FEM Supported Thermal Insulation Tube Testing Instrument Design

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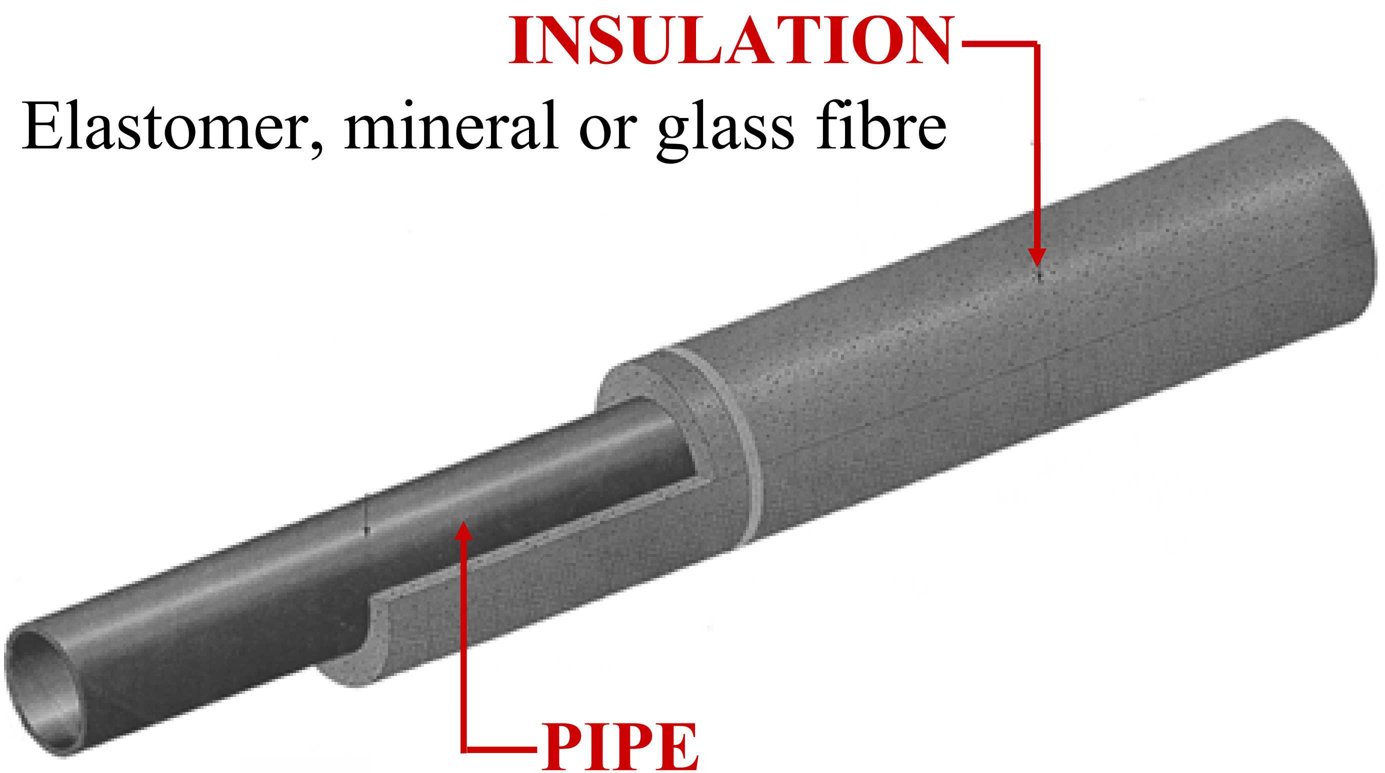
Thermal Insulation Tubes



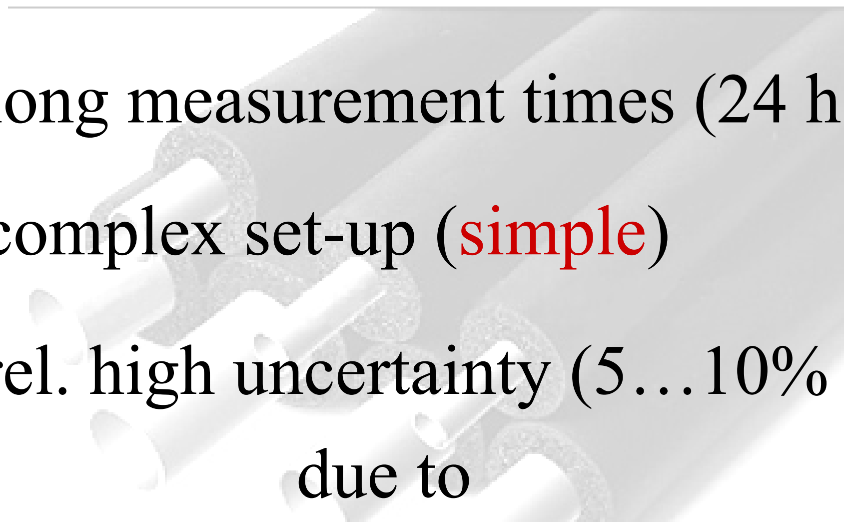
retard heat gain from chilled water of refrigeration system

reduce heat loss for hot water plumbing

⇒ λ (tube) should be as small as possible

TIT Testing Instruments
WHY to design a new instrument ?

Commercially available instruments suffer from



- ☹ long measurement times (24 h / 3 h)
- ☹ complex set-up (simple)
- ☹ rel. high uncertainty (5…10% / 3…5%)

due to

the so-called „end-effect"

Contents

TIT Testing Instruments principle of measurement

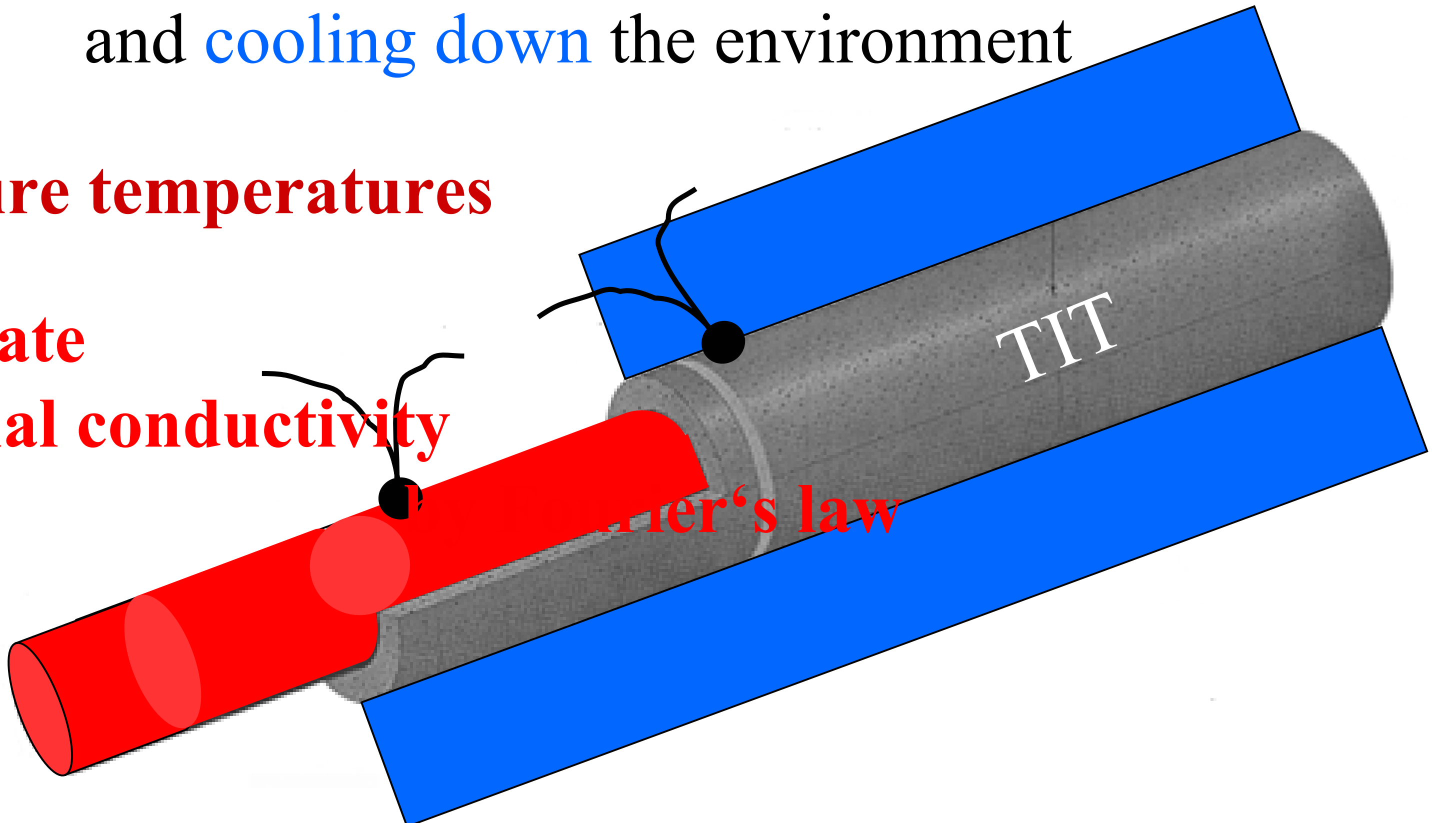
How to

establish a defined rate of heat flow across a TIT ?

by heating up the cylindrical core
and cooling down the environment

measure temperatures

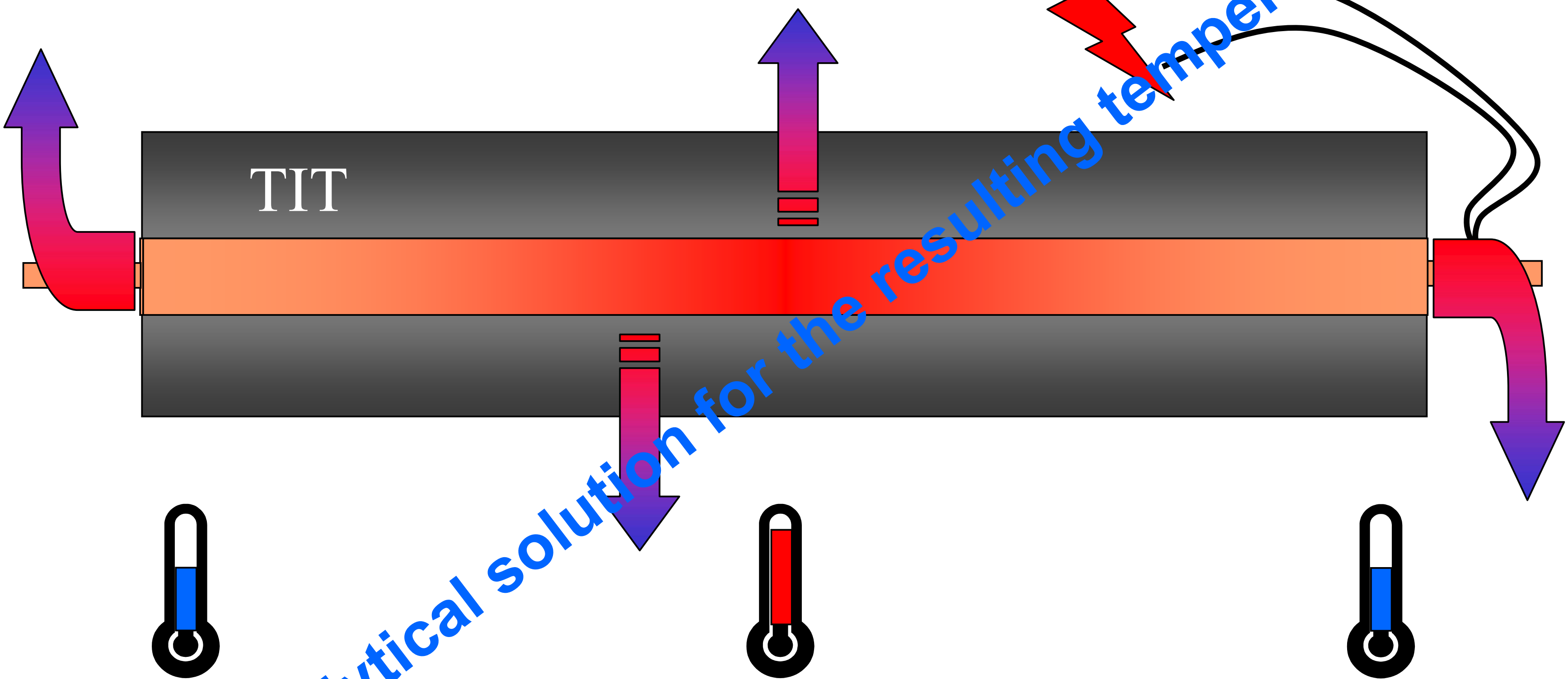
calculate
thermal conductivity



rier's law

TIT Testing Instruments

Test Tube

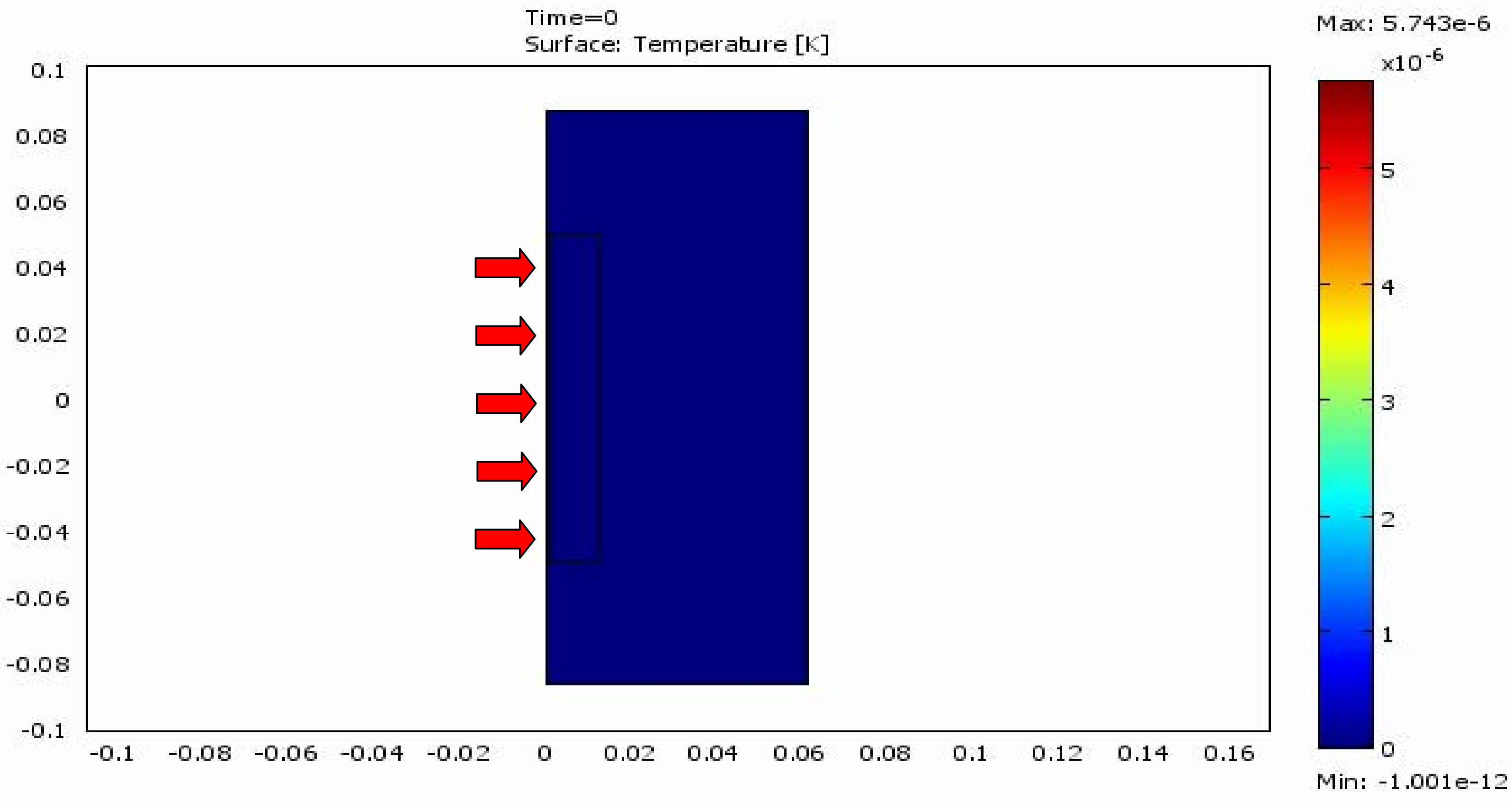


End-effect of cylindrical heaters
disturbs uniform temperature profile

there is no analytical solution for the resulting temperature profile

TIT Testing Instruments

Test Tube / Isotherms



TIT Testing I...

there is no

analytical solu...

to this problem...

No pain – no gain

...lations

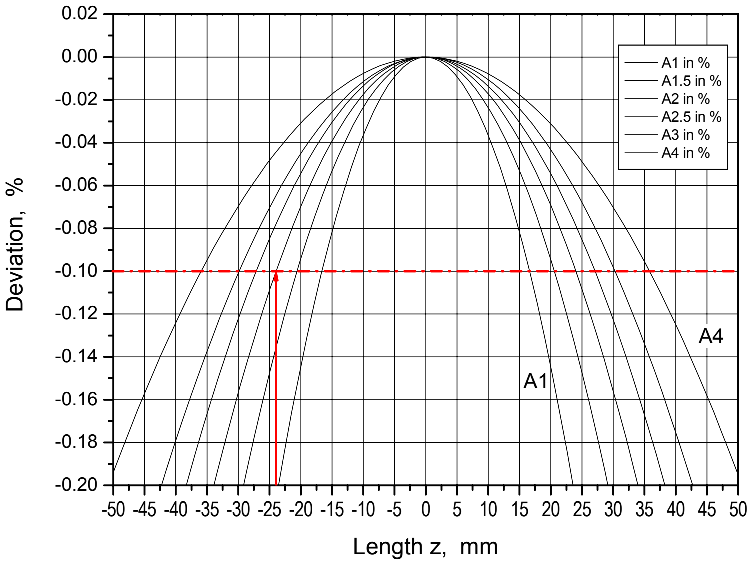
...eters

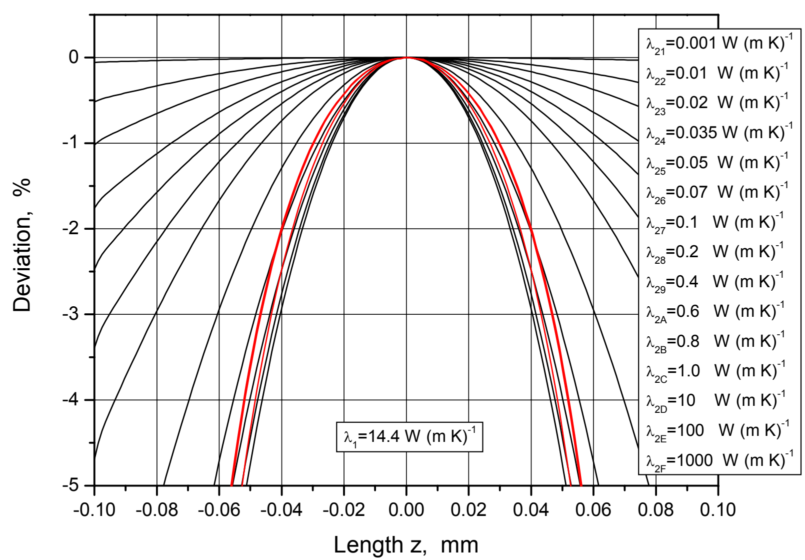
...al solution

...ly

Calculate the temperature profile
on the lateral surface of an embedded cylinder
while heated from longitudinal axis

$$\frac{T(z,t) - T(z=0,t)}{T(z=0,t)} = B_2(A, \lambda_2)\, z^2$$





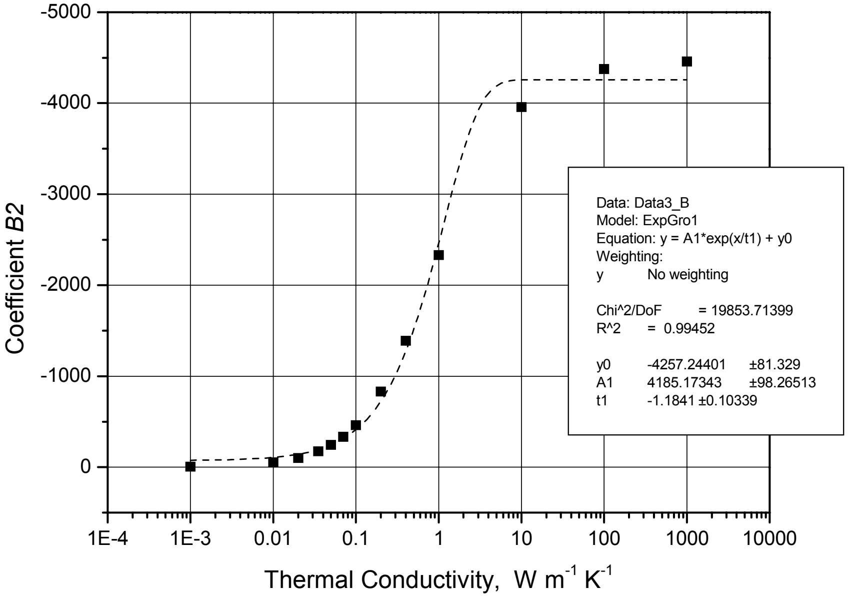
A: aspect ratio of cylinder length z to radius

λ_1: thermal cond. of test tube

λ_2: thermal cond. of sample (TIT)

TIT Testing Instruments
FEM-Results

$$\frac{T(z,t)-T(z=0,t)}{T(z=0,t)} = B_2(A,\lambda_2)\,z^2$$



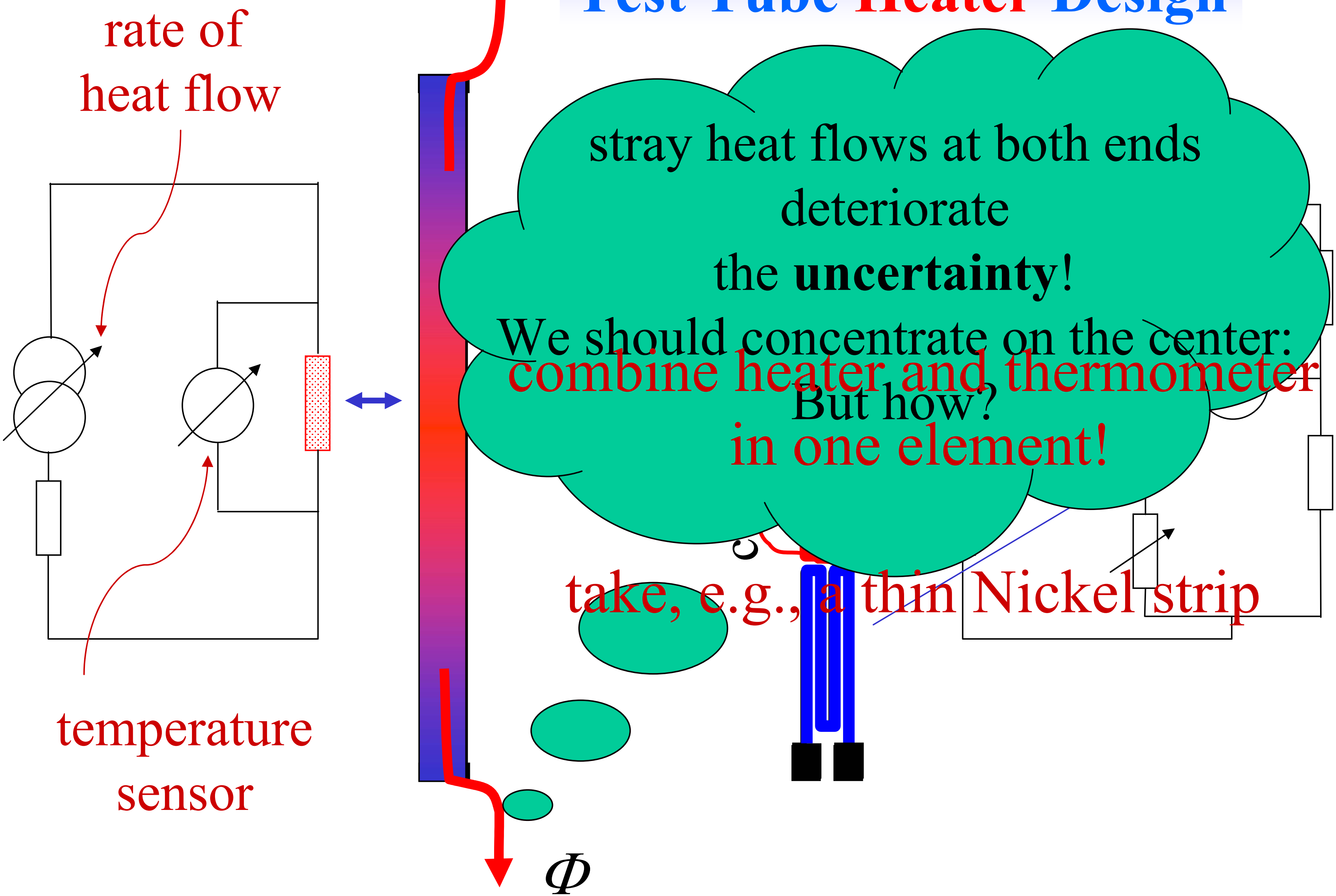
of thermal insulation tube

Design Criteria for dev(*T*) < 0.1%

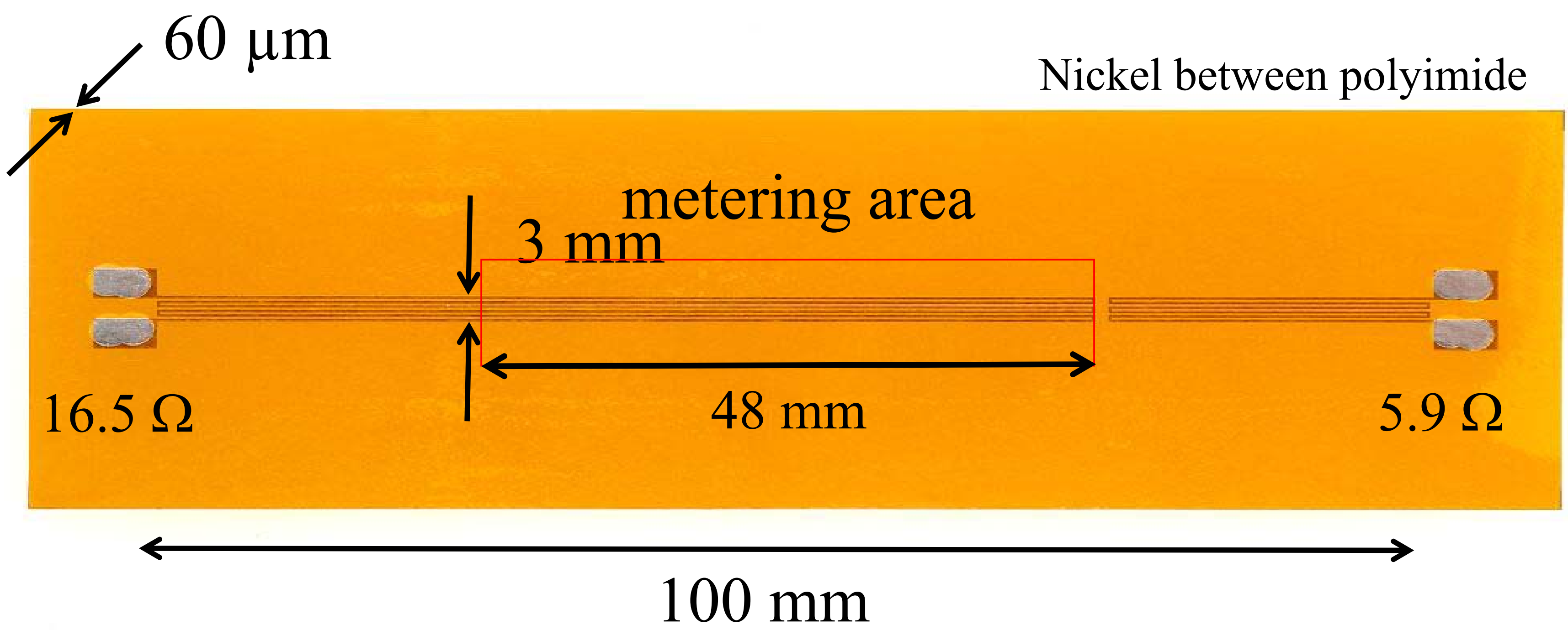
cylinder: A = A2 (L = 100 mm, r = 9 mm)

metering area length: l = 2 x 24 mm

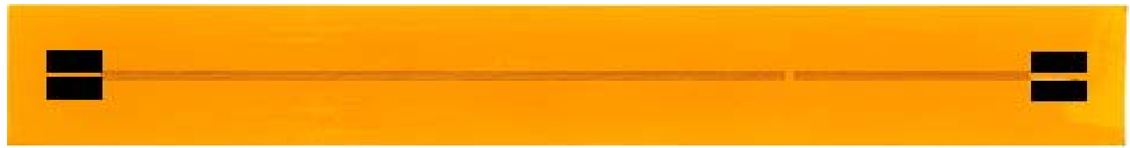
Test Tube Heater Design

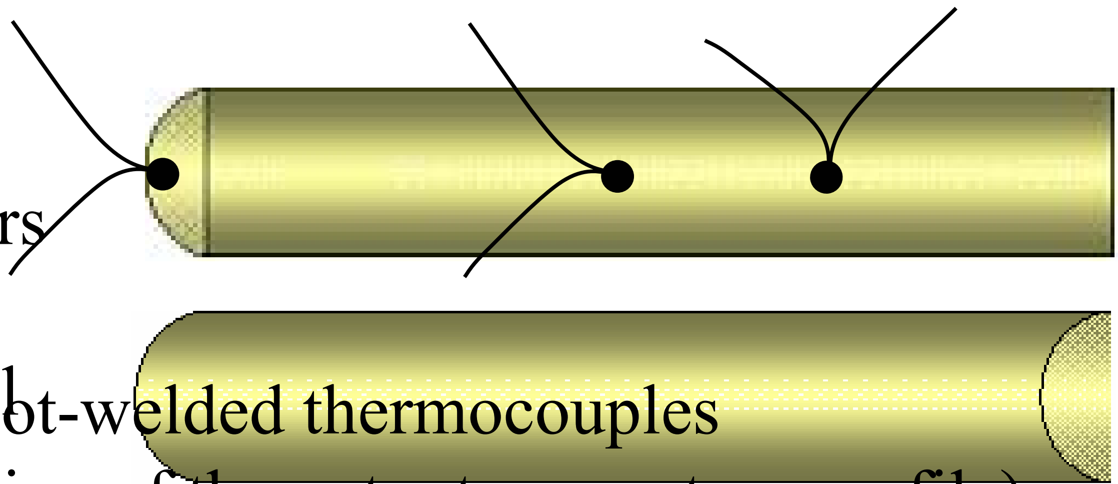


Test Tube Heater Design: Tandem Strip

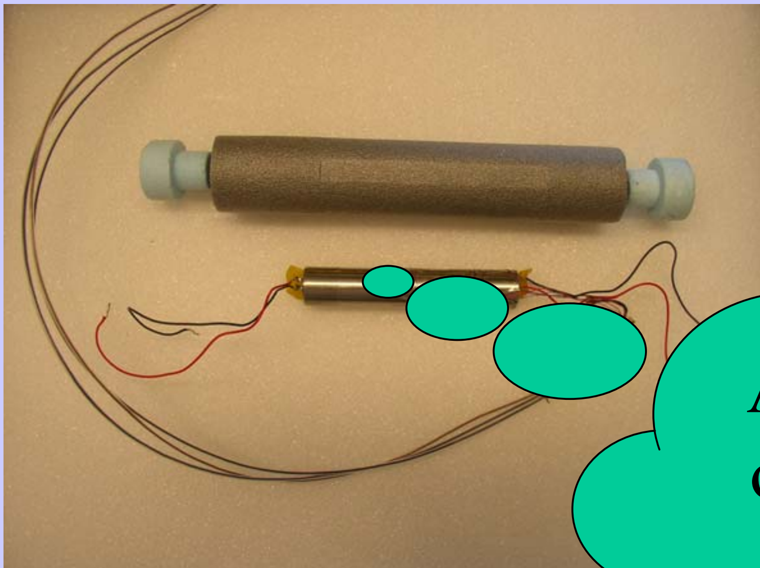


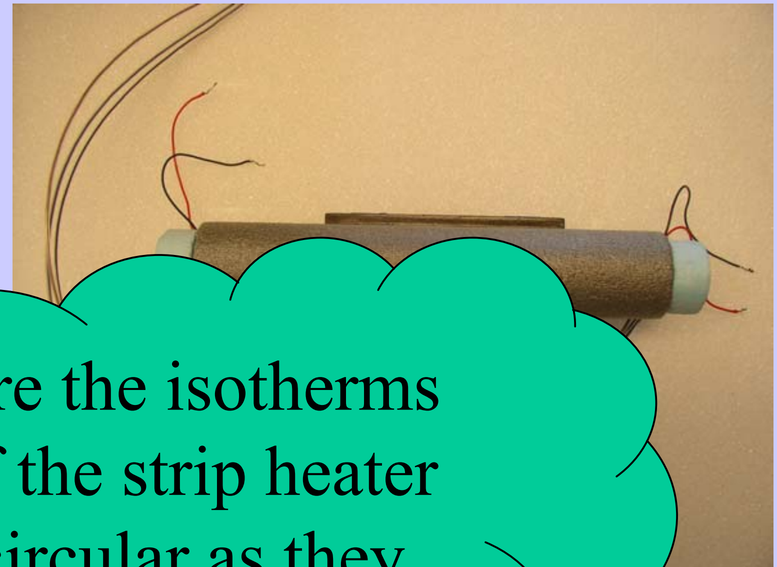
Test Tube Heater Design: Assembling of Sensor





Tube test sensor → **sample preparation**

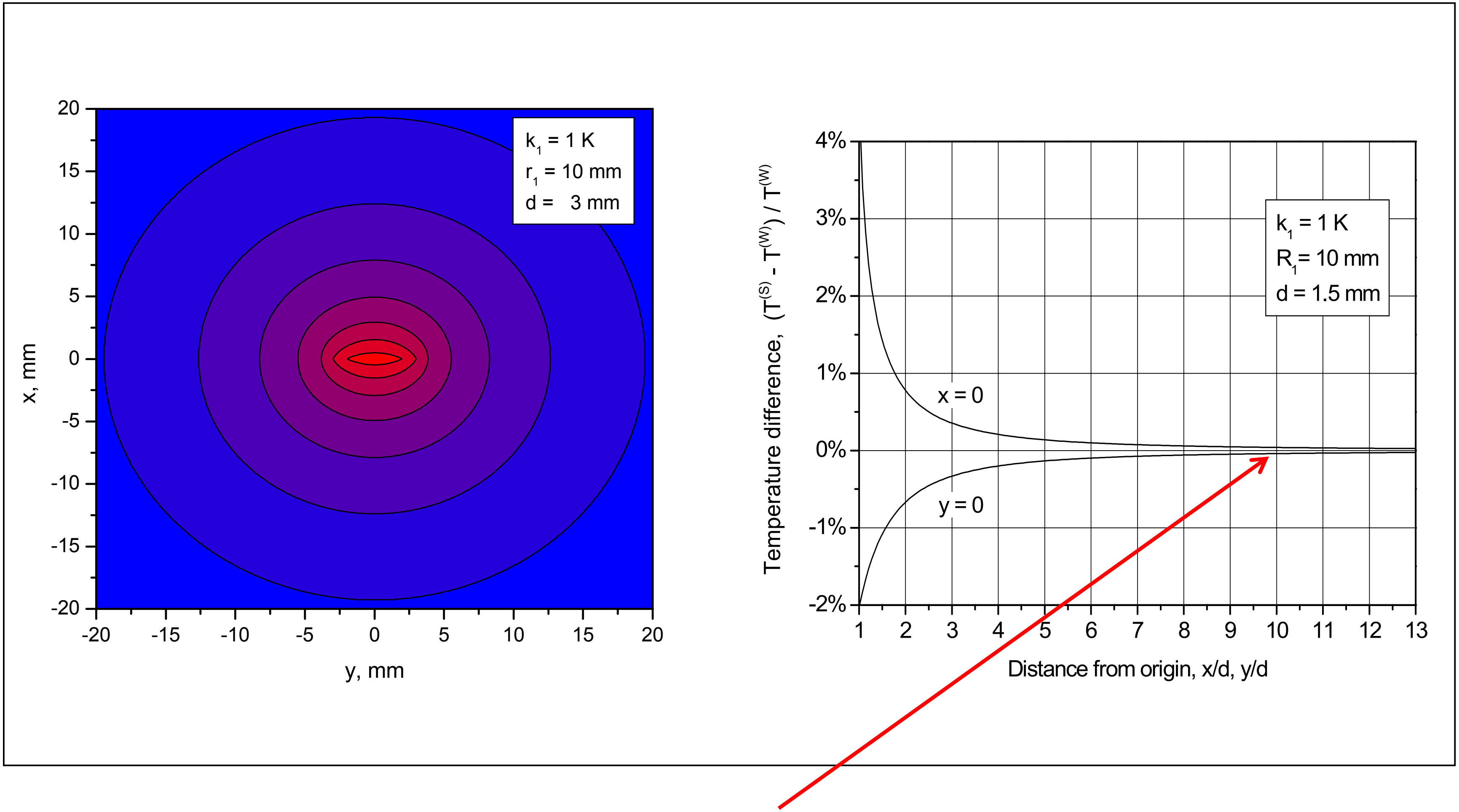




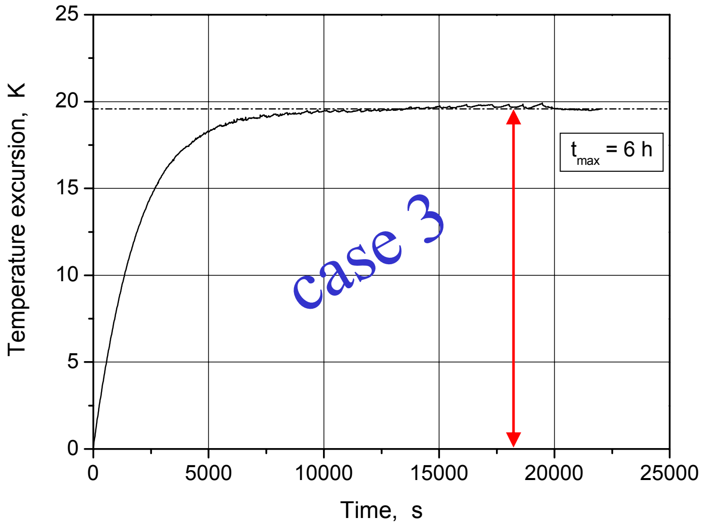
Are the isotherms of the strip heater circular as they must be?

how it rea

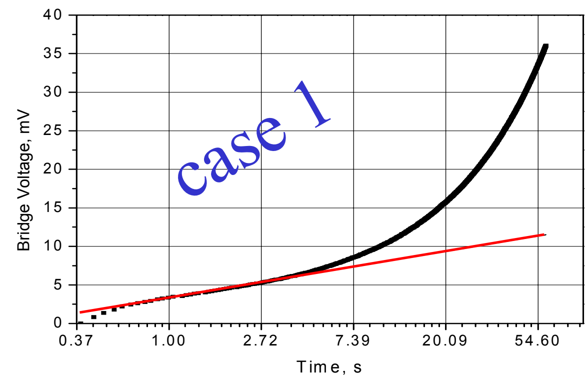
Tube Test Sensor → theory



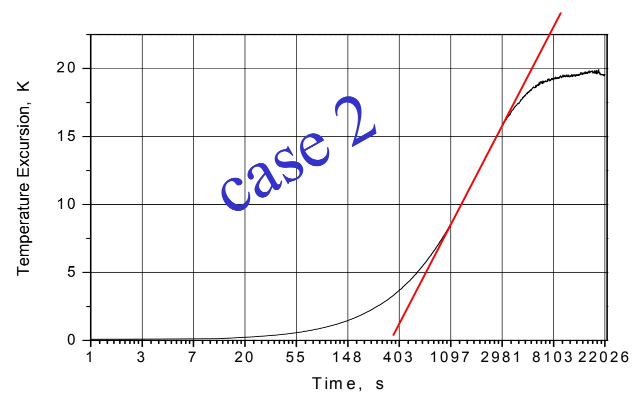
Tube Test Sensor → proof - of - concept test



tube thermal insulation



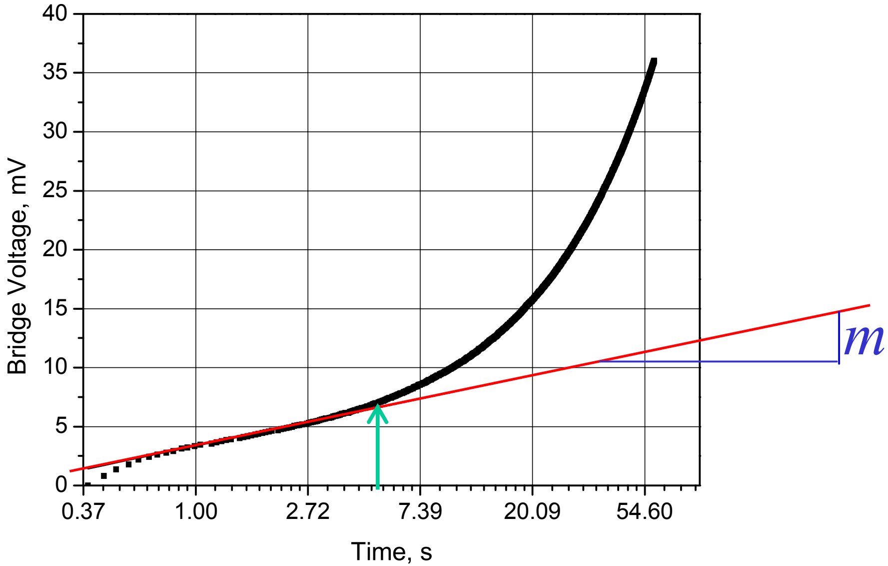
stainless steel



tube thermal insulation

Tube Test Sensor → working equations – case 1

case 1: this is a (well-understood) transient hot strip measurement



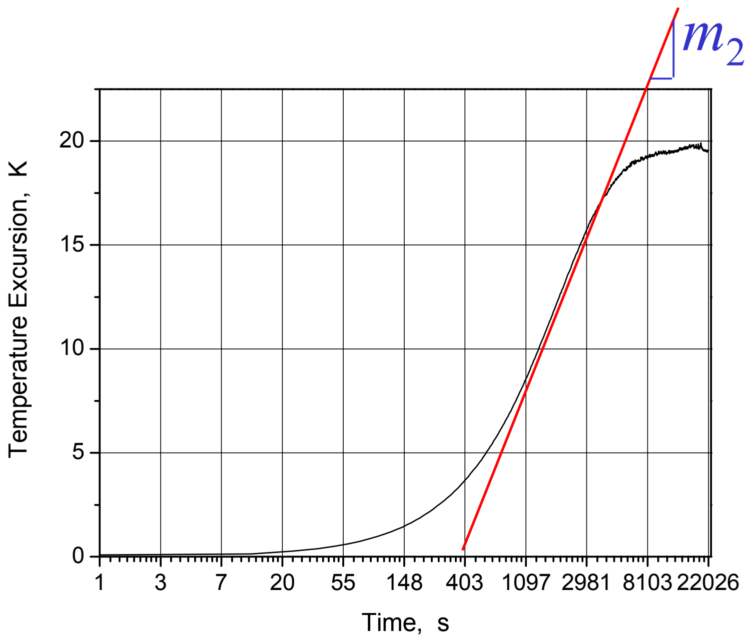
stainless steel: 1.4301

$$\lambda = \frac{\alpha R_0^2 I^3}{4\pi L \boxed{m}}$$

$$\boxed{t_{\max}} \le 0.18 \frac{R^2}{a} \approx 4\,\mathrm{s}$$

$$\lambda = 14.4\ \mathrm{W m^{-1} K^{-1}} \pm 3\%$$

case 2: this again is a transient hot strip measurement



thermal insulation tube

$$\lambda = \frac{\alpha R_0^2 I^3}{4\pi L m}$$

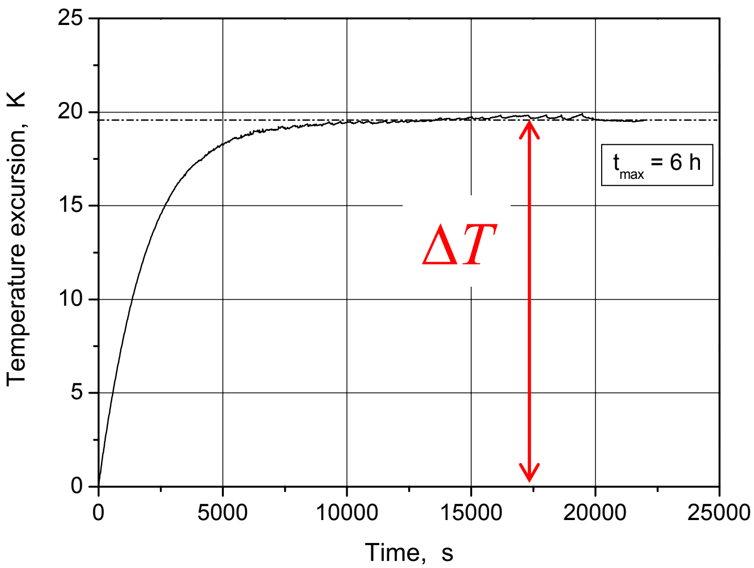
…but…

…due to limits in theory there is no solution for a second layer…

FEM-simulations yield

$$\lambda = 0.046\ \mathrm{W m^{-1} K^{-1}} \pm 5\%$$

case 3: this finally is a steady state hot strip measurement



$$\lambda_2 = \frac{\ln\left(\frac{r_2}{r_1}\right)}{\frac{2\pi L \boxed{\Delta T}}{\alpha \Phi} - \frac{1}{\lambda_1}\left[\ln\left(\frac{r_1}{D}\right) + \frac{3}{2}\right]}$$

$$\lambda = 0.045\ \mathrm{W m^{-1} K^{-1}} \pm 3\%$$

Conclusion

Advantages

small specime

uncomplica

no need fo

wide range

short measu

Drawbacks

ering area

any questions?

(1) FE mulations under way for larger aspect ratios

( ) Longer sensor under construction

the sensor is patented / licenses are granted to a German and a Swedish SME