Influence of water on the total heat transfer in 'evacuated' insulations

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Content

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- Motivation
- Heat transfer mechanisms
- Experimental investigations
- Simplified theoretical approach
- Conclusions

Thermal conductivity

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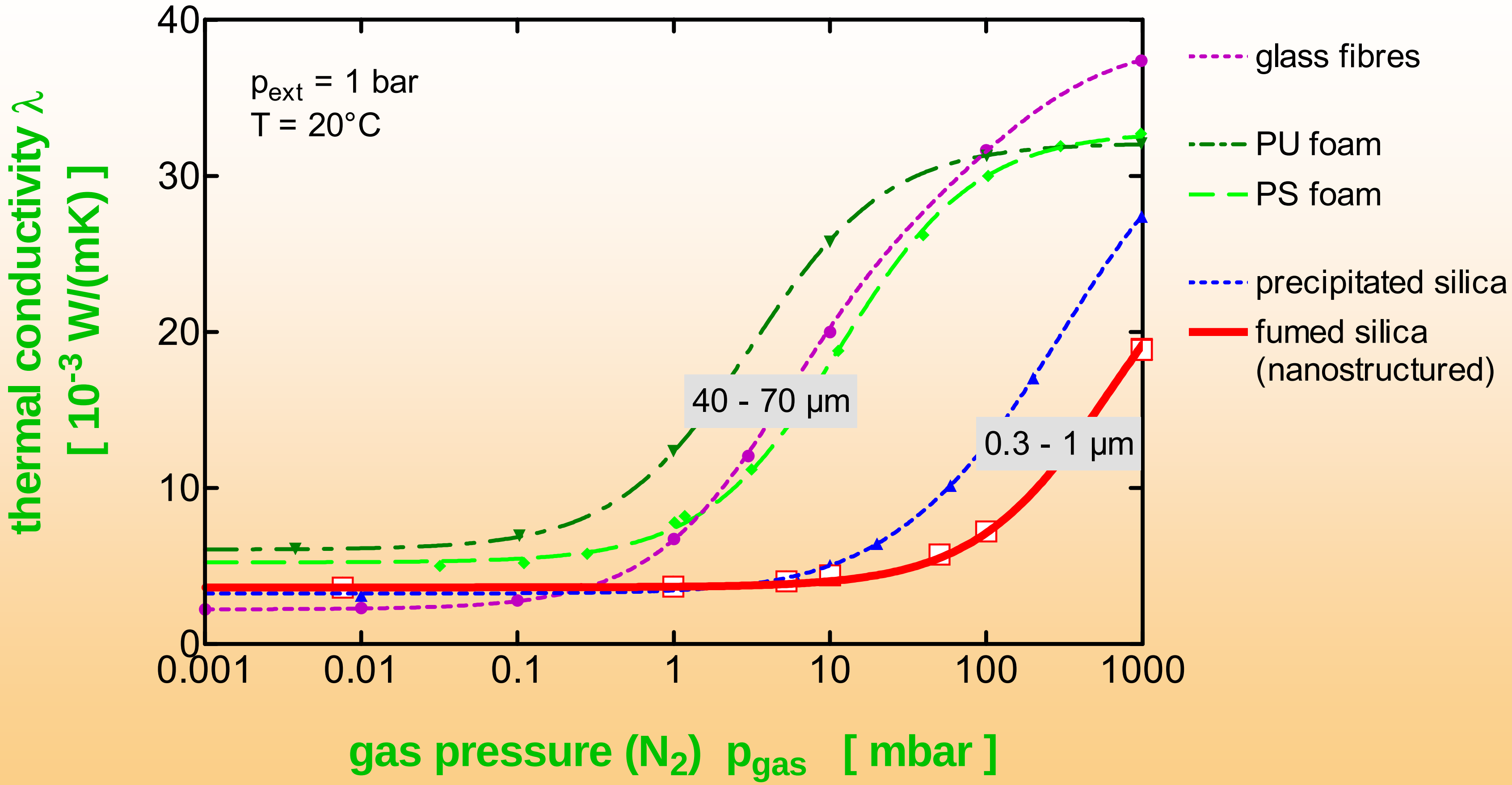

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Vacuum insulation panels with high barrier laminates

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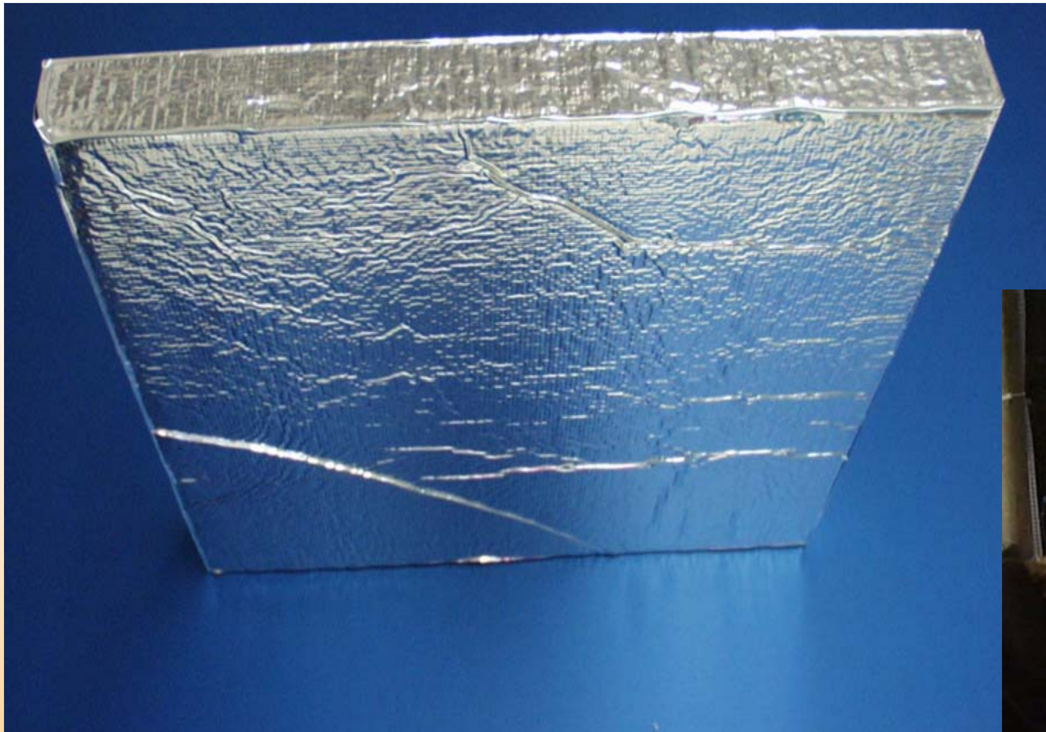
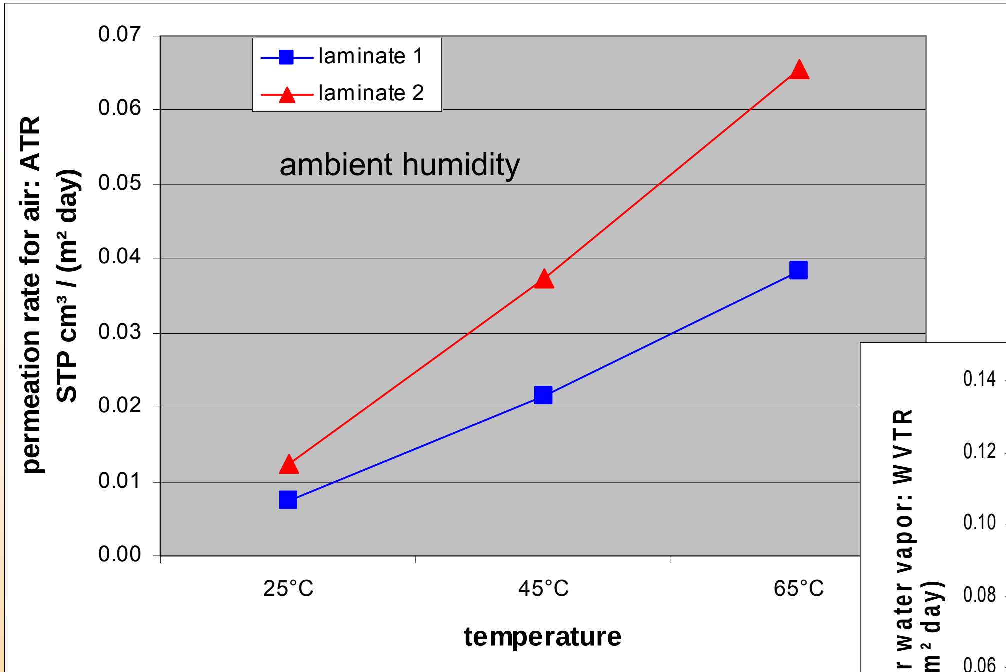
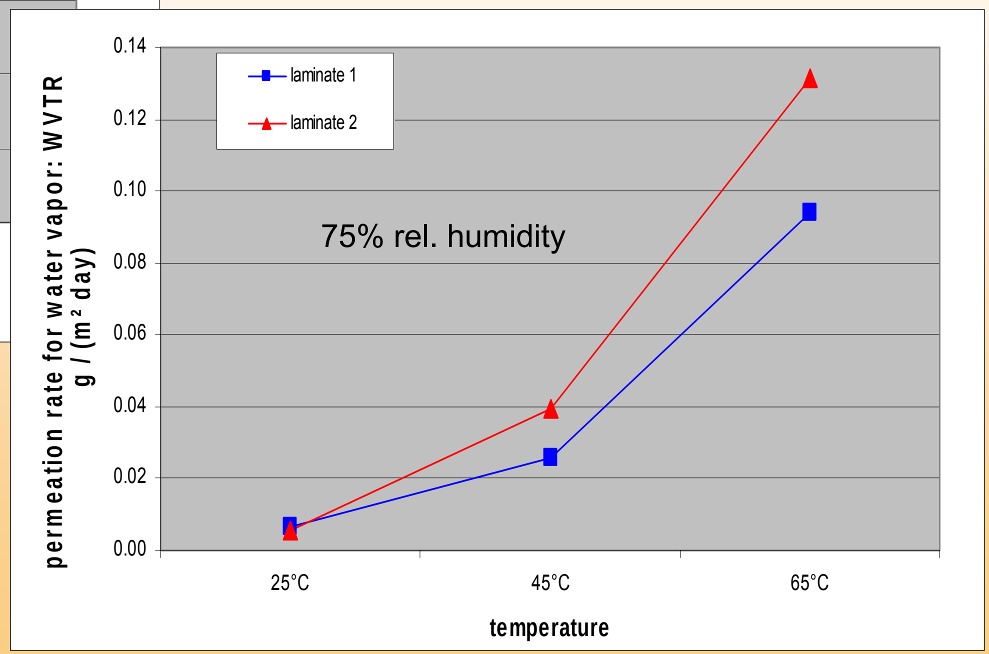


Permeation in high barrier laminates





Motivation

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- What is the influence of water on the thermal conductivity?
- Is it of relevance for the application in praxis?

Heat transfer of moisturized VIPs

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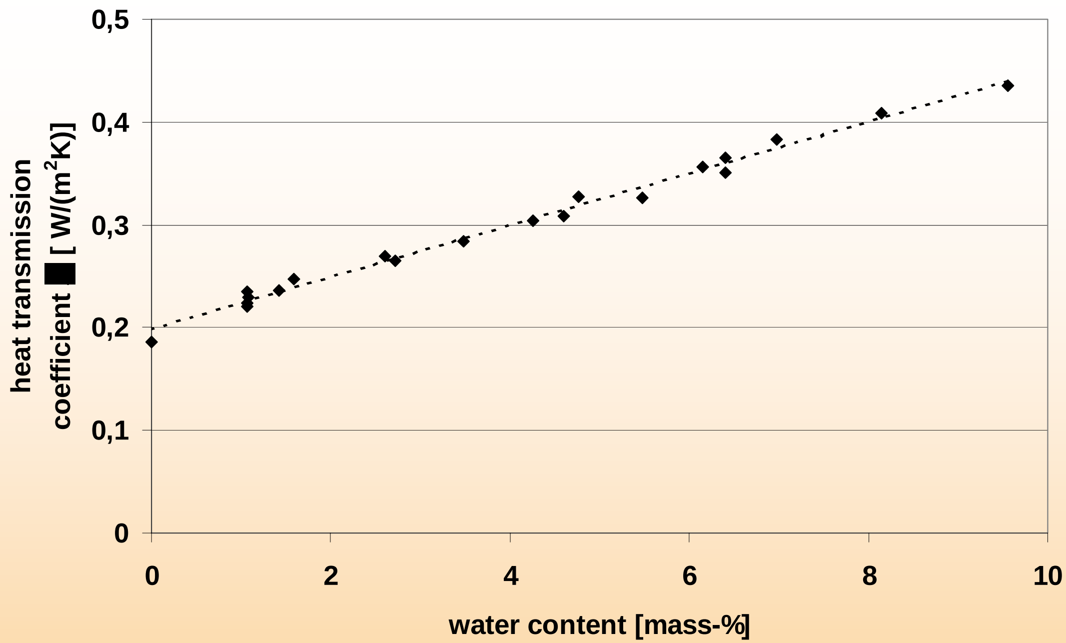

Measured heat transfer coefficient versus the water content for specially prepared VIP (thickness 20 mm, mean temperature 10°C).

➔ Influence of water larger than expected for water in the gaseous phase .

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Heat transfer in porous insulations

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$$\boxed{\lambda = \lambda_s + \lambda_r + \lambda_g + ?}$$

λ : thermal conductivity

λ_s : solid conduction (structure, density, pressure load)

λ_r : thermal radiation (density, “particle“ size, $\propto T^3$)

λ_g : gas conduction (gas, porosity, structure, pore sizes)

? : coupling terms (λ_s, λ_g), additional effects

gaseous conductivity in a porous system

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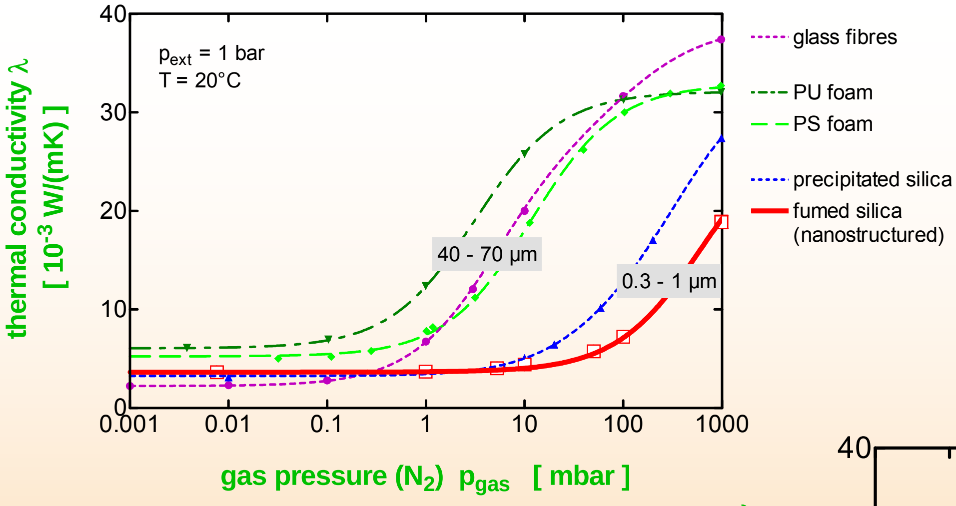
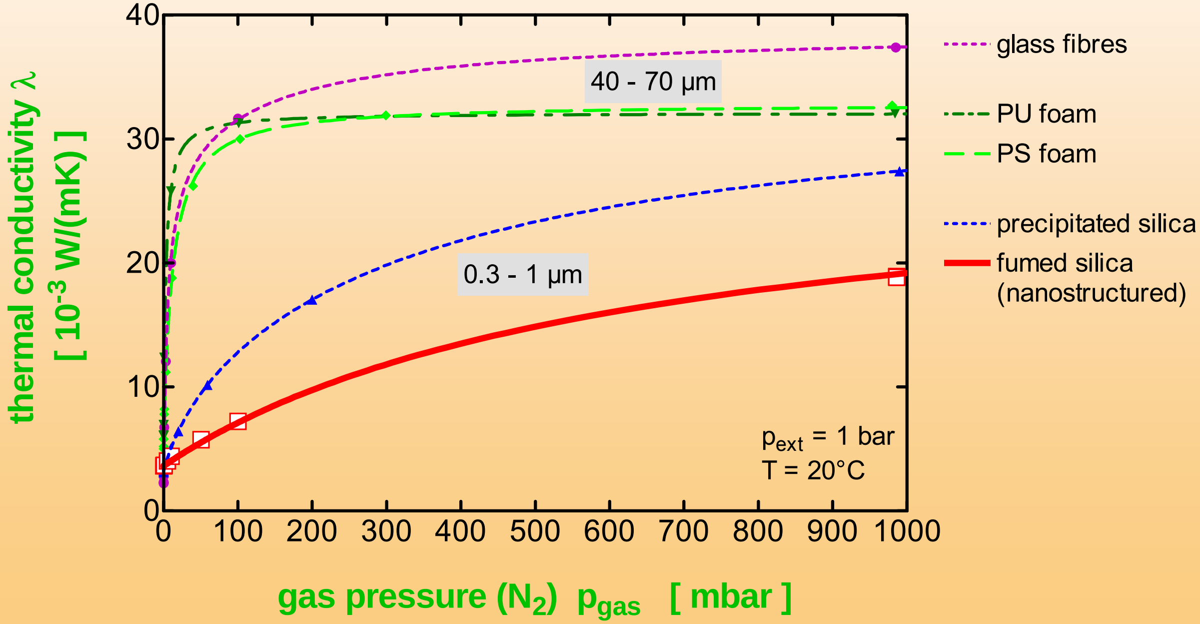


high pressure: λ_{gas} = const

low pressure $\lambda_{gas} \propto p_{gas}$



Knudsen model

Knudsenformula (1911)

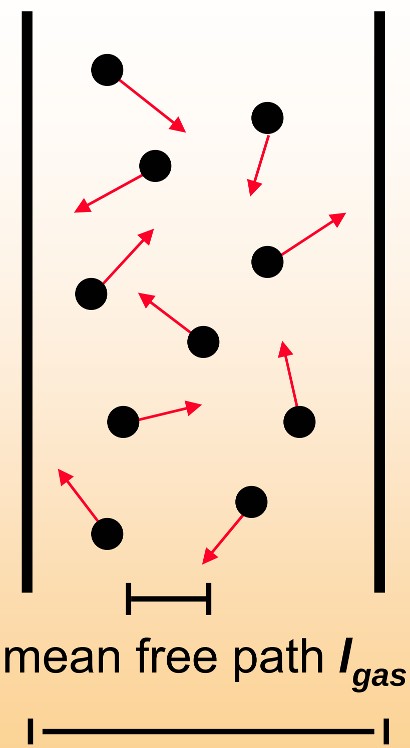
$$\lambda_{gas} = \lambda_{gas,0} \Big/ (1 + 2\beta \cdot Kn) = \lambda_{gas,0} \Big/ (1 + p_{1/2} / p)$$

with Knudsennumber $Kn = l_{gas} / D$

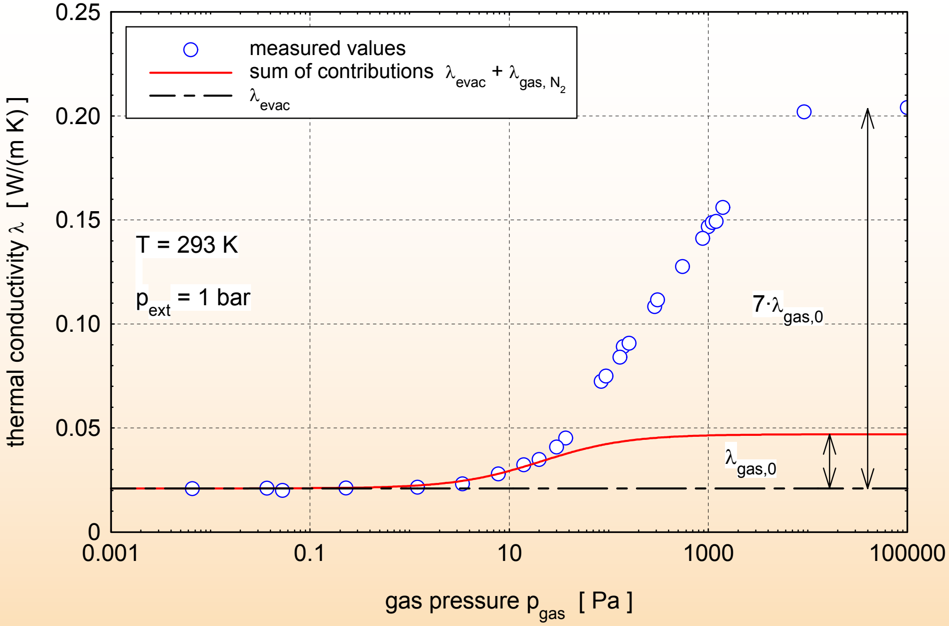
$\beta = f(\kappa, \alpha)$ typically in the range 1 … 1.5

κ adiabatic exponent, f(Gas)

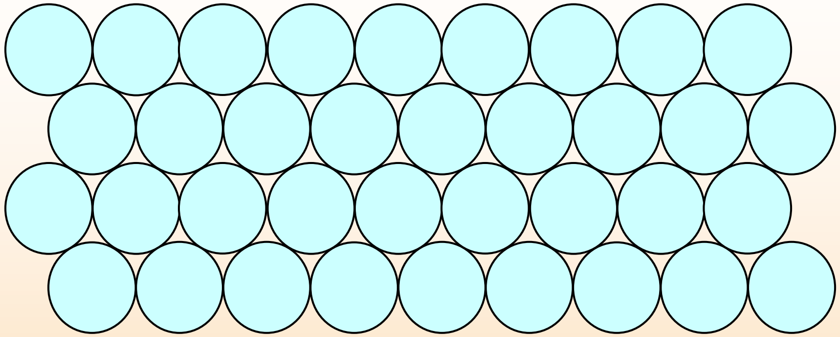
α accomodation coefficient, f(gas, matrix, T)
!!! Take care when sorption occurs !!!



Coupling of gas and solid conduction



bed of glass spheres



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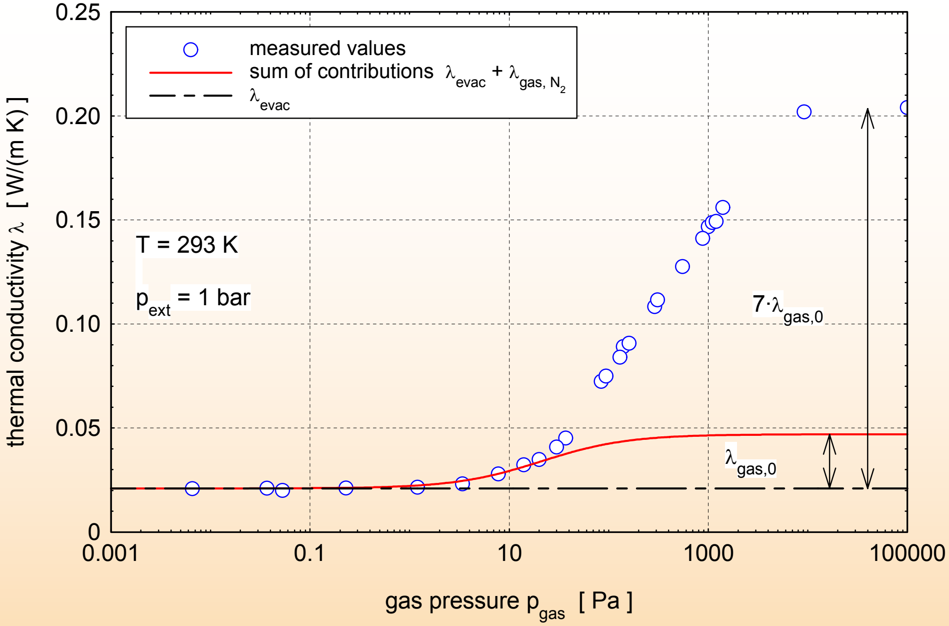

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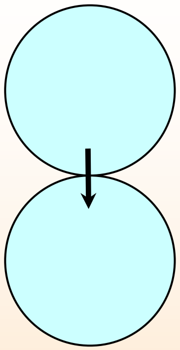

Coupling of gas and solid conduction

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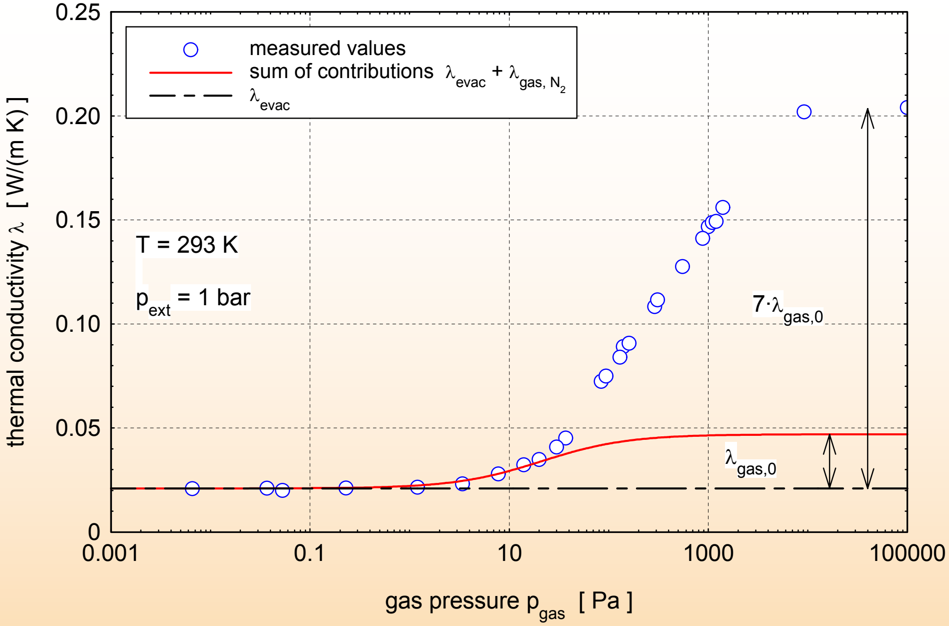

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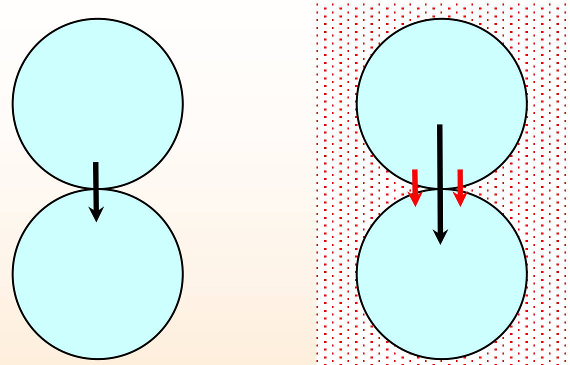

Coupling of gas and solid conduction

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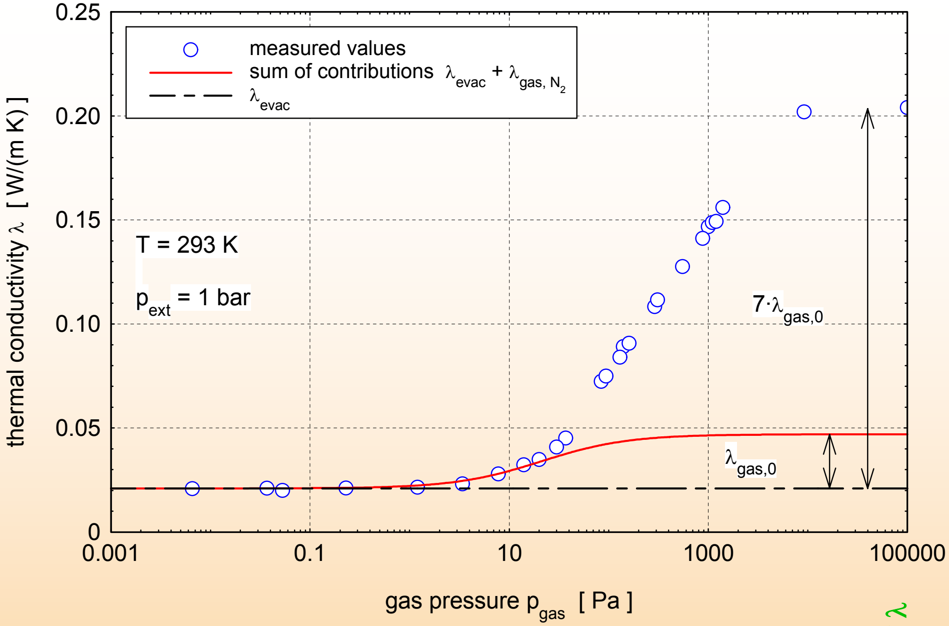

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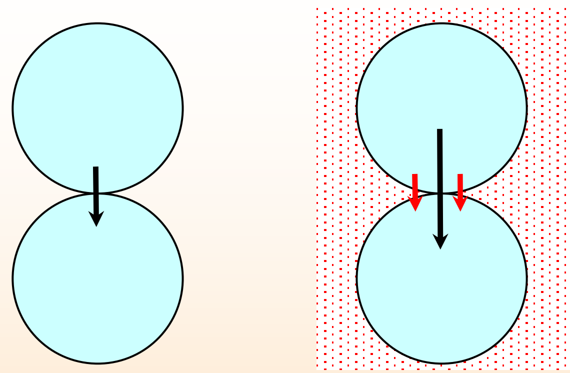

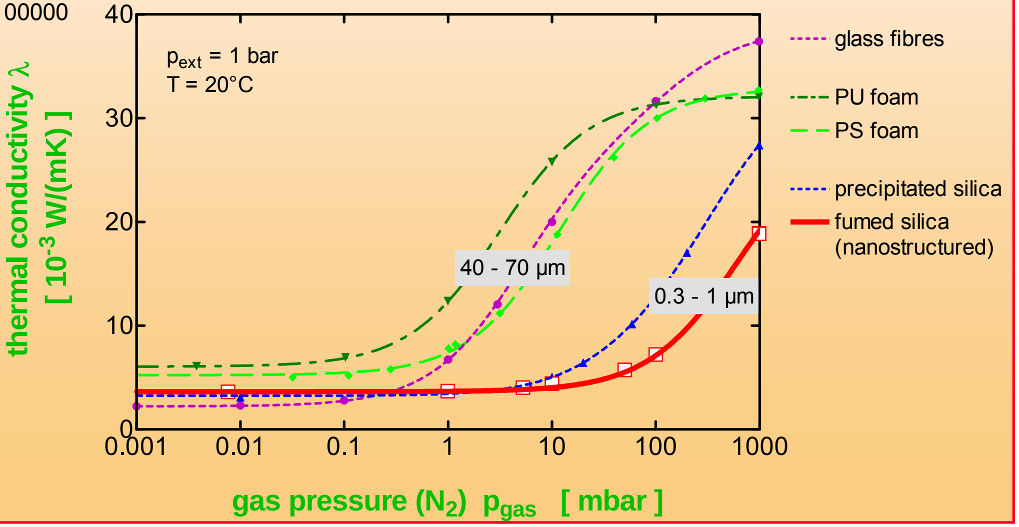

Ad- and desorption

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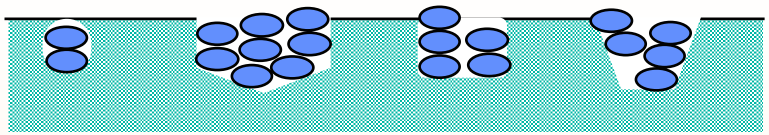
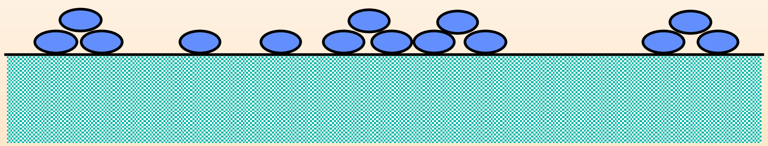
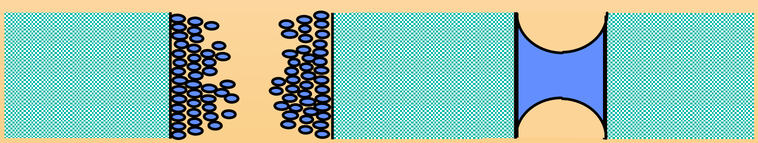


micropore condensation
pores < 2nm
"condensation even
above critical point"

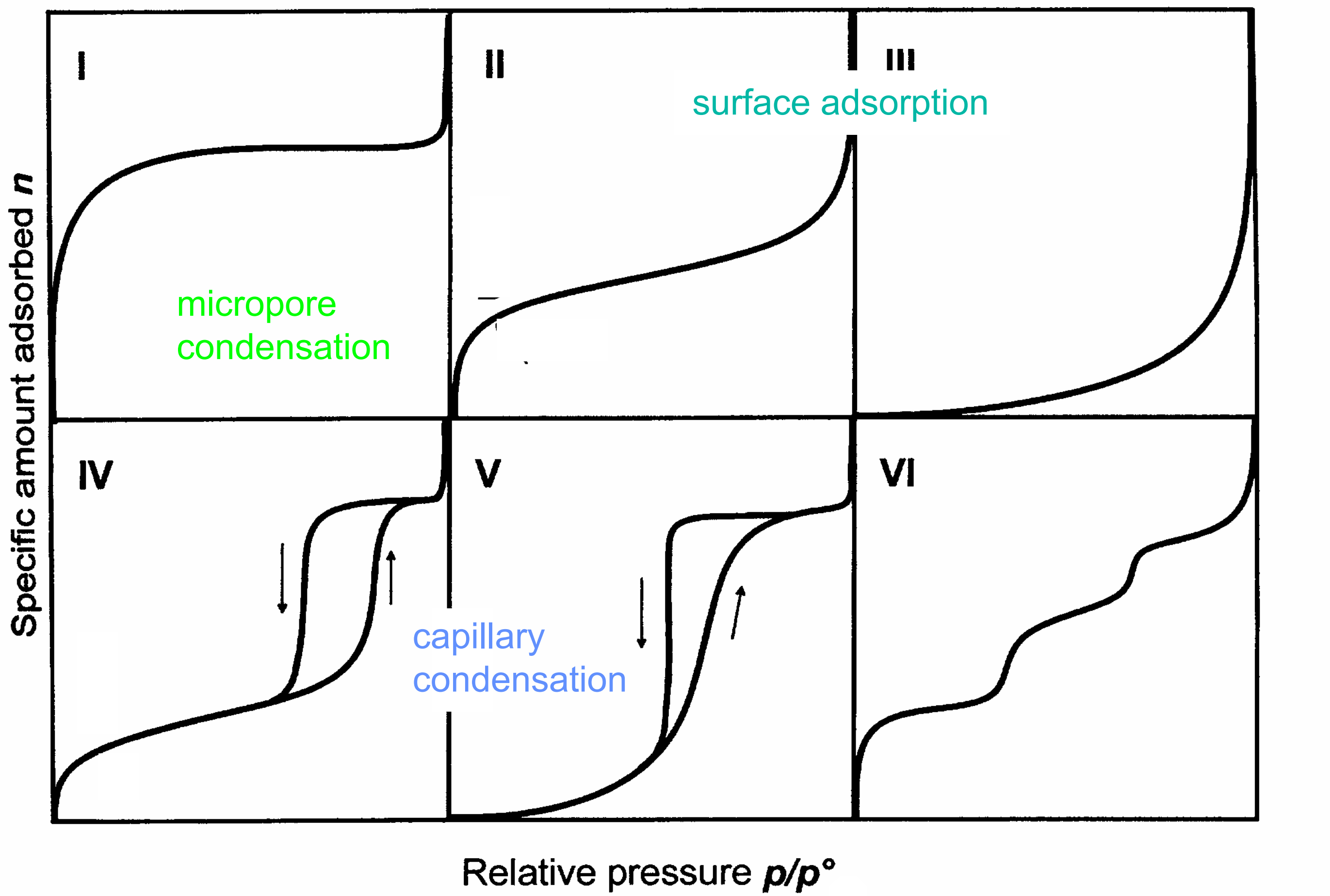


surface adsorption
physisorption or chemisorption



capillary condensation

Classification Adsorption Isotherms



Sorption isotherms of fumed silica

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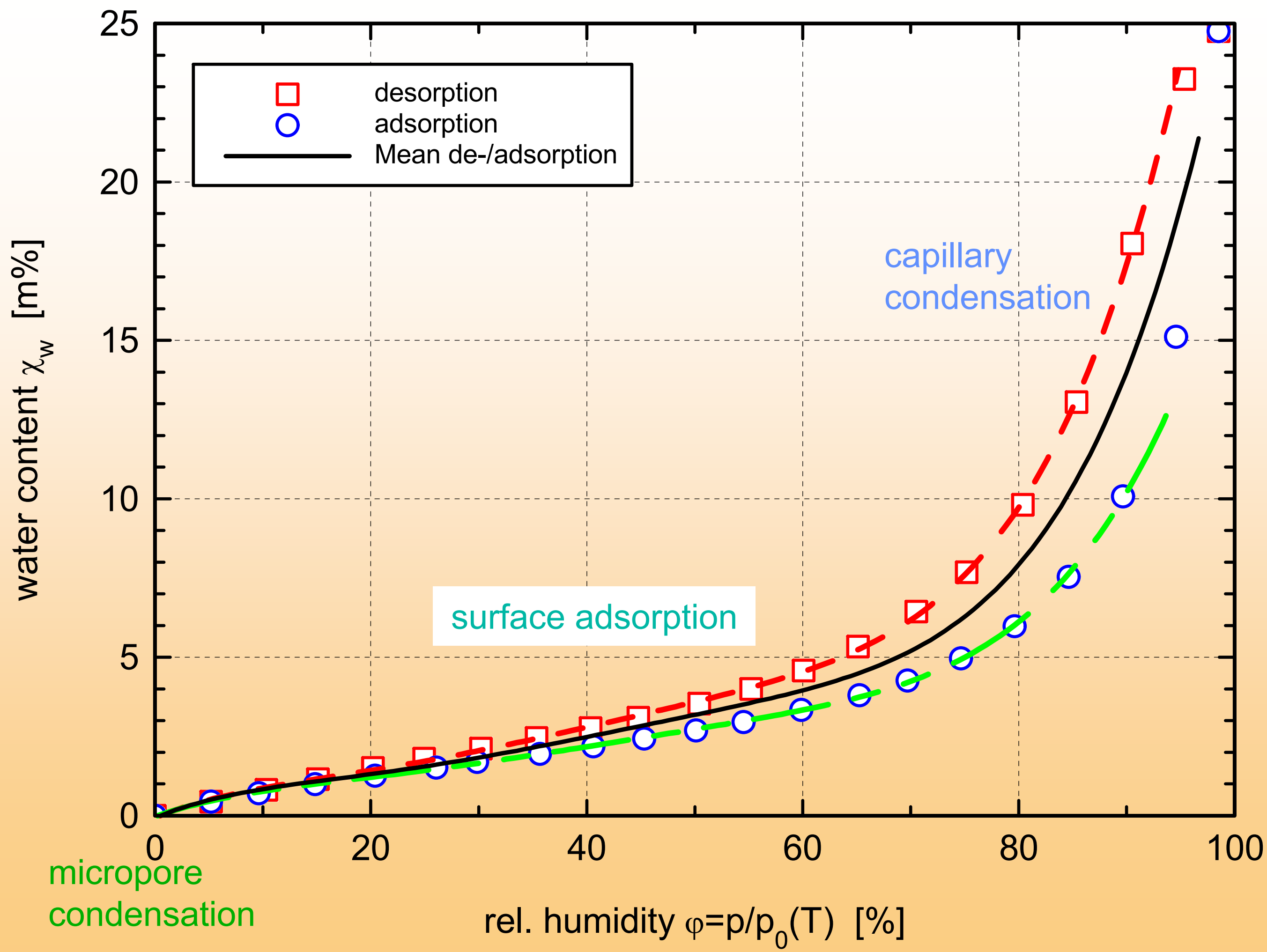

Diffusion processes

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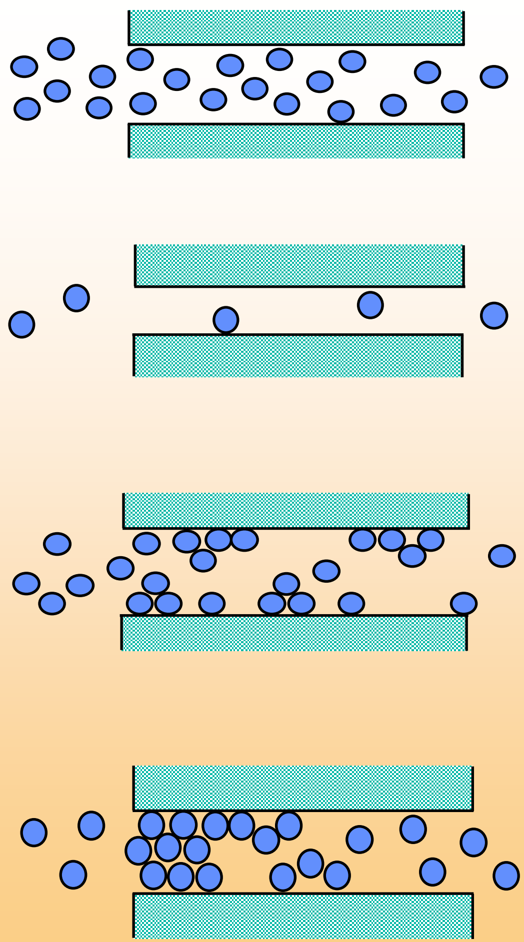

viscous flow
$l_{gas} << r$

water vapour

molecular diffusion
$l_{gas} >> r$

surface diffusion

water adsorbed

liquid flow

Heat pipe

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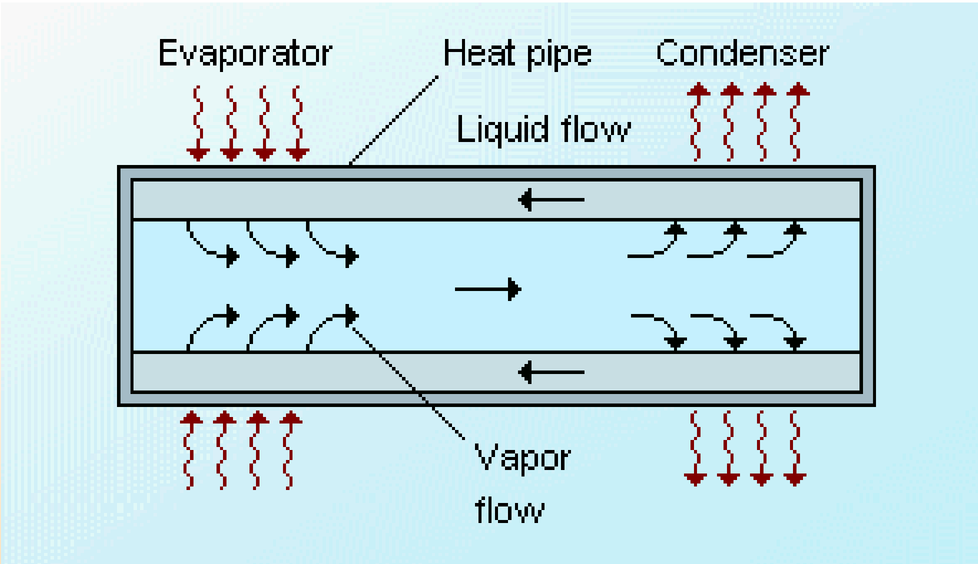

Source: Osaka Gakuin Univ. Japan

Due to enthalpy of evaporation and condensation this is the most efficient heat transfer mechanism.

If there is a mass transfer in a VIP (closed system) there might be a considerable contribution to the total conductivity also measured in steady state.

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Evacuable guarded hot plate device

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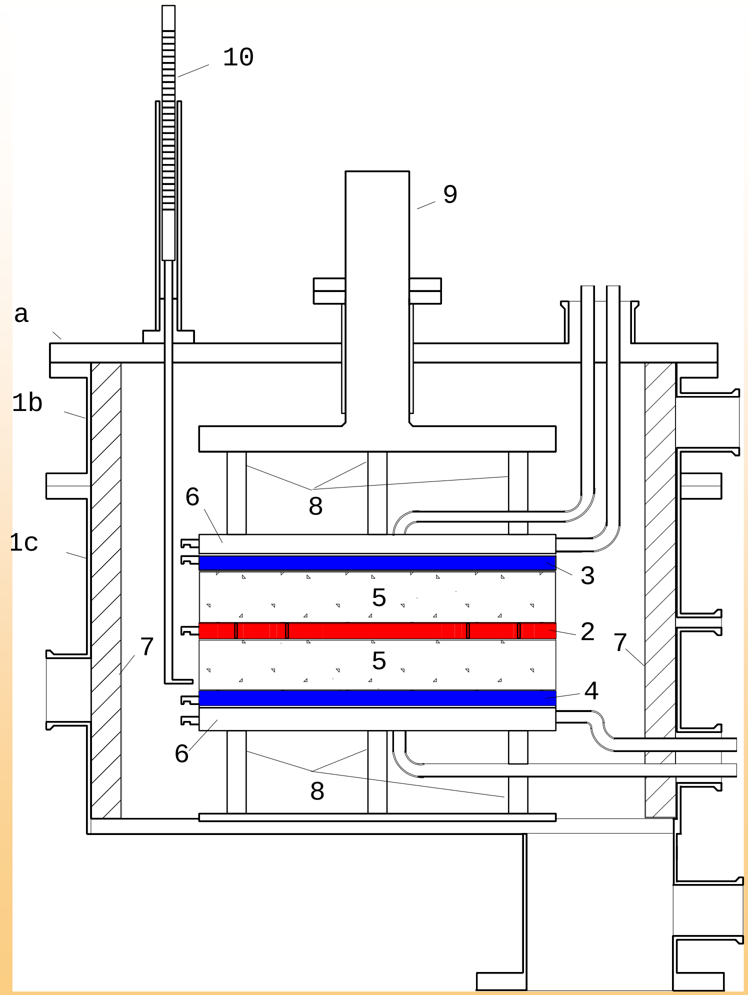
Measurement of the thermal conductivity (steady state):

Evacuable, pressure loadable guarded-hot-plate apparatus LOLA 4. Additionally a source of water vapour was connected, the electrically heated cold plates (3,4) were removed.



Specifications:

Measurable variable thermal conductivity:
0.0001 to 0.1 W/(m·K)

temperature range: -200°C to 400°C
internal gas pressure: 10-5 mbar to 1000 mbar (different gases)
external load pressure: 0 to 1.5 bar
emissivity of the surfaces: 0.8 to 0.04

samples (two identical):
thickness: 1 to 28 mm
diameter: 280 mm

Thermal conductivity measurements

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Measurement of the thermal conductivity (steady state):

two series:

• a first one in 2003,

• a second more extended one in 2005.

Beside measurements on the dry material - $\lambda_{evac}(T)$ and $\lambda(p_{gas})$ - variation

• of the relative humidity (up to 50%)

• of the temperature (263K to 323K)

• of the temperature difference (4 to 40K)

• a mixture of air and water (34 mbar of air, 50% r.h.)

Results on the dry material

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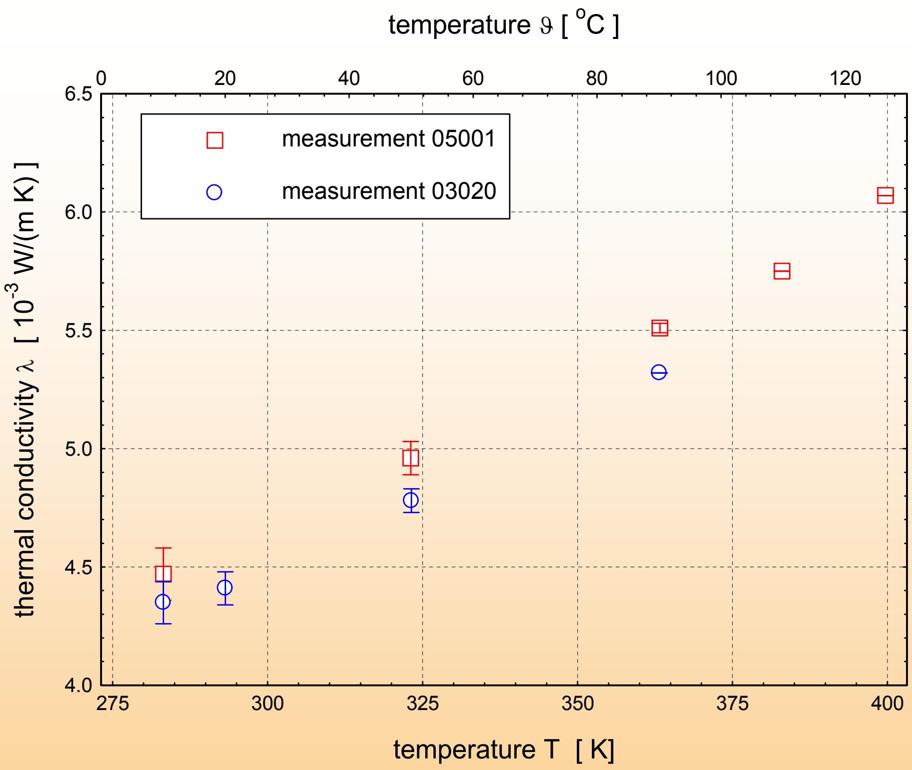

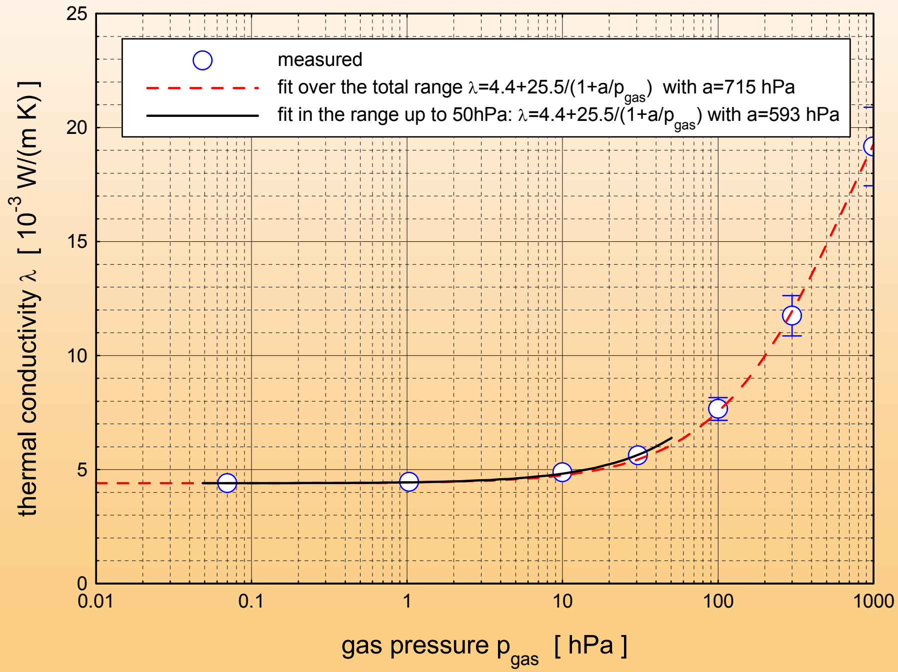

Results on the moisturized material I

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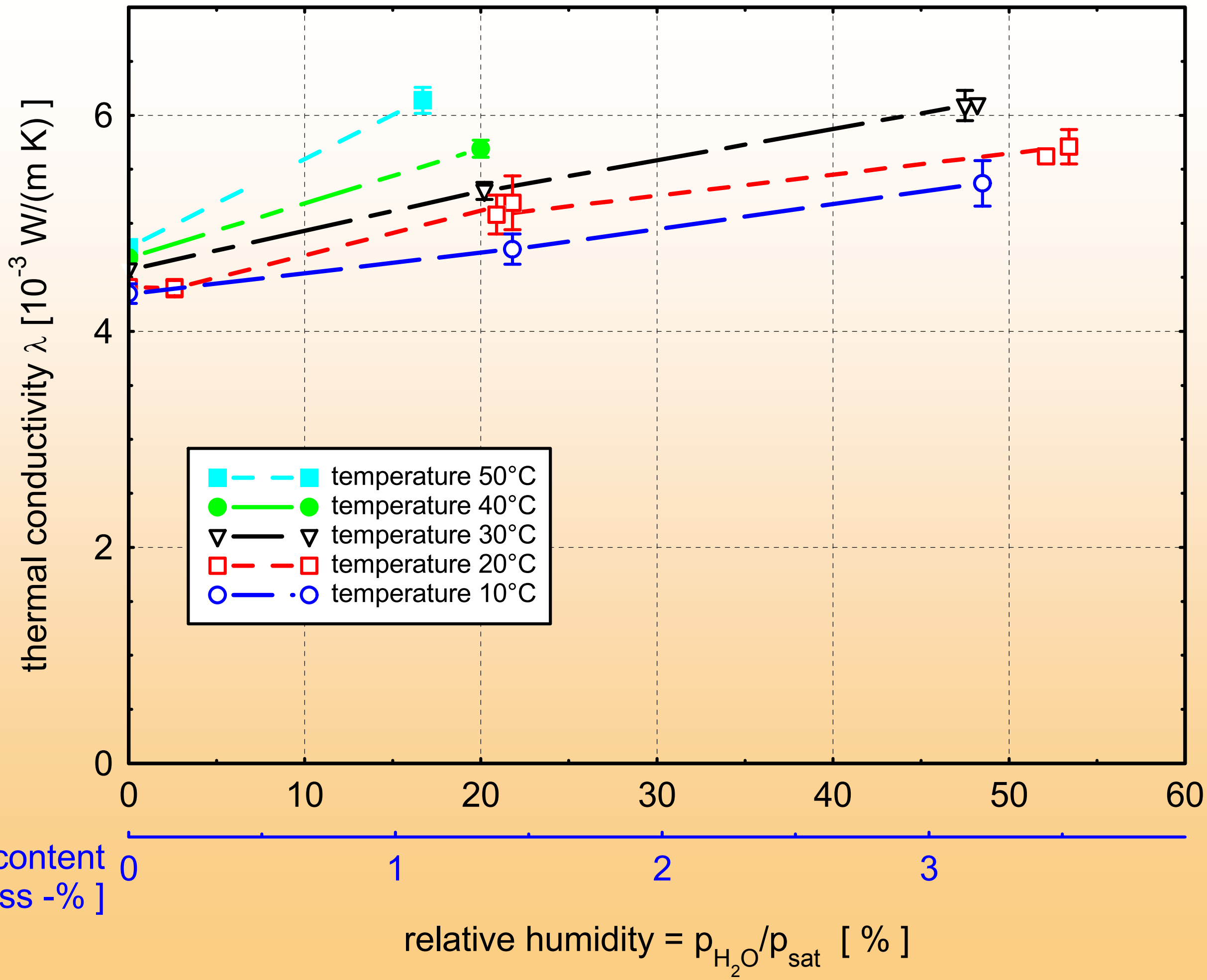
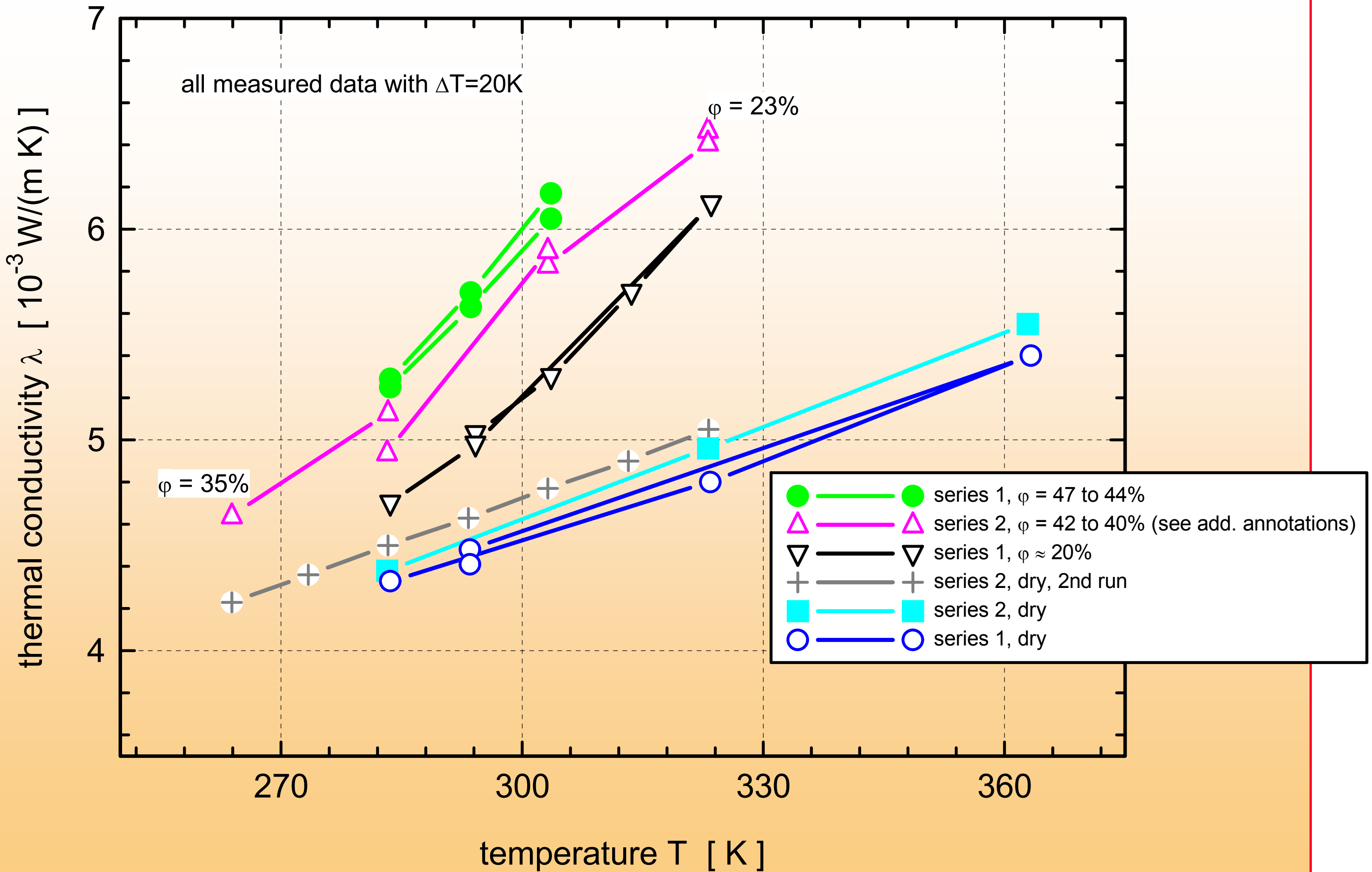
Series 1, 2003



Results on the moisturized material II

both series



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Simplified theoretical approach

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$$\lambda = \lambda_{evac}(T) + c' \cdot X_w(\varphi) + d \cdot \left(\frac{\lambda_{gas,0}}{p_{1/2}} \right)_{N_2} \cdot p_{H_2O}(T)$$

- Assuming effect of adsorbed water is proportional to the amount of water
- Assuming a constant factor between the gaseous contributions of nitrogen and water vapour
- Neglecting possible effects of mass transfer by vapour diffusion and counter surface and capillary diffusion
- Neglecting effects of non constancy of the accomodation coefficient

Fit to all data

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A numerical fit to all data measured (with ΔT = 20K) yields:

- Adsorbed water increases the 'solid conductivity' by

  about ≈ $0.01 \cdot 10^{-3}$ W/(m K) per % r.h.

  ➔ e.g. at 50%r.h. effect of adsorbed water is $0.5 \cdot 10^{-3}$ W/(m K).

- The effect of the water vapour is quite close to that of nitrogen

  (Fitparameter d=1.08)

Comparison of measured and fitted results

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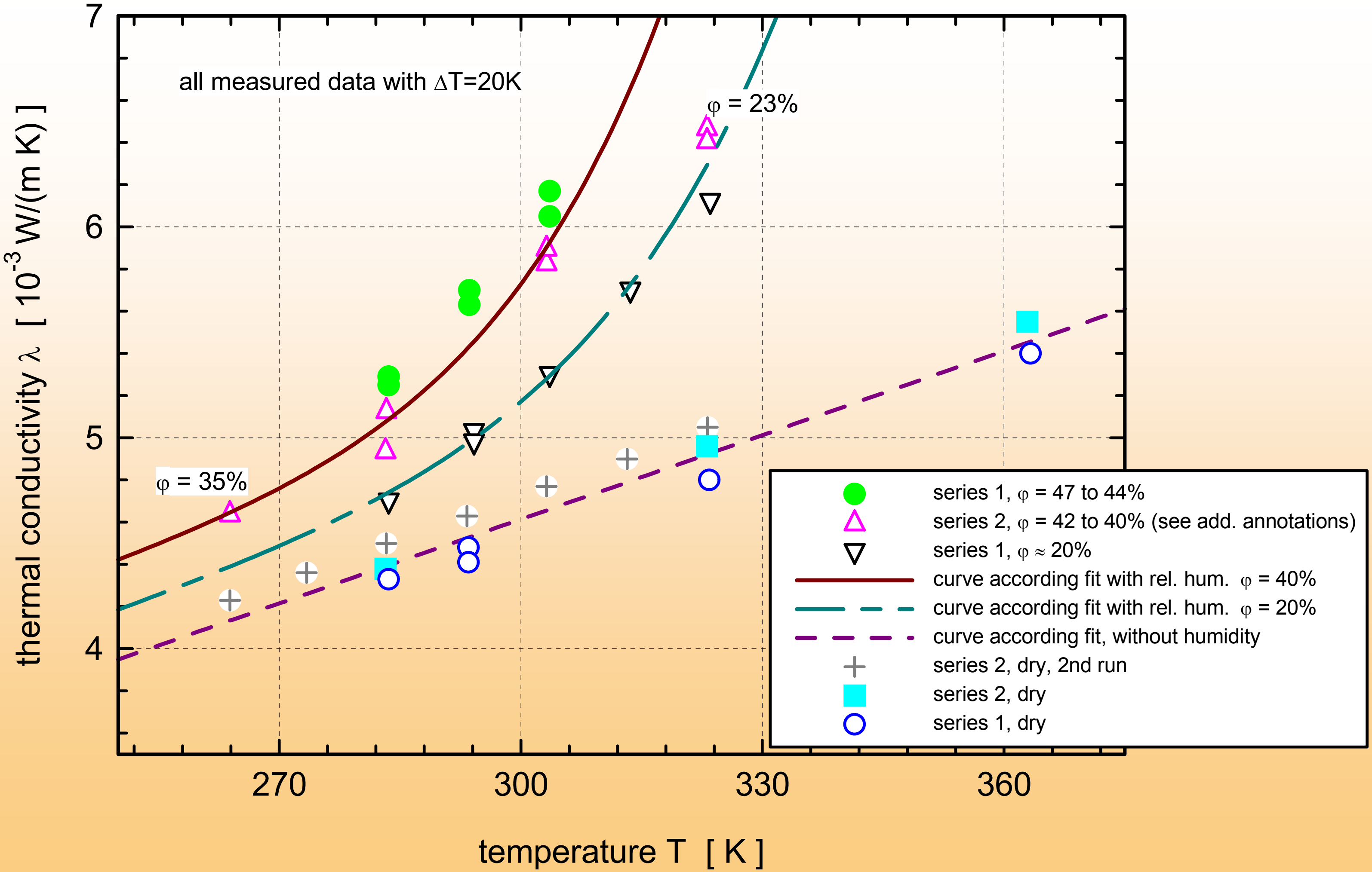

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Conclusion I

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- Thermal conductivity of ‘evacuated’ fumed silica has been measured as function of moisture content and temperature.
- The question whether heat pipe effects have an impact on the total heat transfer up to now could not be answered.
- Neglecting effects of mass transfer the impact of moisture can be described as an increase of solid conductivity by the water adsorbed and an increase of gases conduction that is quite close to that of nitrogen.
- High moisture content seems to cause a modification in the structure of the material and thus an increase in solid conductivity.
- Effects of air and moisture proved to additive.

Conclusion II

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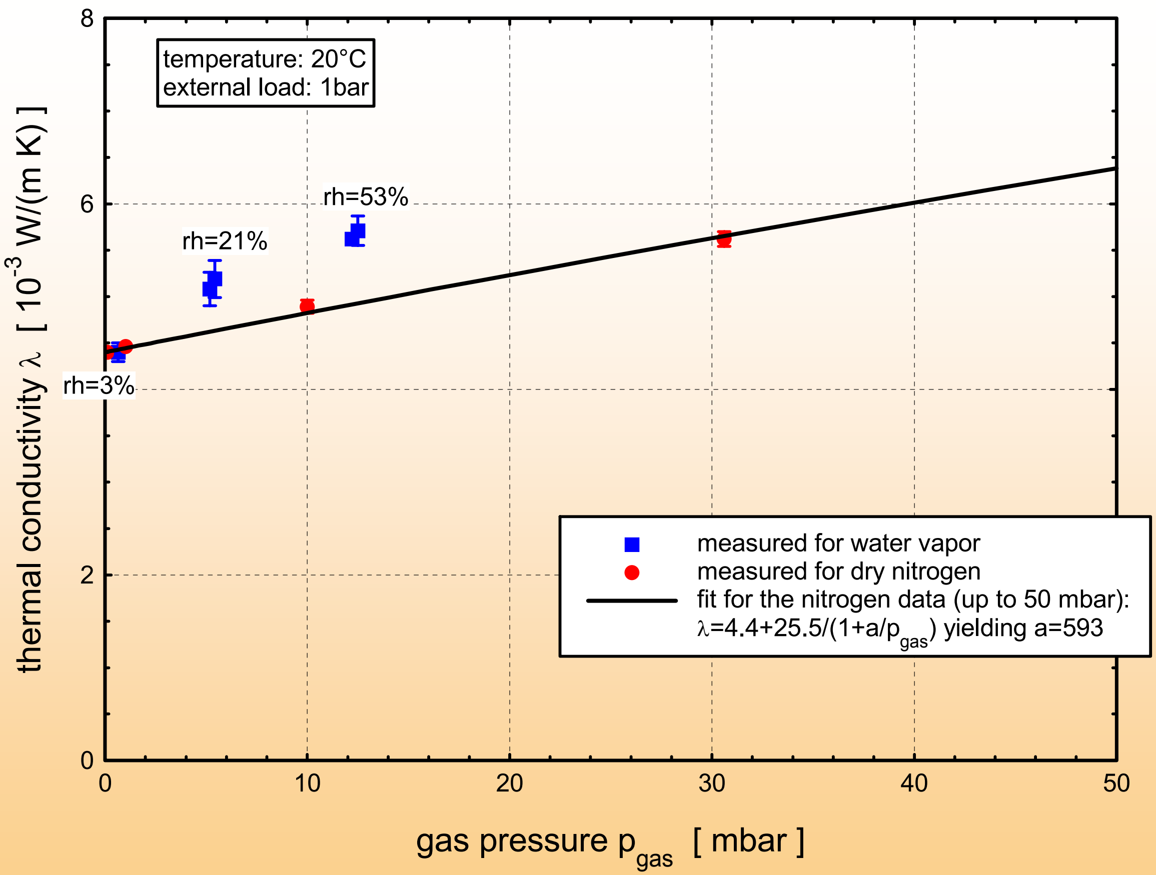

- Is it of relevance for the application in praxis?