BASF The Chemical Company

UNIVERSITEIT GENT

FACULTY OF ENGINEERING AND ARCHITECTURE

Improving temperature measurement and control using the EXACTUS® optical thermometers

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The 28th Ethylene Producers' Conference, Houston, TX
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Temperature measurements

Contact Measurements versus Non-contact Measurements

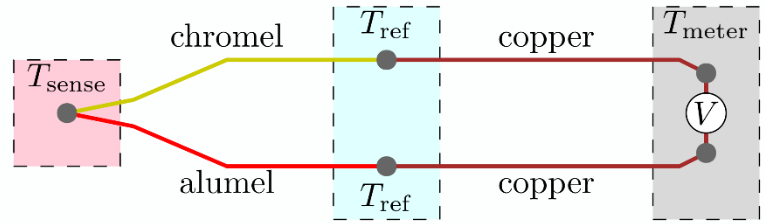
Mechanical effect

⟶ Expansion of gas/liquid/solid

Electrical effect

⟶ ΔV between dissimilar metals

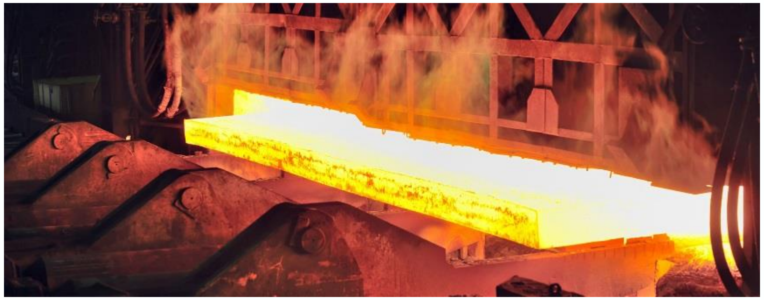
⟶ Change in metal resistance

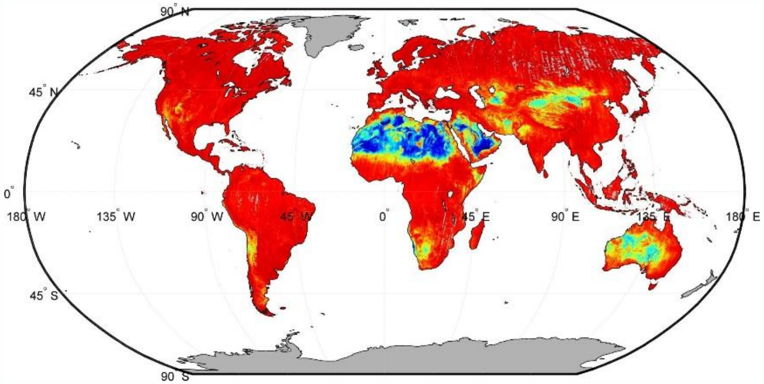


Optical effect

⟶ Intensity of radiation

⟶ Surface emissivity

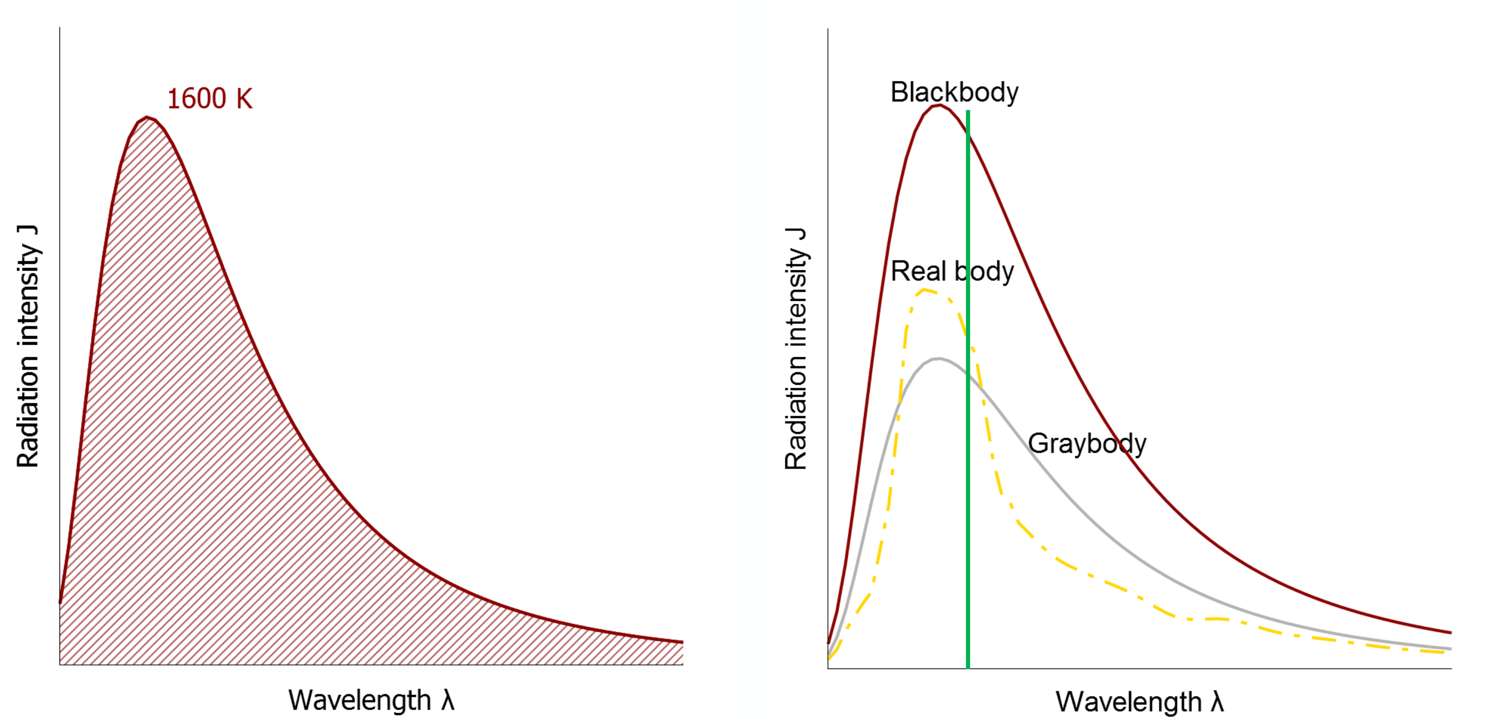




Optical temperature measurements

Stefan-Boltzmann law: $J = \varepsilon \, \sigma \, T^4$

- Total emitted radiation J is difficult to quantify
- Emissivity ε of real body is difficult to quantify, dependent on λ and T

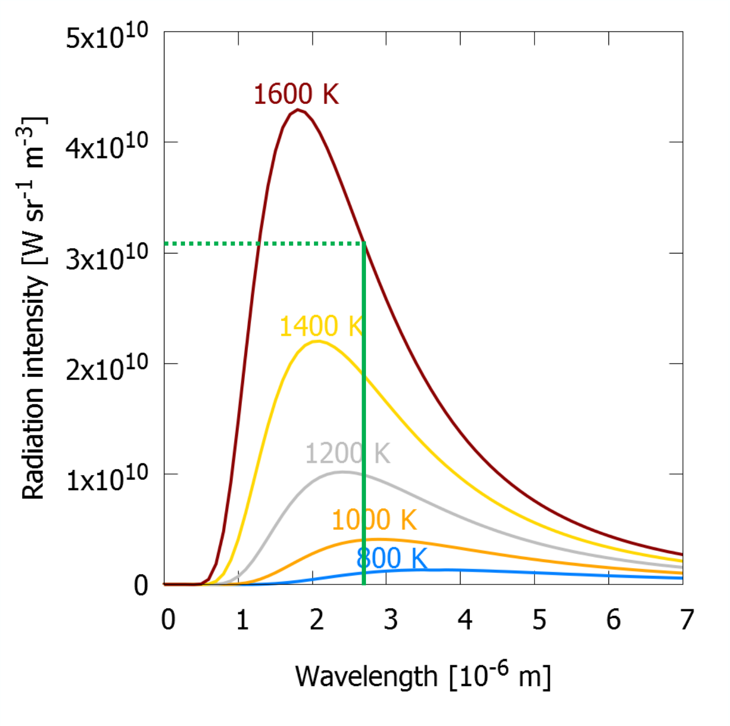


→ Measure radiation intensity at a single wavelength

Optical temperature measurements

Planck law: $I'_{black\ body}(\lambda, T) = \frac{2\,h\,c^2}{\lambda^5} \frac{1}{e^{\frac{h\,c}{\lambda\,k_B\,T}} - 1}$

Wavelength and temperature dependent on emissivity

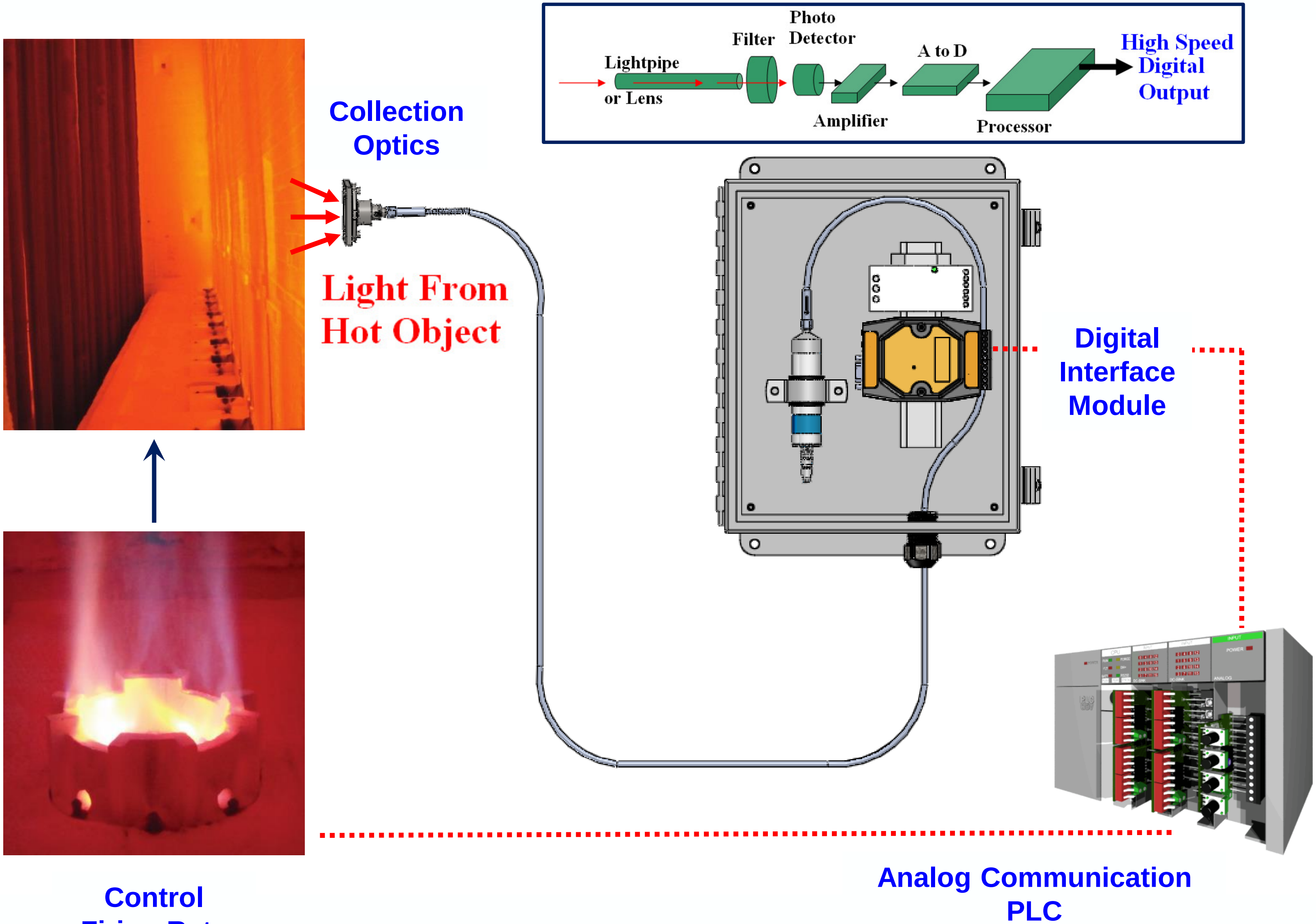


→ Measure at a single wavelength

→ Accurately determine emissivity

$$I'_{black\ body}(\lambda, T) = \frac{I'_{actual}(\lambda,T)}{\varepsilon(\lambda,T)}$$

EXACTUS® Optical thermometers



Developed by the Temperature Sensing Group of BASF Corp.

Pilot plant for steam cracking

At Laboratory for Chemical Technology (LCT) of Ghent University

FEED SECTION

Gas/liquid feed

CORI-FLOW

PREHEATING & MIXING

Water/feed evaporation

Mixing

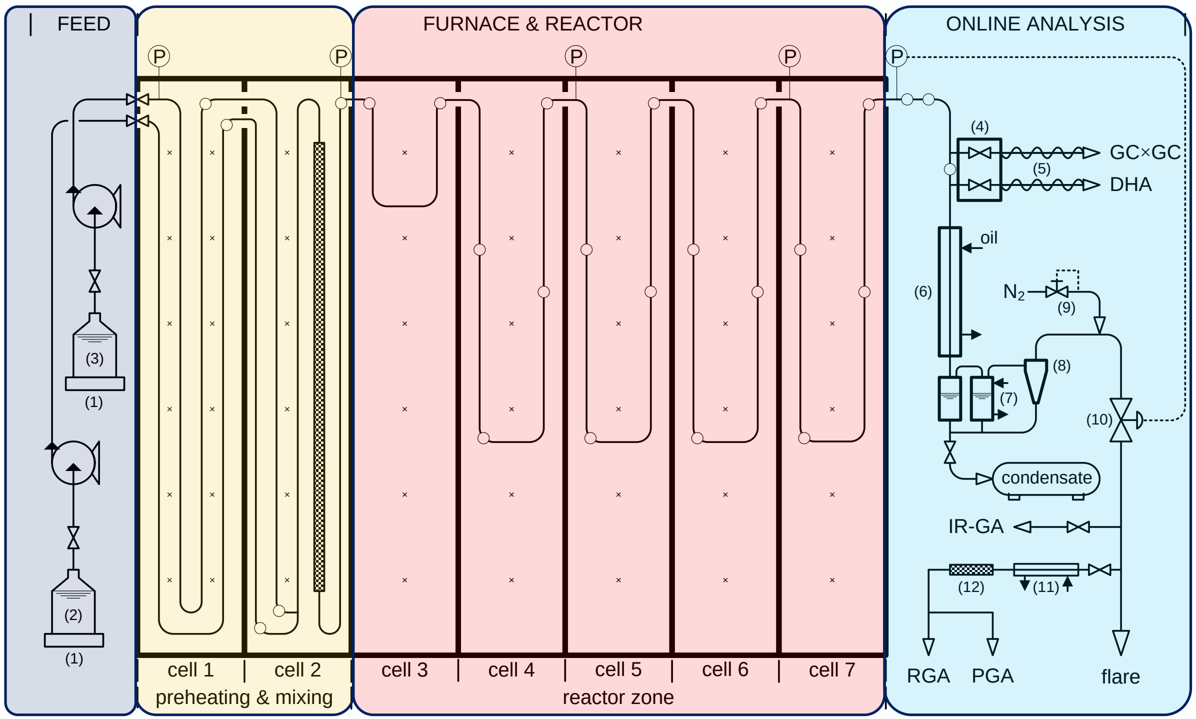
Preheating

FURNACE & REACTOR

Silica furnace: 4.0 x 0.7 x 2.6 m

Reactor coil: l=12 m, d=0.009 m

Natural gas fired: 110 wall burners



ONLINE ANALYSIS

C_5^+ analysis: GC x GC

C_4^- analysis: RGA, PGA

CO/CO_2 analyser

Pilot plant for steam cracking

Laboratory for Chemical Technology (LCT) of Ghent University

FEED

PREHEATING & MIXING

FURNACE & REACTOR

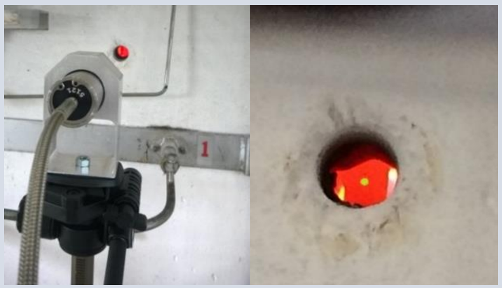
ONLINE ANALYSIS

CONTROL

EXACTUS® in the Pilot plant

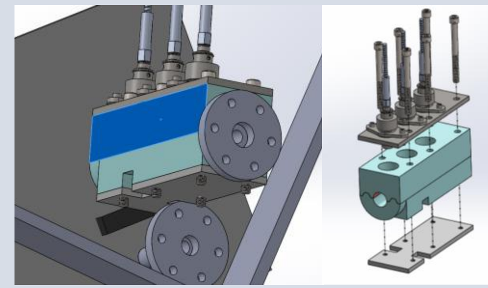
4 temperature measurements used during the test

EXACTUS FURNACE

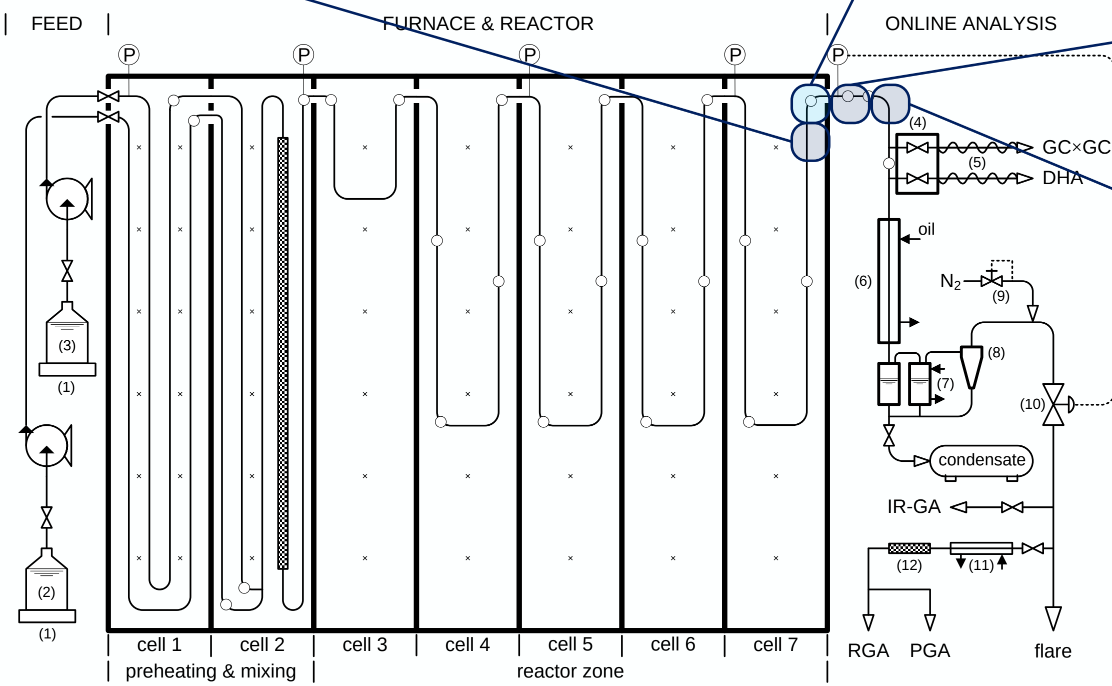


TK FURNACE

EXACTUS ADIABATIC



TK ADIABATIC



Used for control

Reference measurement

EXACTUS® in the Pilot plant

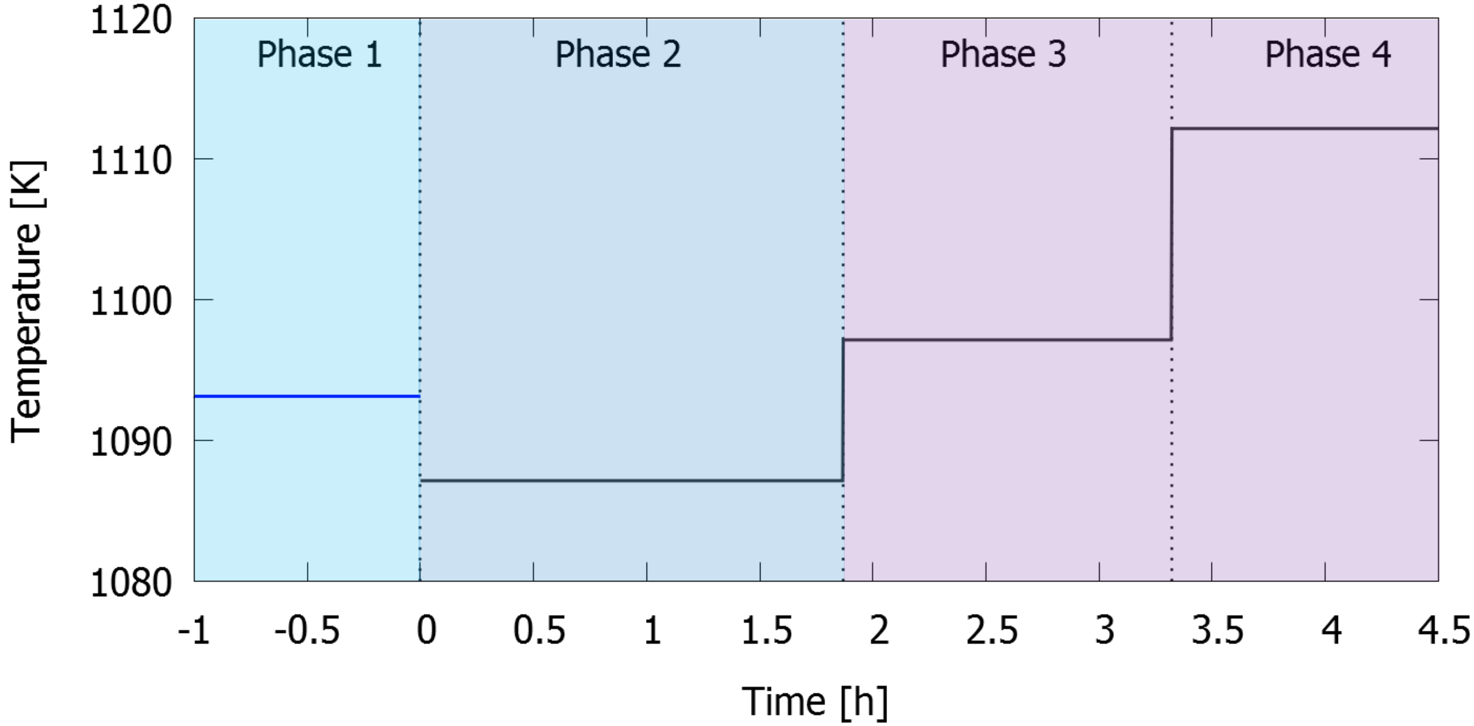
Experimental procedure

HC feed: 3000 g/h C_2H_6, dilution: 0.385 kg/kg, COP: 1.7 bar, 100 ppm sulfur/kg HC (DMDS)

Phase 1: Stabilization, fixed set point temperature on TK FURNACE

Phase 2: Maintain stable situation with alternative control (set point temperature shown)

Phase 3-4: Increase set point temperature to observe transient behavior



Results: temperature

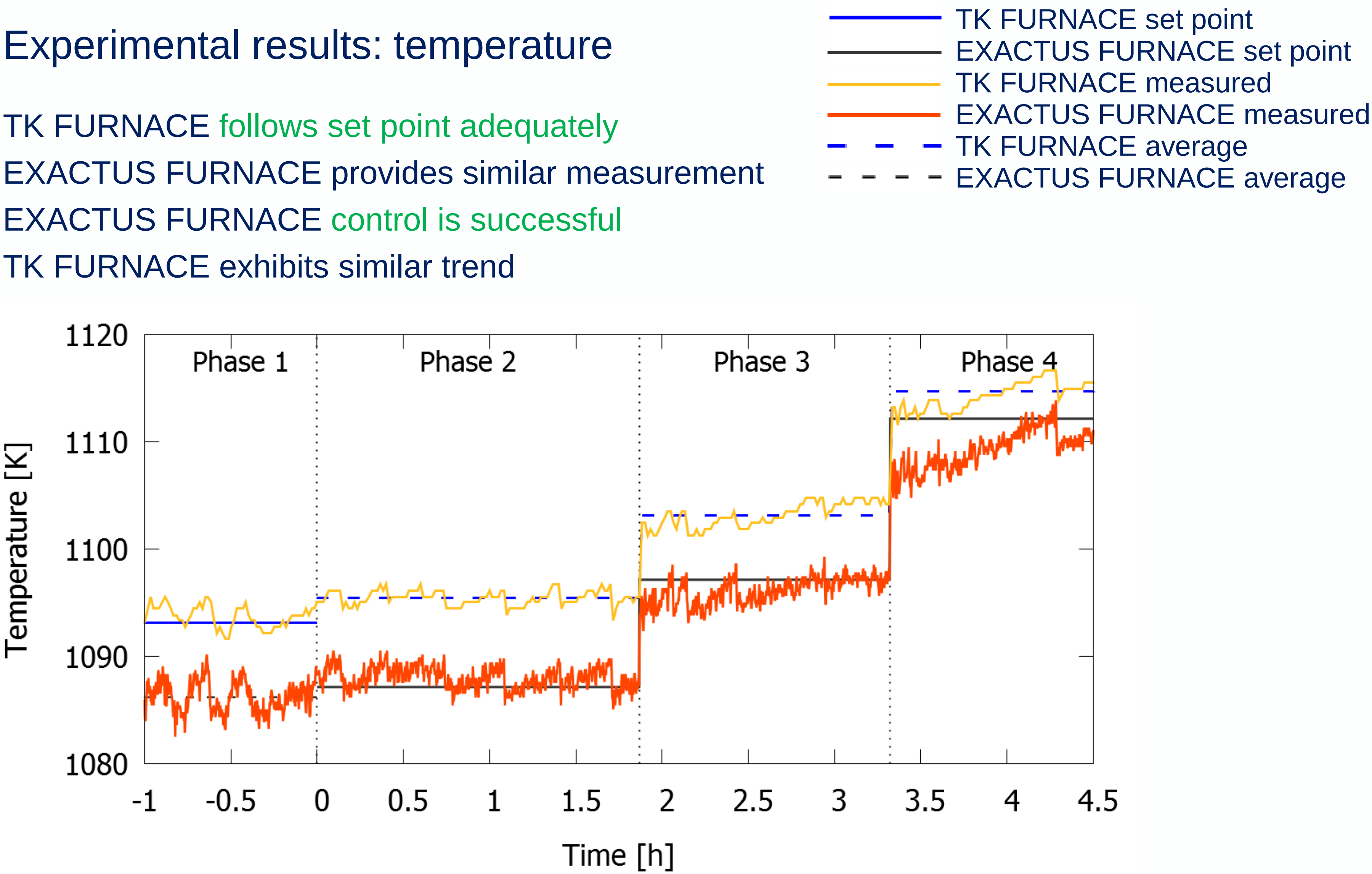
Experimental results: temperature

TK FURNACE follows set point adequately

EXACTUS FURNACE provides similar measurement

EXACTUS FURNACE control is successful

TK FURNACE exhibits similar trend



Results: temperature

Experimental results: temperature

	ε_{MAX} (process set point) [K]	ε_{MAX} (TK FURNACE) [K]
EXACTUS ADIABATIC	8.59	12.15
TK ADIABATIC	7.60	12.58
EXACTUS FURNACE	8.34	2.72

→ Maximum deviation on process set point similar for thermocouple compared to EXACTUS® equipment

→ Maximum deviation on TK FURNACE depends on location of the temperature measurement: FURNACE outperforms ADIABATIC

Results: conversion

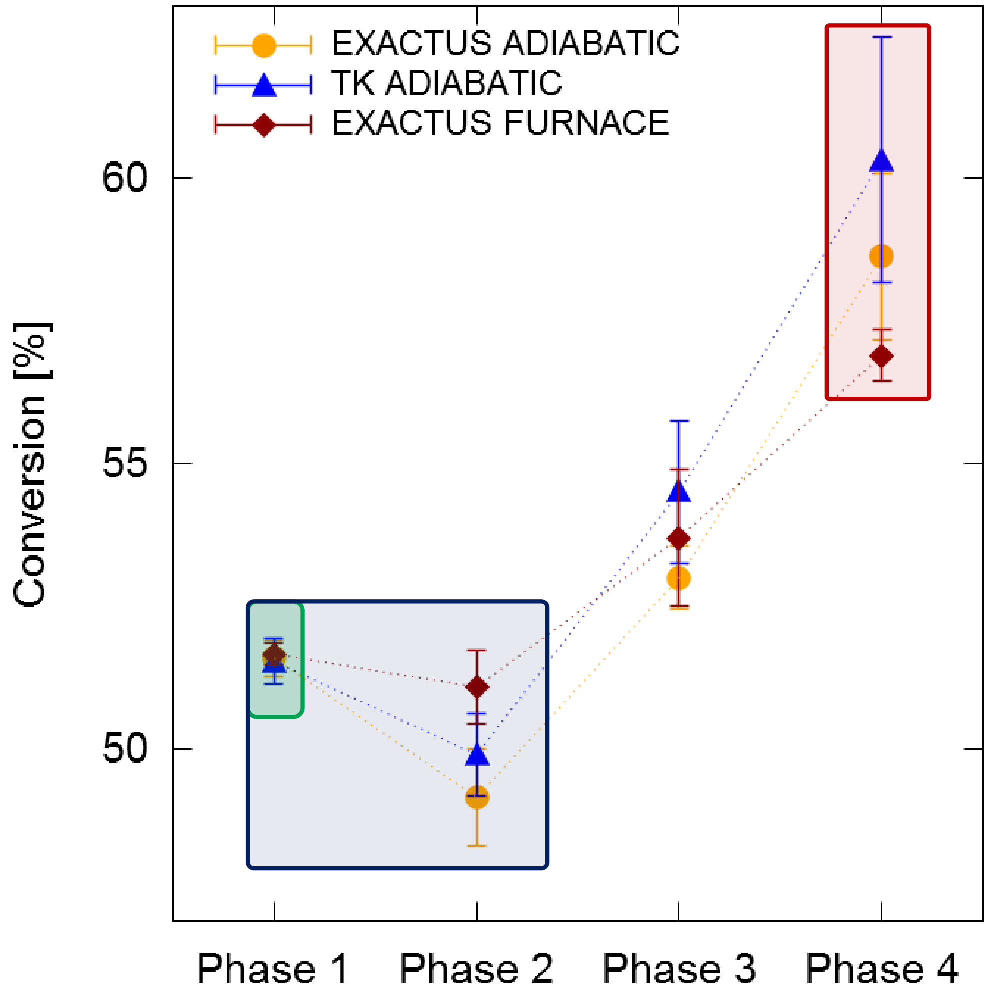
Experimental results: ethane conversion

Excellent reproducability in Phase 1

Decreased conversion in Phase 2

Conversion increases with increasing temperature

High standard deviation on TK ADIABATIC in Phase 4



Results: conversion

Experimental results: ethane conversion

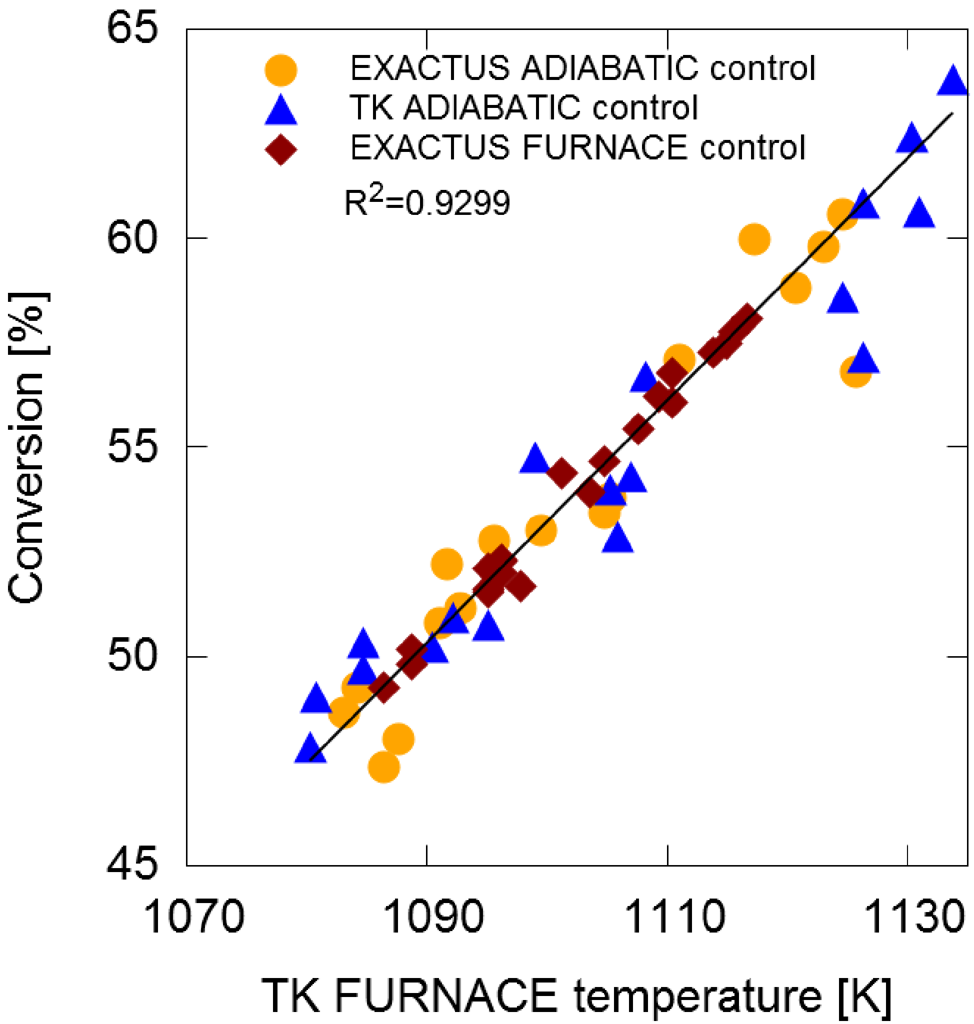
How strong is the correlation between conversion and the reference temperature measurement TK FURNACE as function of the control method?

Good correlation in case of EXACTUS ADIABATIC control ●

Decent correlation in case of TK ADIABATIC control ▲

Excellent correlation in case of EXACTUS FURNACE control ◆

EXACTUS® control methods provide a stronger correlation between reference temperature measurement and the conversion



Results: coke formation

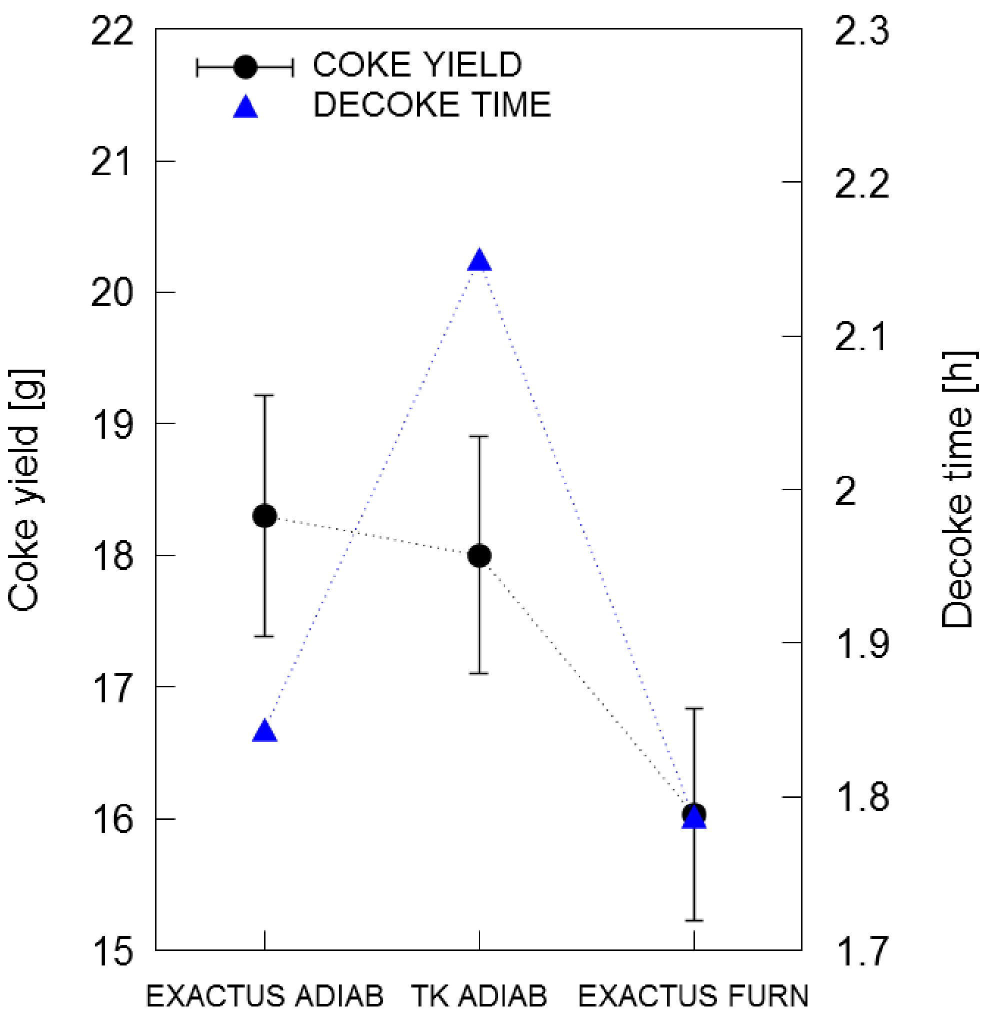
Experimental results: coke formation

Less coke in EXACTUS FURNACE case

Similar coke yields for ADIABATIC Cases

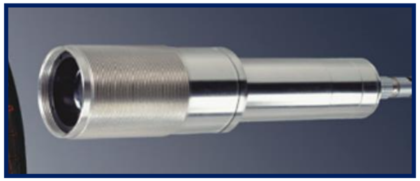
Similar decoke times for EXACTUS cases

Higher decoke time for TK ADIABATIC due to higher coke density



Conclusions

EXACTUS® optical thermometer is a viable alternative to traditional contact temperature measurements



- ✓ Higher measurement frequency
- ✓ Lower thermal drift
- ✓ High accuracy
- ✓ Measurement location can be changed during operation: potential for 'scanning' of the tube metal temperatures

Experiments at the LCT Pilot plant prove the applicability of EXACTUS® for furnace control

- ✓ Low spread on conversion over time compared to contact measurement
- ✓ Similar coke formation but less dense coke

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