Improved Temperature Measurement Techniques in Furnaces
(Bättre temperaturmätning i ugnar)

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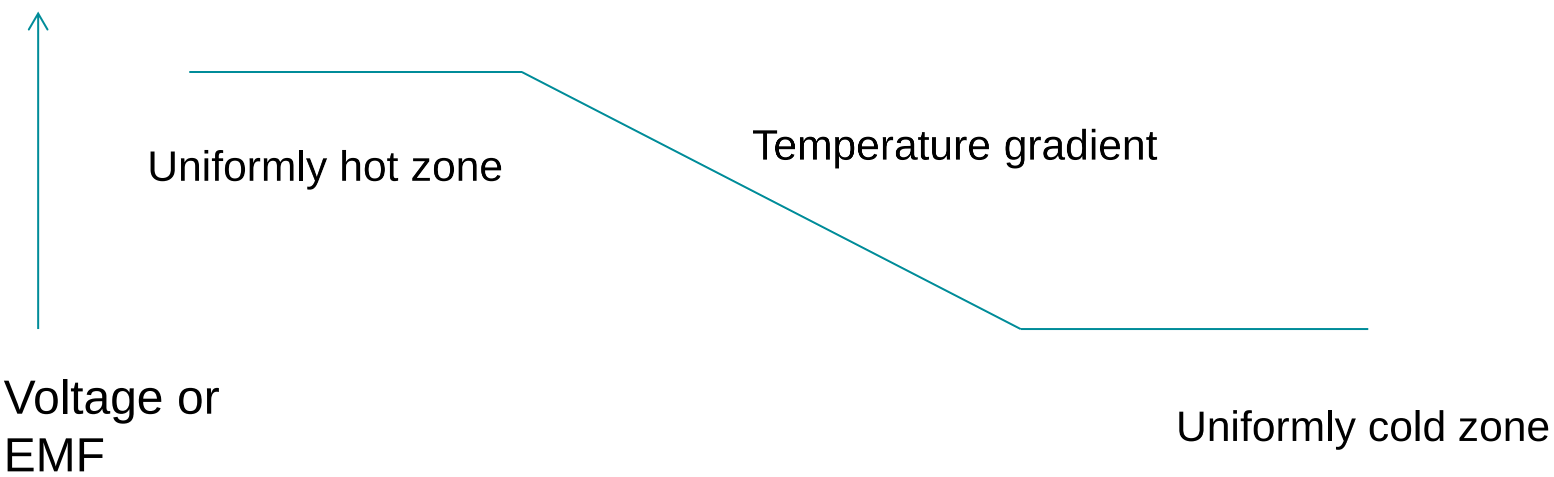
Outline of the Presention

1. Improving Contact Type Temperature Measurements -- Thermocouples
    1. Sources of temperature errors
    2. Methods to avoid temperature errors

2. Improving Non-contact Type Temperature Measurements -- IR Pyrometers
    1. Theory of IR pyrometers
    2. Swerea MEFOS trial with a radiation shield

Part 1. Thermocouple Operation

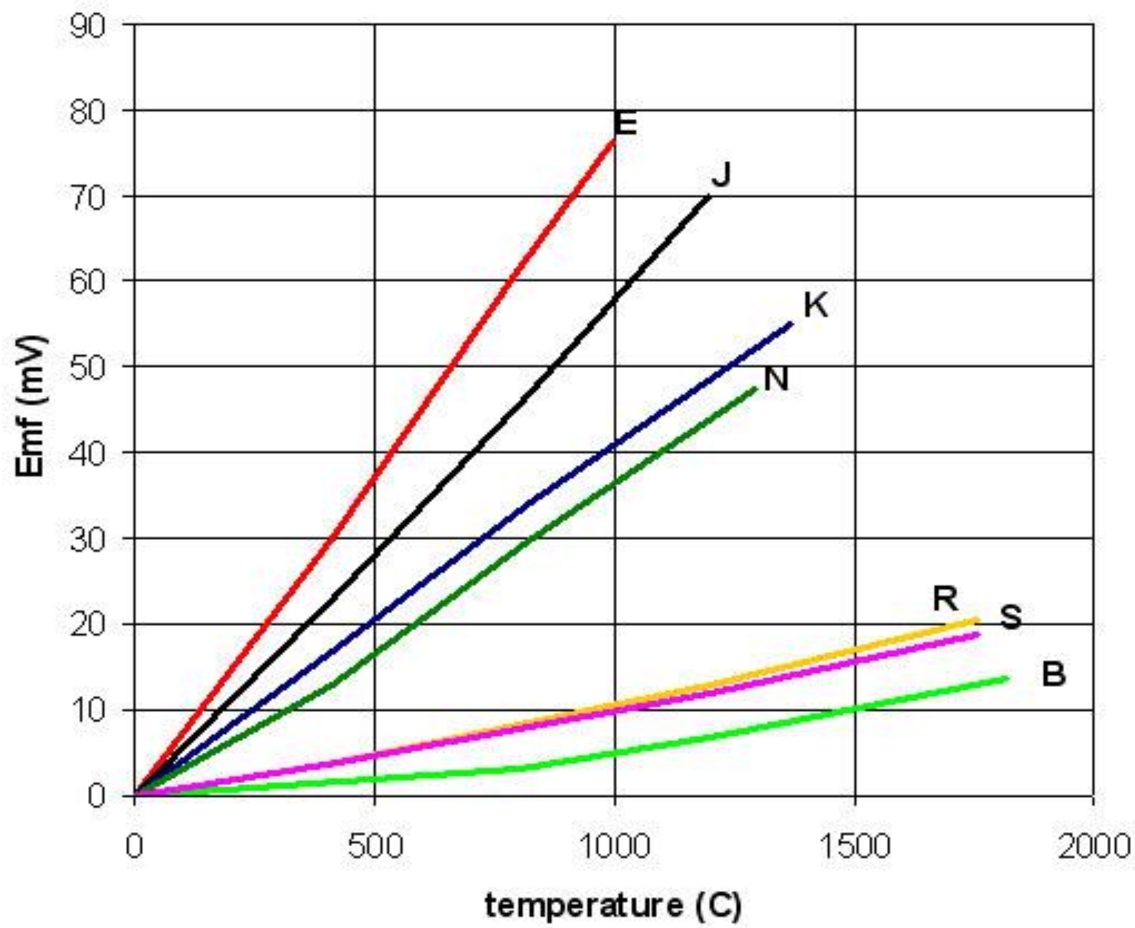
A thermocouple measures a voltage due to a temperature gradient along the length of two dissimilar metal wires which meet at the temperature sensing junction and measured at the cold junction— Therefore, the quality of the entire wire pair is important and the performance of the signal analyser at the cold junction.



http://www.advindsys.com/ApNotes/tcfundamentals.pdf

Thermocouple Voltages – Lower for Noble Metals

Type	Positive Wire	Negative Wire
Noble Metal		
B	Pt-30% Rh	Pt-6% Rh
R	Pt-13% Rh	Pt
S	Pt-10% Rh	Pt
Base Metal		
K	Ni-10% Cr	Ni-2%Mn, 2% Al
N	Ni-14%Cr-1.5%Si	Ni-4.4%Si-0.1% Mg
E	Ni-10% Cr	45%Ni-55% Cu
J	Fe	45%Ni-55% Cu

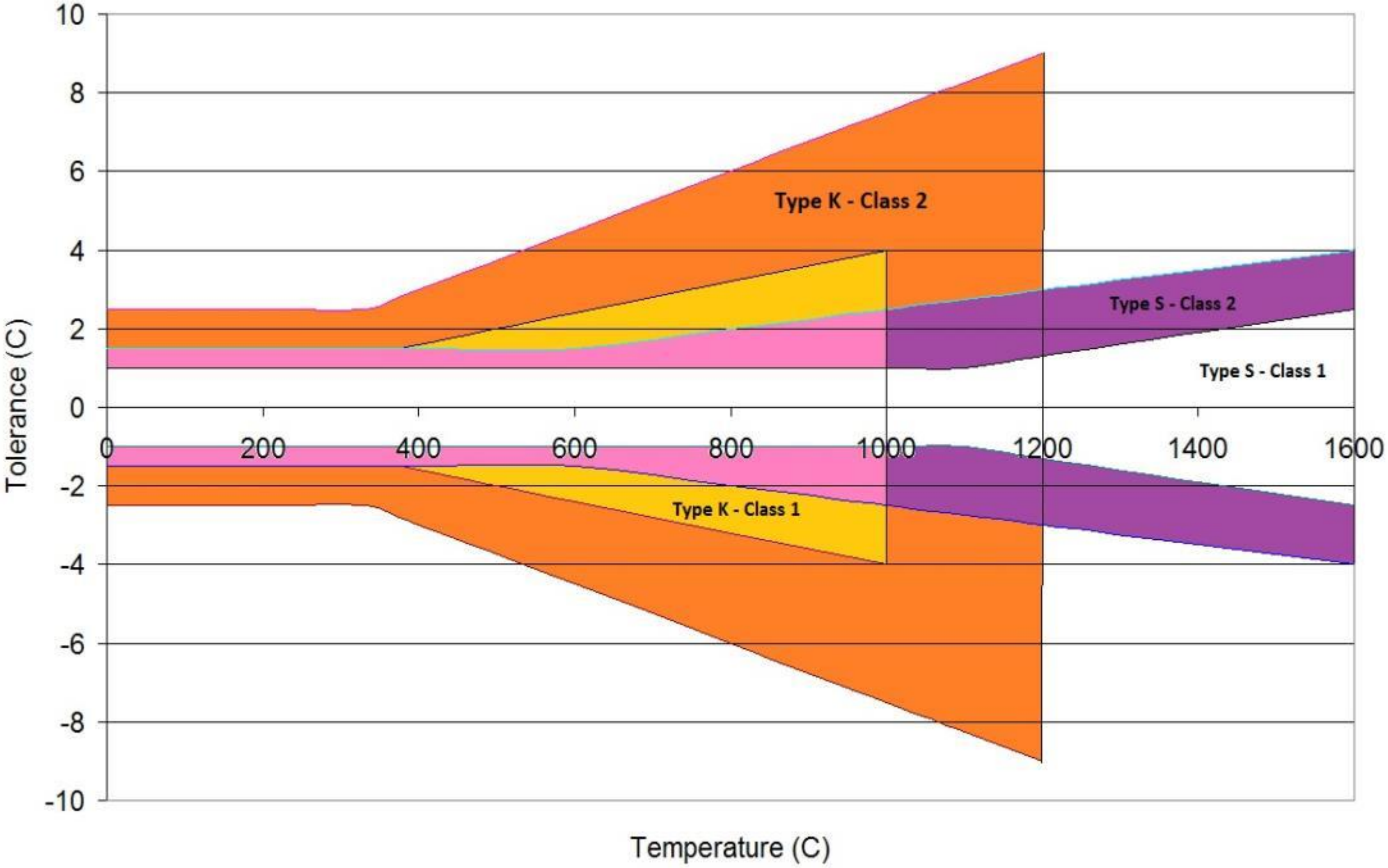


at: http://www.msm.cam.ac.uk/utc/thermocouple/pages/ThermocouplesOperatingPrinciples.html

Thermocouple Manufacturing Tolerances

Note: Tolerance for Type K and Type N are equal, likewise Type S and Type R, see IEC 60584:2013

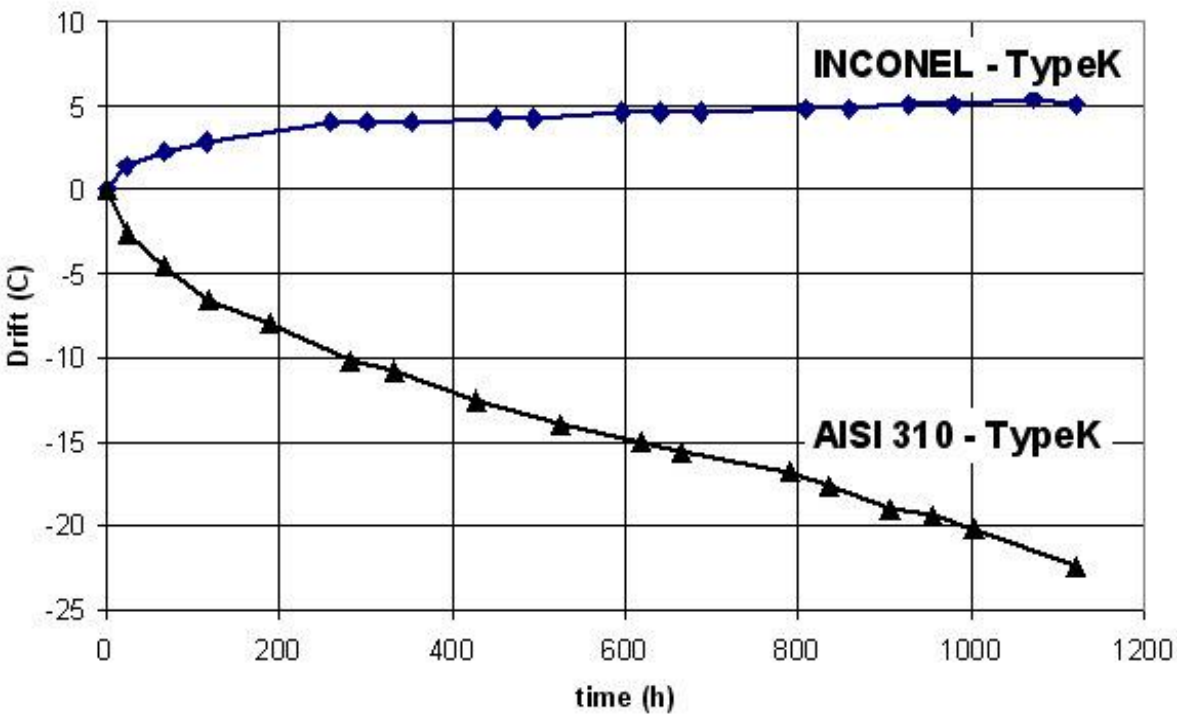
Calibration can reduce the measurement errors for individual thermocouples



Information at: http://www.pentronic.se

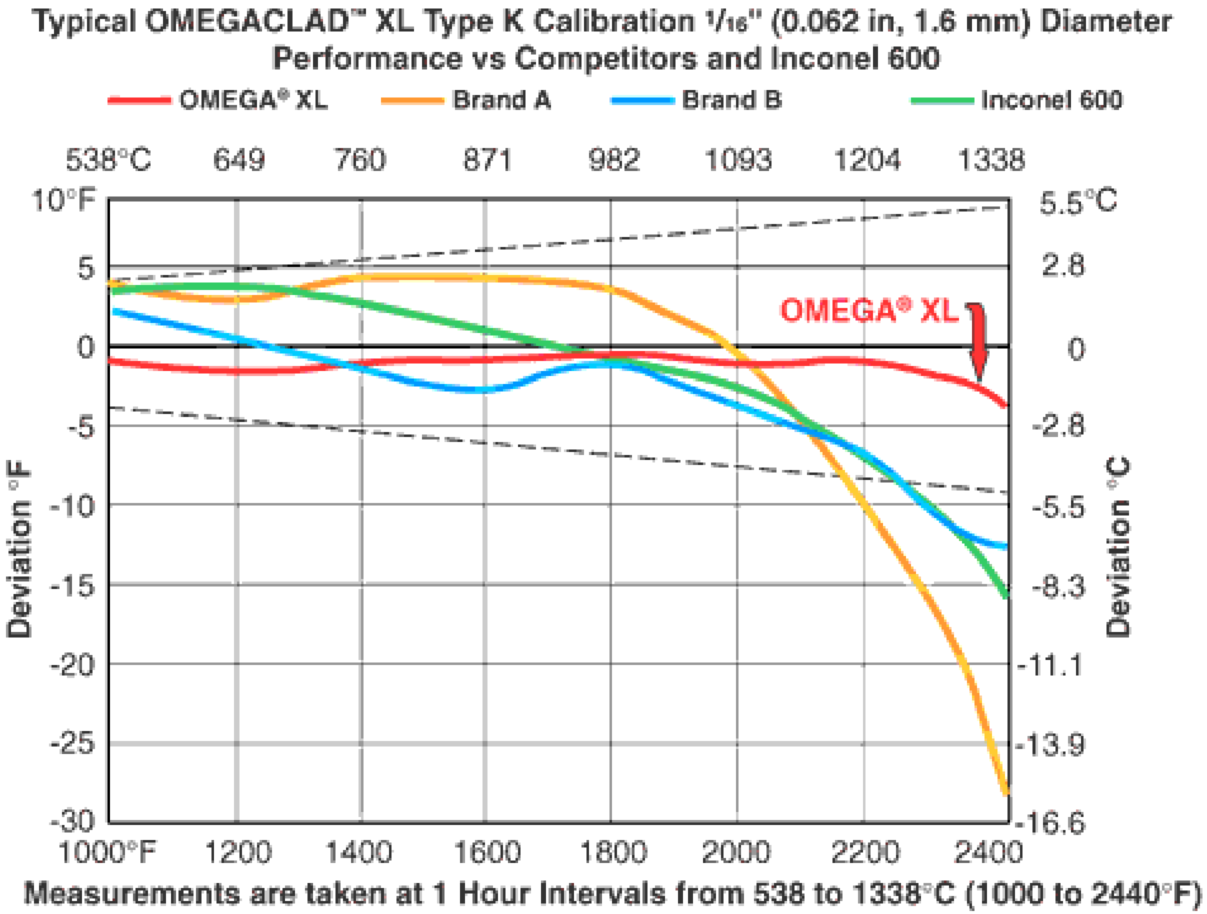
Thermocouple Drift – Effect of Shielding Tube

Conditions: T = 1200°C. 3 mm sheath
Mn in AISI 310 could be a source of contamination and temperature drift



[At: http://www.msm.cam.ac.uk/utc/thermocouple/pages/DriftInTypeKMIMSThermocouples.html quoting R.L. Anderson, et.al. ”Decalibration of sheathed thermocouple” in Temperature, vol 5, 1982.](http://www.msm.cam.ac.uk/utc/thermocouple/pages/DriftInTypeKMIMSThermocouples.html)

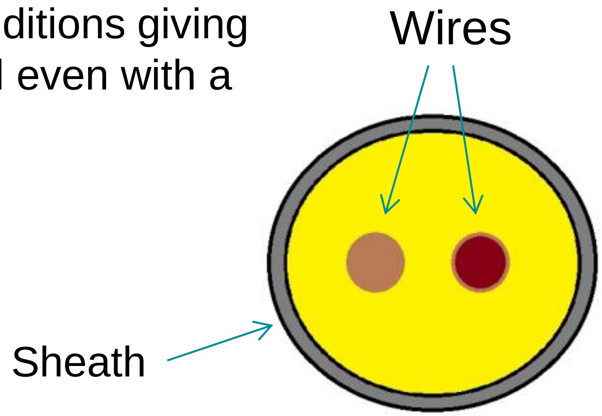
Effect of Sheathing on Type K Thermocouple Drift



at: http://www.omega.com/ppt/prodimages/OmegacladXL_Chart.gif

Problems with Type K Thermocouples

- Metallurgical instability in the 300-550°C range due to short range crystal lattice ordering (SRO) which returns to the disordered state above 550°C. Temperature errors of 3-8°C can arise*
- Mn in Type K thermocouples can contribute to internal oxidation at high temperatures
- Somewhat reducing conditions can cause the Chromel® wire to lose Cr and grow a green chromic oxide (Cr_2O_3 called ”green rot”) giving a negative drift (or low temperature readings).
- Oxidizing conditions can cause the Alumel® wire to oxidize faster than the Chromel® wire and cause a positive drift
- Type K thermocouples can absorb carbon with reducing conditions giving a negative drift especially with small wires (0.8 mm dia.) and even with a stainless steel sheath for T≥980°C*



* P.A. Kinzie, Thermocouple temperature measurement, Wiley, 1973.

** Photo from: http://www.resourcechemical.co.uk/pics/chromic%20oxide.jpg

Thermocouple Monitoring Systems

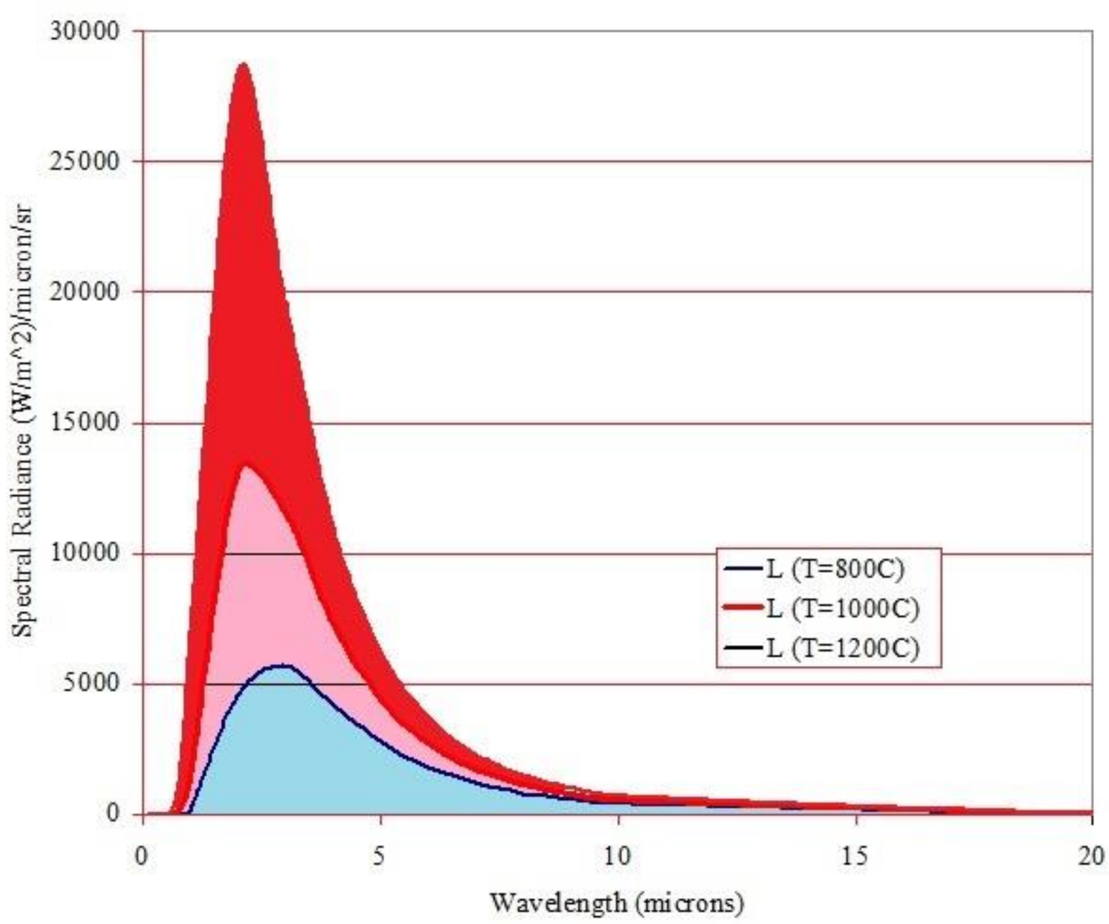
- TESS “Temperature Estimation and Supervision System” (PREVAS*) is a statistical software tool to insure all temperature measurements are functioning properly when using the signals in the furnace control system.
- Multiple thermocouple signals can be compared with each other and their statistical performance history
- A thermocouple error alarm can warn the furnace operator when the temperature signals deviate significantly from their historical performance.
- Reduces the cost of routine thermocouple replacement, since thermocouple monitoring can detect a failed thermocouple to replace them as required, instead of replacement after a fixed period in operation.
- Systems have successfully been installed in the steel industry at SSAB and Outokumpu Stainless

* TESS from PREVAS: http://www.metal-supply.se/article/view/91862/prevas_och_stalindustrin_minskar_energiforbrukningen

Summary:
Improving Thermocouple Measurements

- Select High Quality Thermocouples
  - Choose suitable thermocouple temperature range, tolerance class and calibration for the application, for example,Type S can be used at higher temperatures than Type N
  - Type N thermocouples are recommended instead of Type K thermocouples whenever possible
- Select Suitable Sheath Material
  - Ceramic sheaths should be used for noble metal thermocouples at high temperatures
  - Use compatible metal alloy sheaths or Ni based alloys as Inconel for Type K and N thermocouples
- Control oxidation and contamination of the thermocouple wires
  - Larger diameter thermocouple wires can have longer useful lives at high temperatures
  - Use shielding sheaths and avoid temperatures above the max. operational temperature
- Monitor and Replace Aged Thermocouples
  - Aging and contamination can occur along the length of the thermocouple so replacement is recommended for long wires when recalibrating is difficult
  - A thermocouple monitoring system like TESS can be useful

Part 2. IR Pyrometers
Radiation Pyrometry Theory



Radiance $L(\lambda,T)$ can be calculated using Plancks or Wiens law

The emissivity and reflectivity sum to 1 for metal surfaces:

$$\varepsilon_s + \rho_s = 1$$

A spectral radiance signal model for pyrometers is*:

$$\varepsilon_{pyro} S(T_{pyro}) =$$

$$\varepsilon_s \; S(T_{target}) + (1-\varepsilon_s) \; S(T_{wall})$$

* Radiation Thermometry, Peter Saunders, SPIE vol. TT78, 2007

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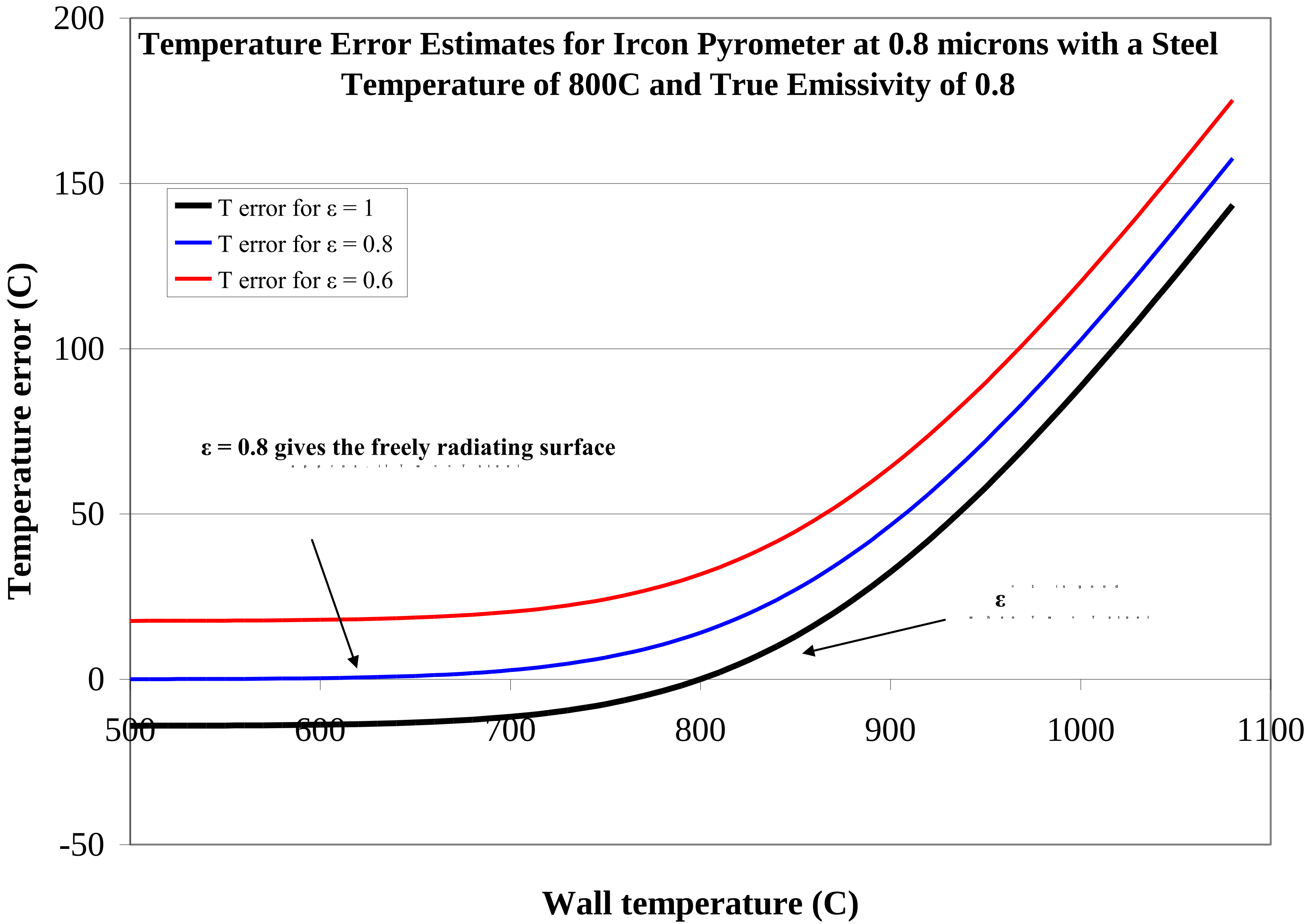
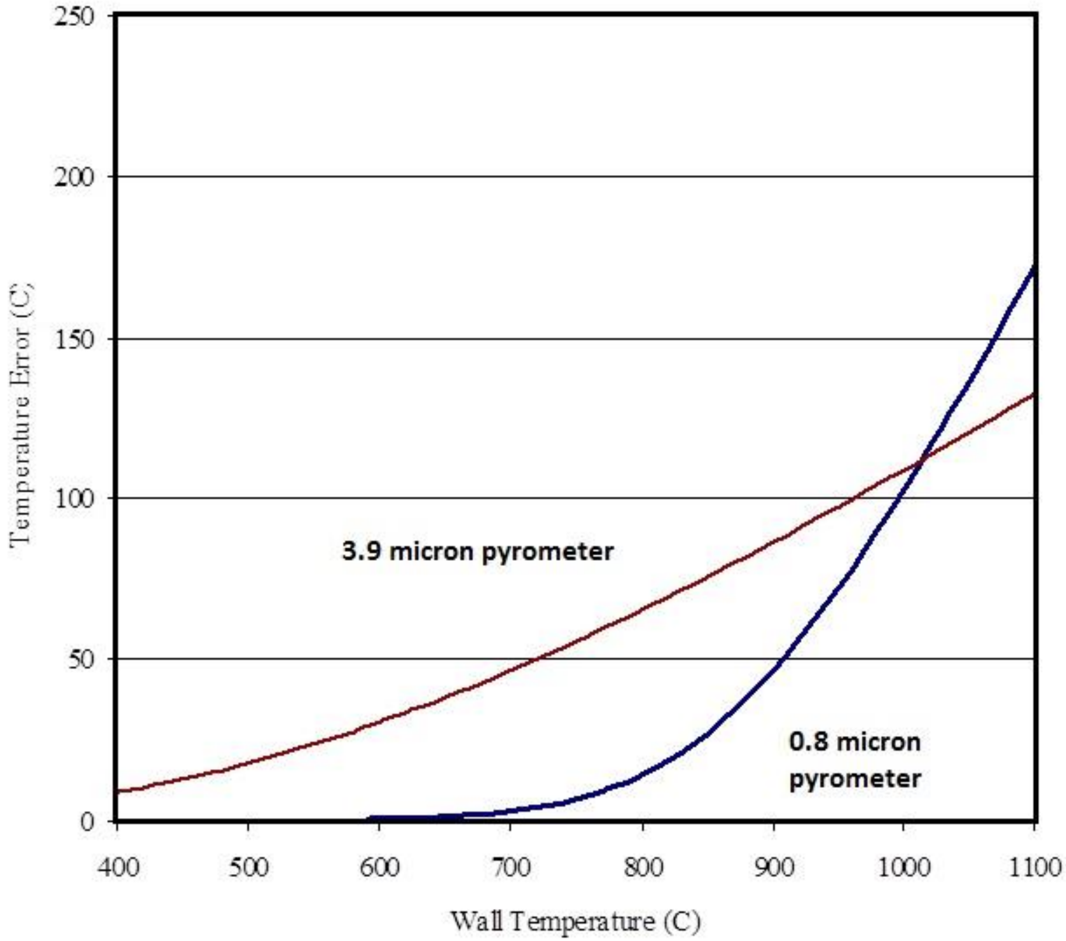


Temperature Error Estimates for Ircon Pyrometer at 0.8 microns with a Steel Temperature of 800C and True Emissivity of 0.8
T error for ε = 1
T error for ε = 0.8
T error for ε = 0.6
ε = 0.8 gives the freely radiating surface
ε
Temperature error (C)
Wall temperature (C)
200
150
100
50
0
-50
500
600
700
800
900
1000
1100

Temperature Errors for Two Different Pyrometer Wavelengths Due to Wall Radiation for a Surface Emissivity of 0.8



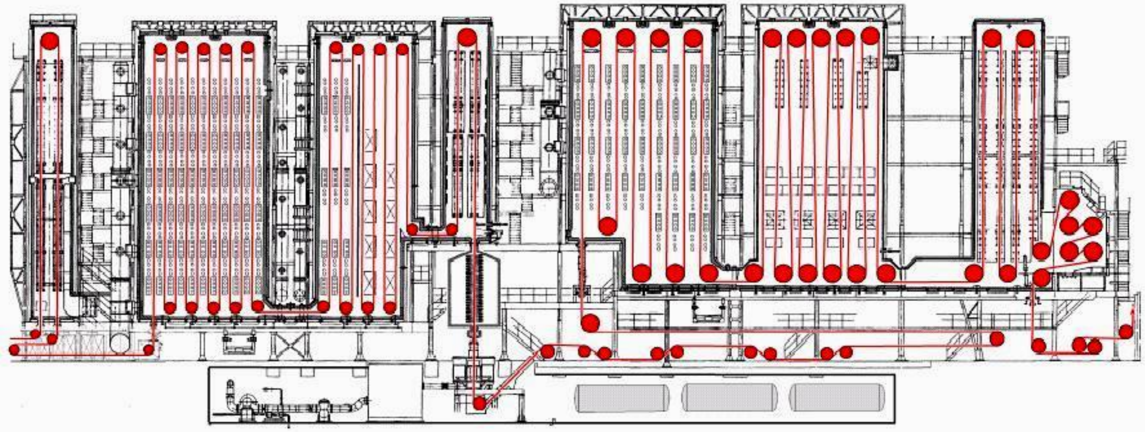
Conclusion:
The temperature of the surroundings should be less than the target to avoid problems with stray furnace radiation for both IR wavelengths but a pyrometer at 3.9 microns has a more linear response.

IR Pyrometers in a Continous Annealing Furnace

- The temperature of a steel strip moving through an annealing furnace is desired
- Normally strip temperatures can be measured for the strip in a roll gap when the emissivity factor of 1 can be assumed
- A contact gold cup pyrometer is unsuitable for a moving strip

Capacity 500,000 t/a
Max. furnace temperature 950° C
Protective gas (atmosphere) 5% H_2 and 95% N_2

Maximum speed in the GJC 180 m/min
Strip width 600-1,550 mm
Strip thickness 0.35-2.2 mm



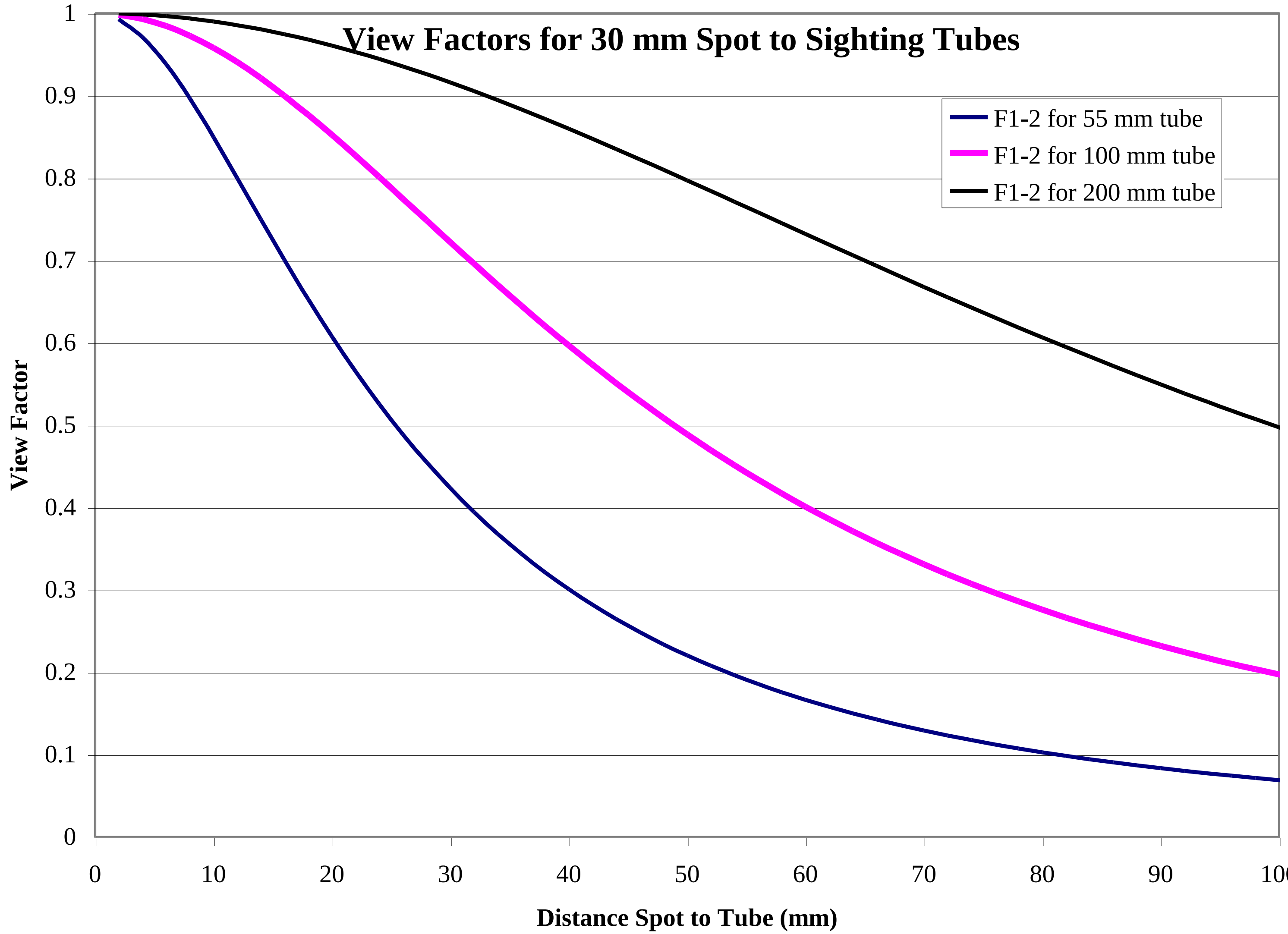
http://www.andritz.com/me-reference-ssab-cal.pdf

Challenge: Investigate a Radiation Shield to Reduce Stray Furnace Radiation

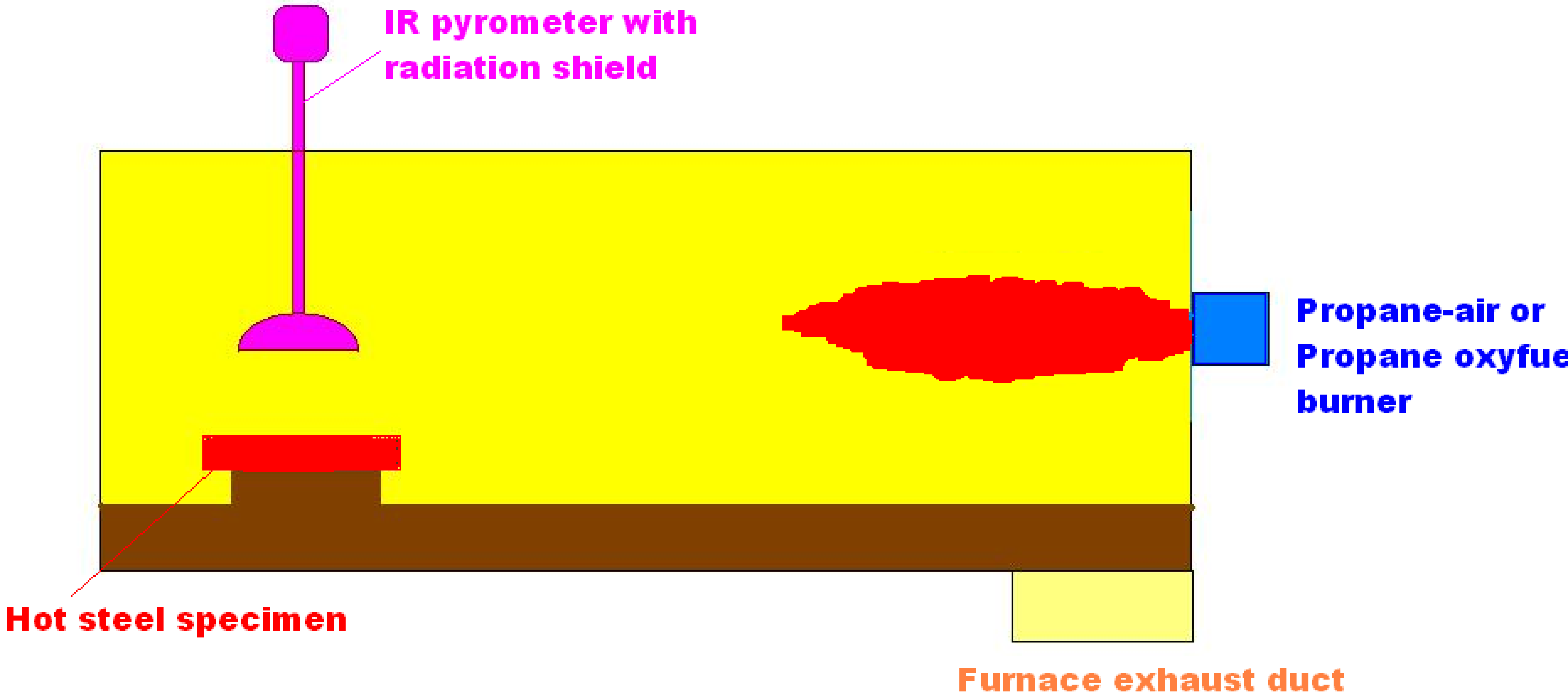
Swerea MEFOS Chamber Furnace :

- Conventional air burners for light fuel oil or propane
- ABB Furnace temperature control system
- Automatic excess oxygen control with zirconia sensor
- Hole in the furnace ceiling to measure with a radiation shield above a steel plate

Use of Radiation Shields—View Factor



A Sketch of the Position of the Pyrometer Relative to the Burner



Two designs for radiation shields

Ceramic radiation shield

Metal shield

The Metal Radiation Shield Shown Above the Steel Target

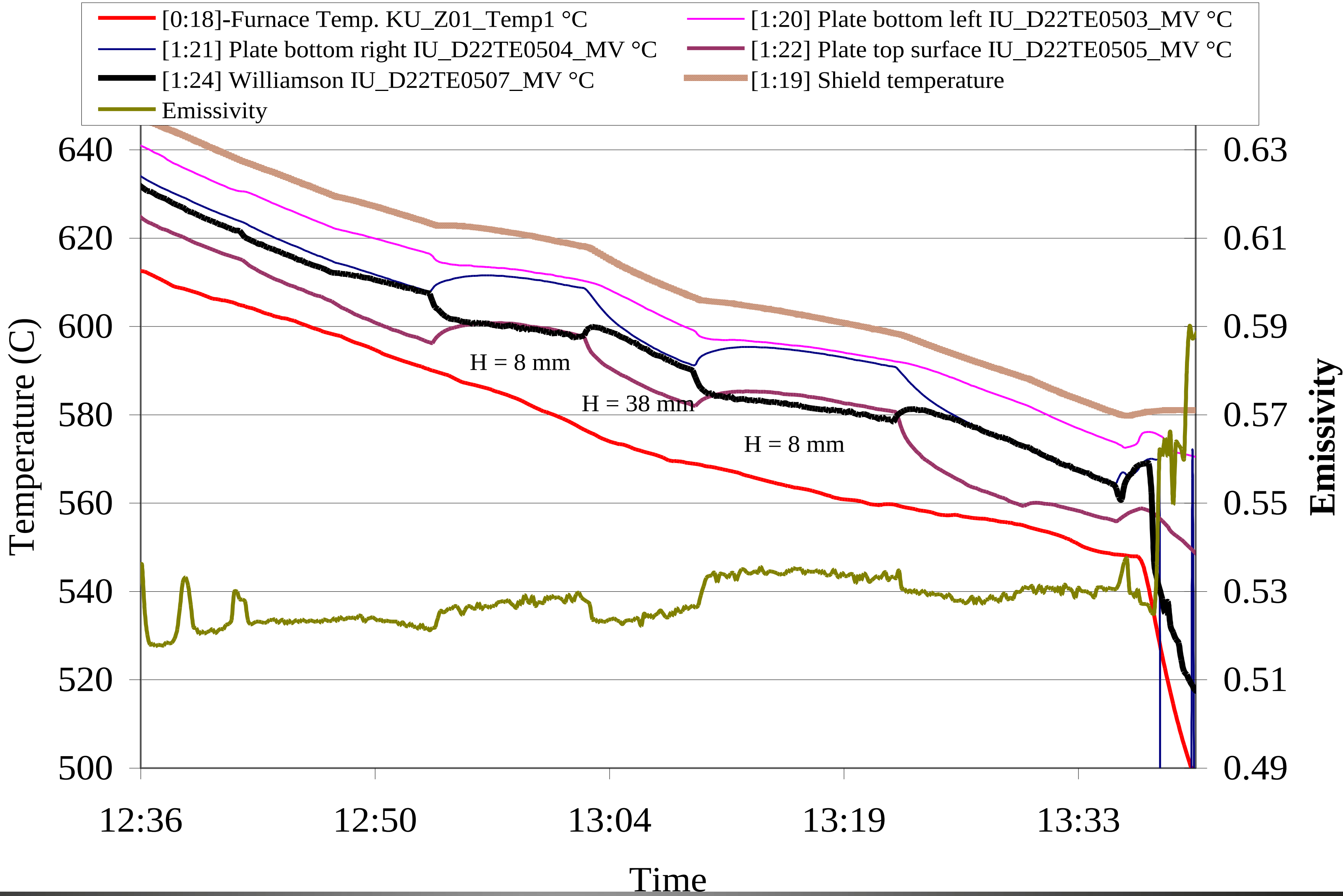
A ceramic radiation shield in the chamber furnace

IR Pyrometer Specifications

Parameter	Williamson [*] PRO 81-20-C-FOV3M/100-23D-40C
1. Temperature range	475-1750°C
2. Wavelength (µm)	2 wavelengths near 1.5 µm (Datasheet)
3. Features	dual wavelength emissivity compensation
4. Accuracy	0.25% of reading or 2°C

*

Temperatures Using the Ceramic Radiation Shield



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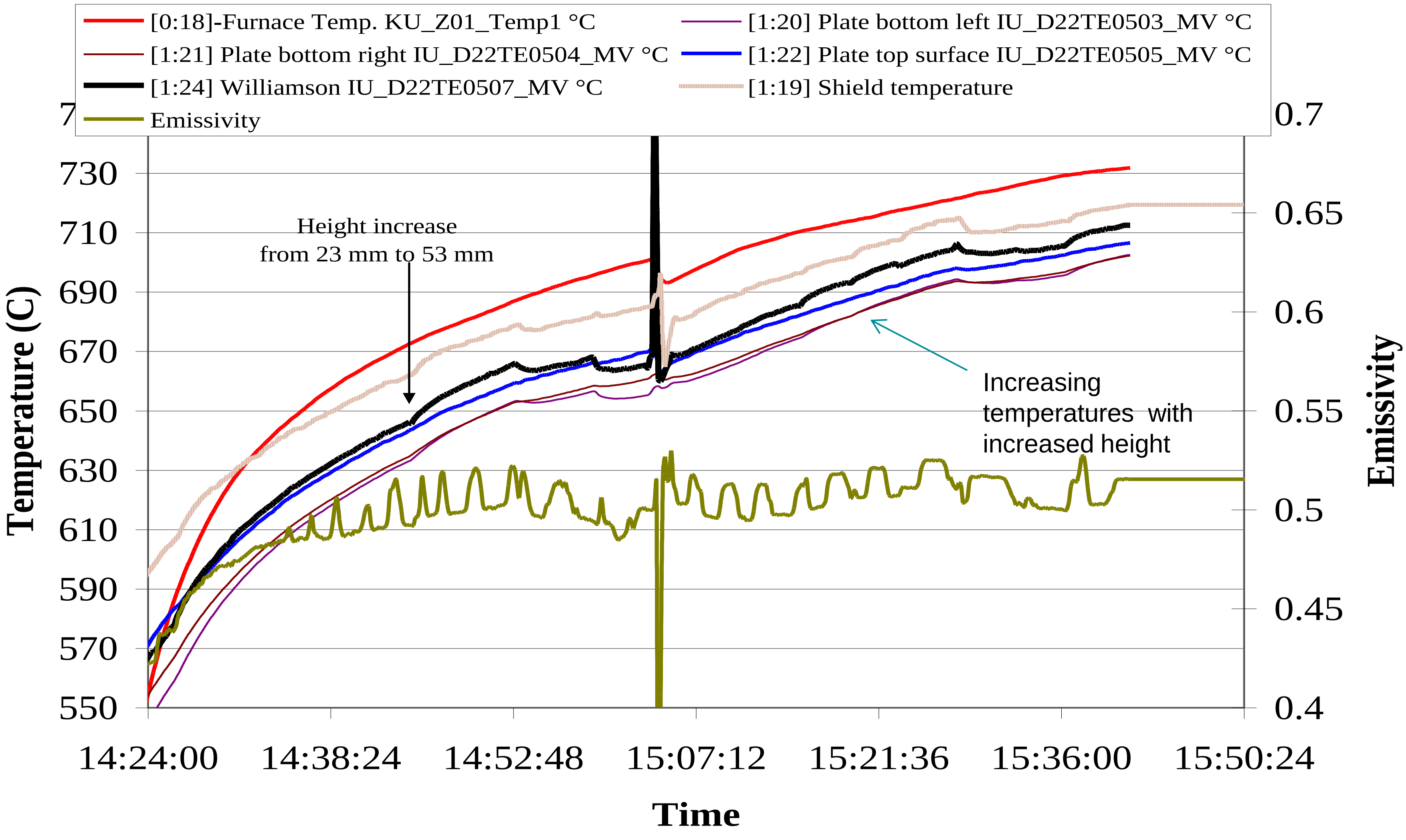
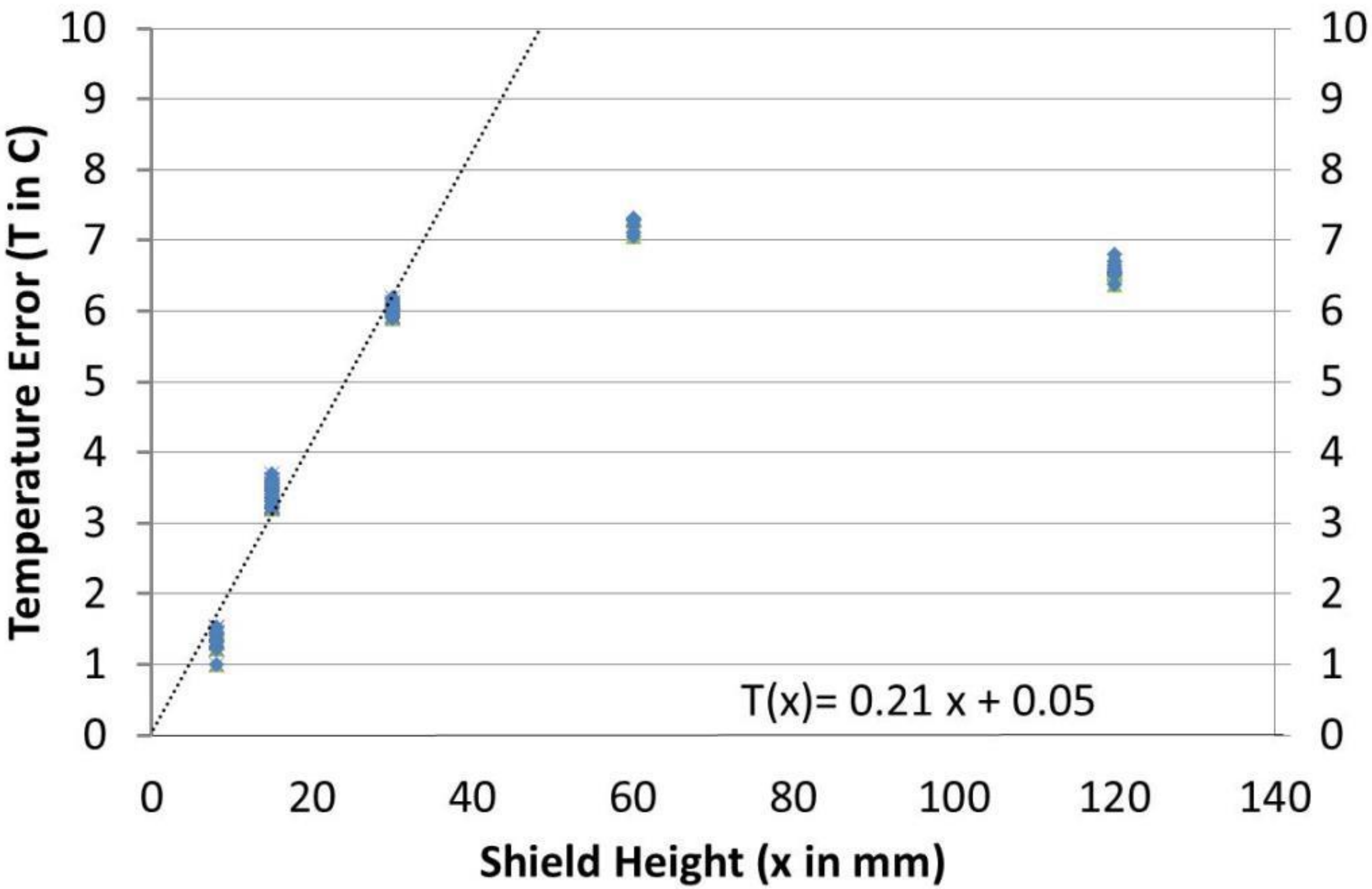
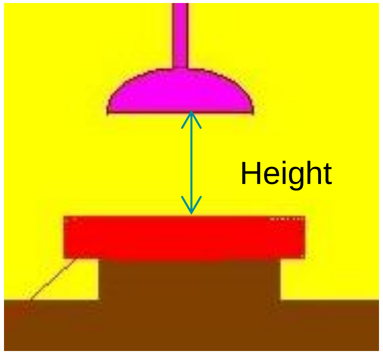
Temperatures Using the Metal Radiation Shield



Extrapolation of Pyrometer Temperature Error versus Shield Height





Reference: J. Niska and A. Rensgard, ”Improved IR pyrometry in Furnaces using a Radiation Shield”, IFRF Swedish-Finnish Flame Days conference, Piteå, 2011.

Summary: Using IR Pyrometer in Furnaces

- Longer wavelength 3.9 micron pyrometers are preferable for use in furnaces with an emissivity setting obtained from surface temperature calibration trials
- A radiation shield can be used to control or minimize the influence of furnace radiation on the temperature measurements
- A large diameter shield close to the surface minimizes interference from furnace radiation
- Temperature data can be extrapolated to a radiation shield height of zero to improve accuracy

Thank you for your attention!

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