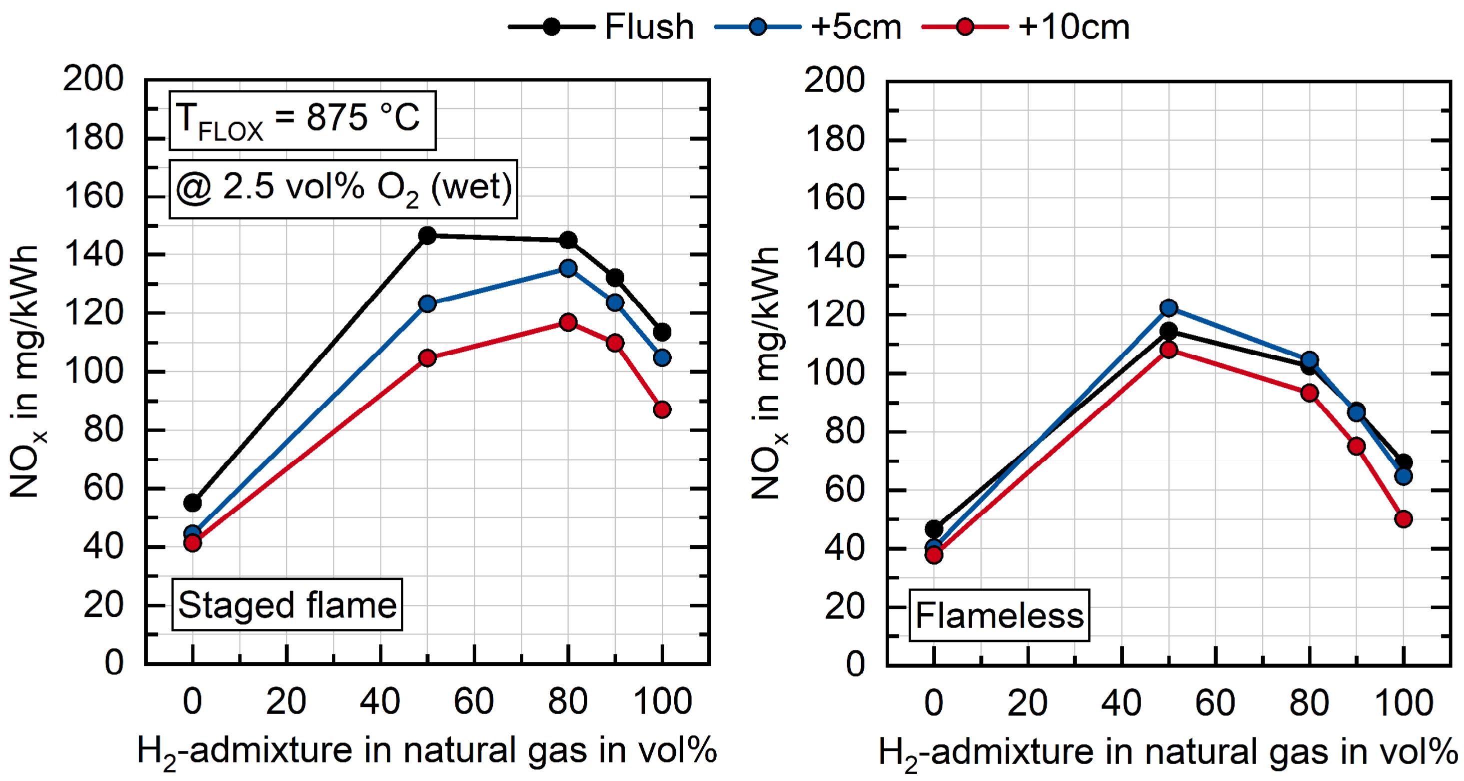
Flame signal and off-gas composition

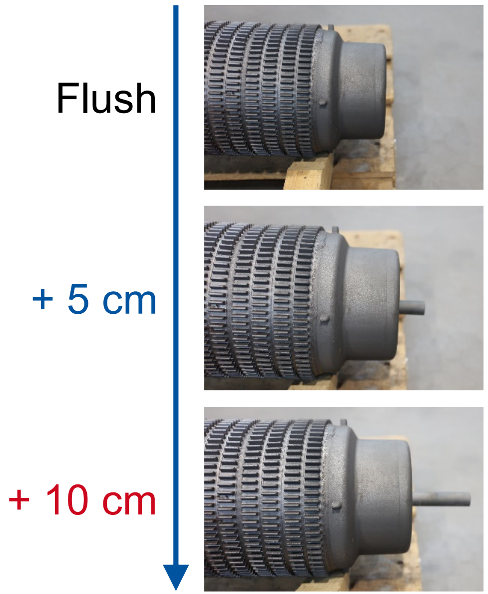




Results: NO_x emissions in the retrofitted burner

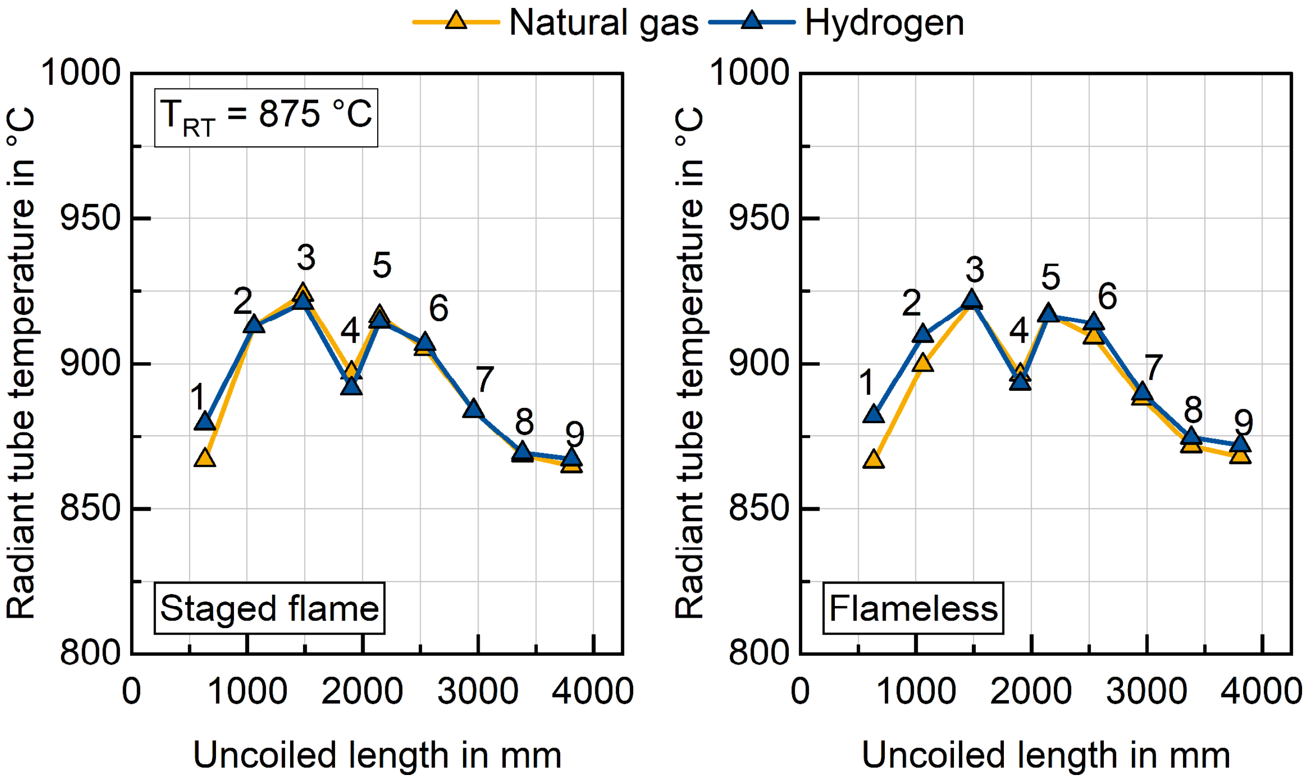
Influence of the gas lance position and operation mode

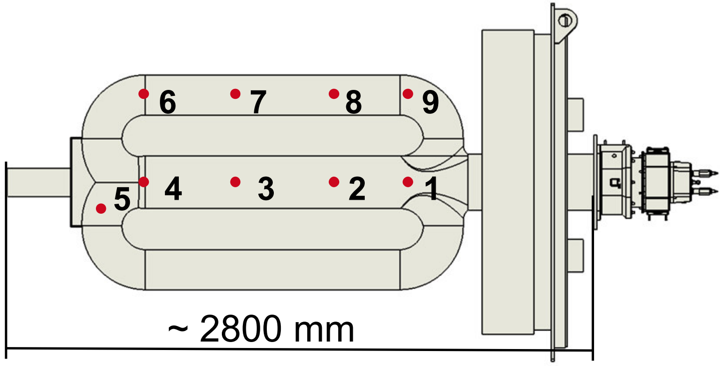




Results: Temperature distribution on the radiant tube

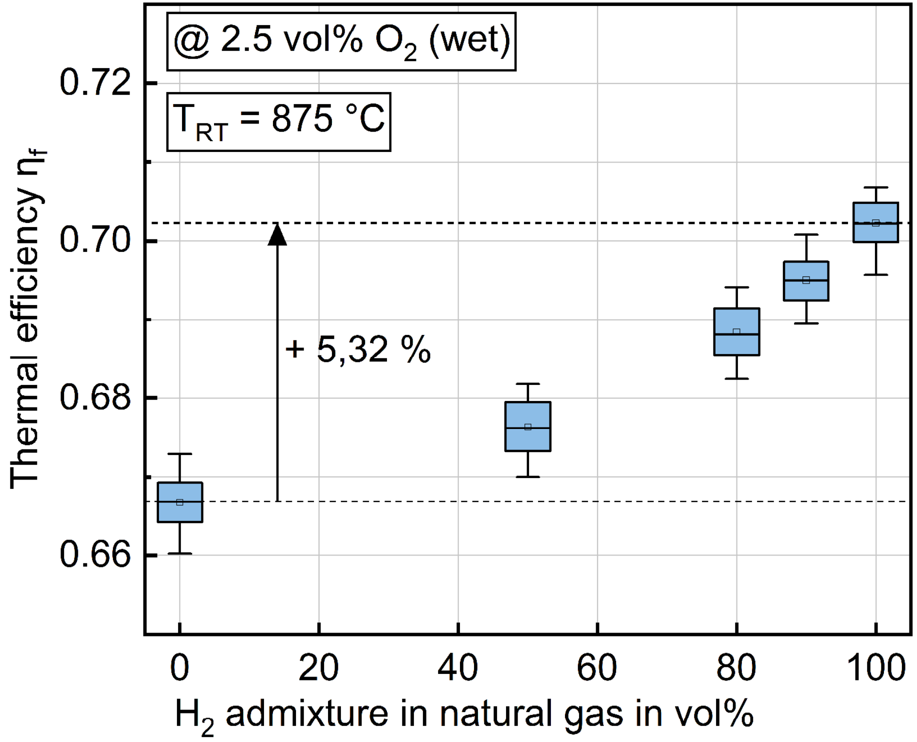
Influence of hydrogen enrichment on the radiant tube temperatures





Results: Thermal efficiency of the self-recuperative burner

Influence of hydrogen enrichment on the thermal efficiency

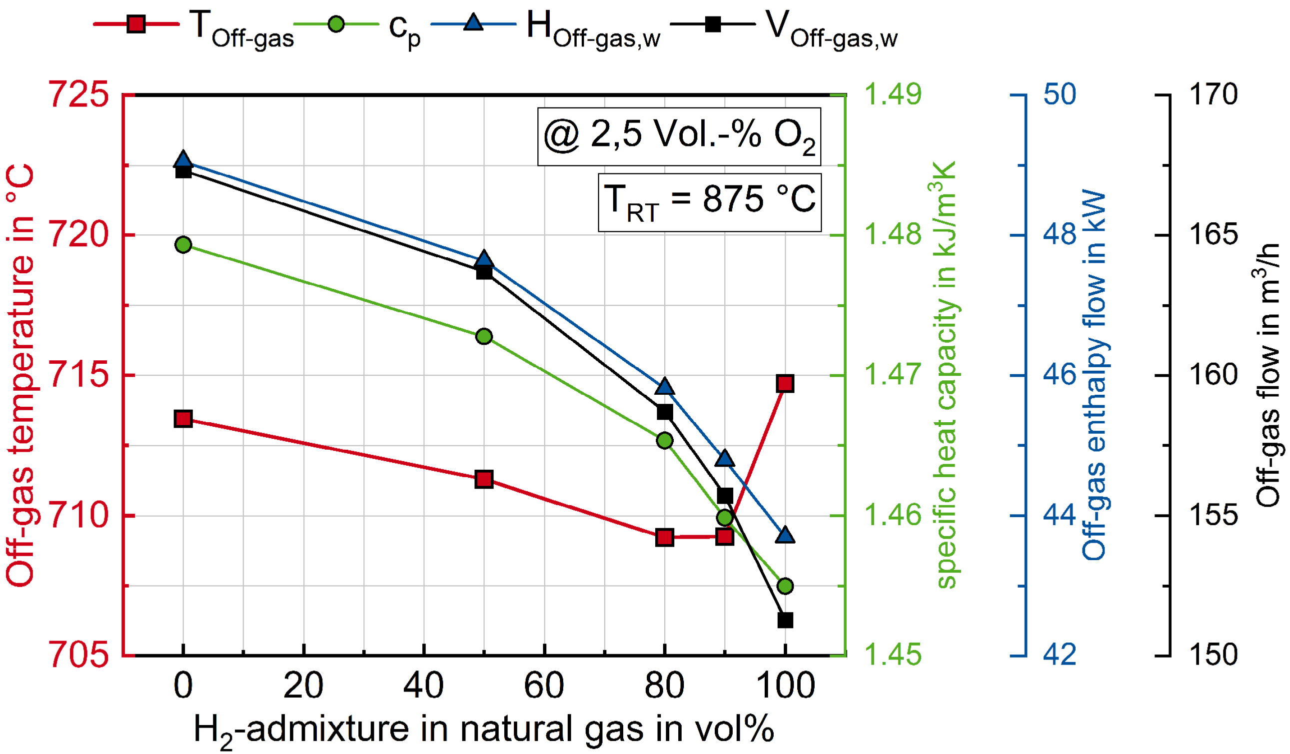


Results: Thermal efficiency of the self-recuperative burner

Influence of hydrogen enrichment on the thermal efficiency

$$\eta_f = \frac{\dot{H}_{Fuel} - \dot{H}_{Off-gas}}{\dot{H}_{Fuel}}$$

$$= 1 - \frac{c_p \cdot (T_{Off-gas} - T_0) \cdot \dot{V}_{Off-gas,w}}{\dot{H}_{Fuel}}$$



Conclusion

- Results of the state-of-the-art burner show:
  - **Stable combustion** possible for all fuel gas mixtures
  - **Need** for **NO_x emission reduction measures** when using H_2 and H_2-blends

- Results of the retrofitted burner show:
  - **Fuel staging** and **flameless combustion** contribute to the **reduction of NO_x** emissions
  - **Low impact** of hydrogen admixture **on radiant tube temperatures**
  - **Increase in thermal efficiency** by 5% when using H_2 instead of natural gas (@ 2,5% O_2 in wet off-gas)

	NO_x in mg/kWh		
	SoA burner	Retrofit burner	
	Flame	Staged flame	Flameless
NG	391	42	38
H_2	648	87	50

Proposed NO_x emission limits*

For feedstock heating in hot dip coating lines:

100-300 $mg/m^3_{Off\text{-}gas}$

*Best Available Techniques (BAT) Reference Document for the Ferrous Metals Processing Industry

Thinking the Future
Zukunft denken

Thank you for your attention

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