ZAE BAYERN

FROM DEWARS TO VIPS - ONE CENTURY OF PROGRESS IN VACUUM INSULATION TECHNOLOGY

Jochen Fricke

ZAE Bayern

Am Hubland, 97074 Würzburg

fricke@zae.uni-wuerzburg.de

CONTENT

ZAE BAYERN

- Introduction
- Materials Research for VIPs
- Progress in Thermophysics Knowhow
- Early VIP-Constructions
- Lessons to heed
- Conclusions and Outlook

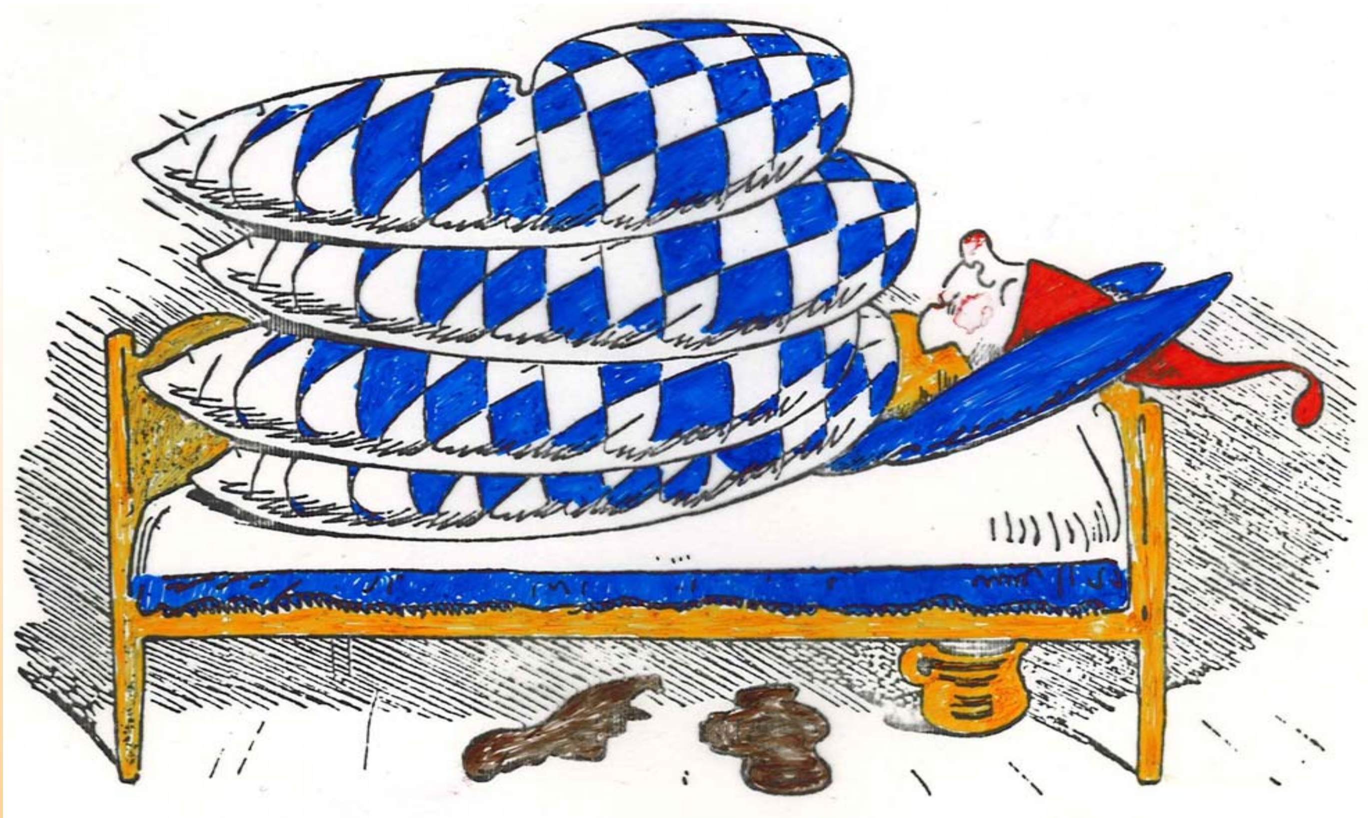
Single, without central heating

ZAE BAYERN

Blood is cold and thick in body
uncle Fritz first dreams of toddy…

Superinsulation ?

ZAE BAYERN

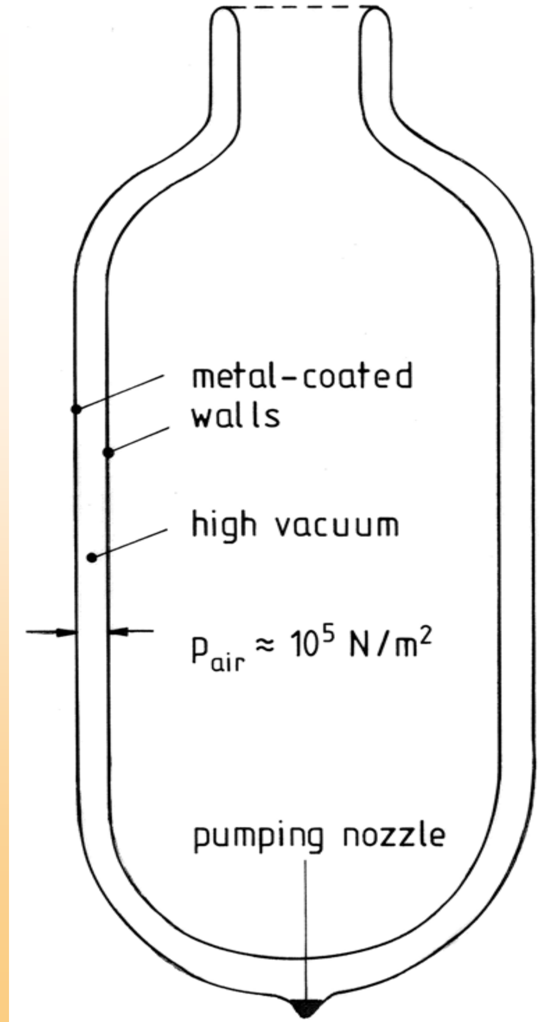


…then he has the revelation,
how to improve the insulation.

Invention of vacuum insulation

ZAE BAYERN

James Dewar, a scientist at Oxford University, invented the vacuum flask in 1882; this „DEWAR“ was made of glass and was uncoated; a charcoal getter helped to reduce the pressure.



Technical realization

ZAE BAYERN

The "vacuum flask" was first manufactured for commercial use in 1904, when two German glass blowers formed Thermos GmbH (a limited liability company). In 1907, Thermos GmbH sold the Thermos trademark rights to 3 companies in the US, Canada and England. In 2004, the Thermos trademark celebrated its 100th birthday.

CONTENT

ZAE BAYERN

- Introduction
- Materials Research for VIPs
- Progress in Thermophysics Knowhow
- Early VIP-Constructions
- Lessons to heed
- Conclusions and Outlook

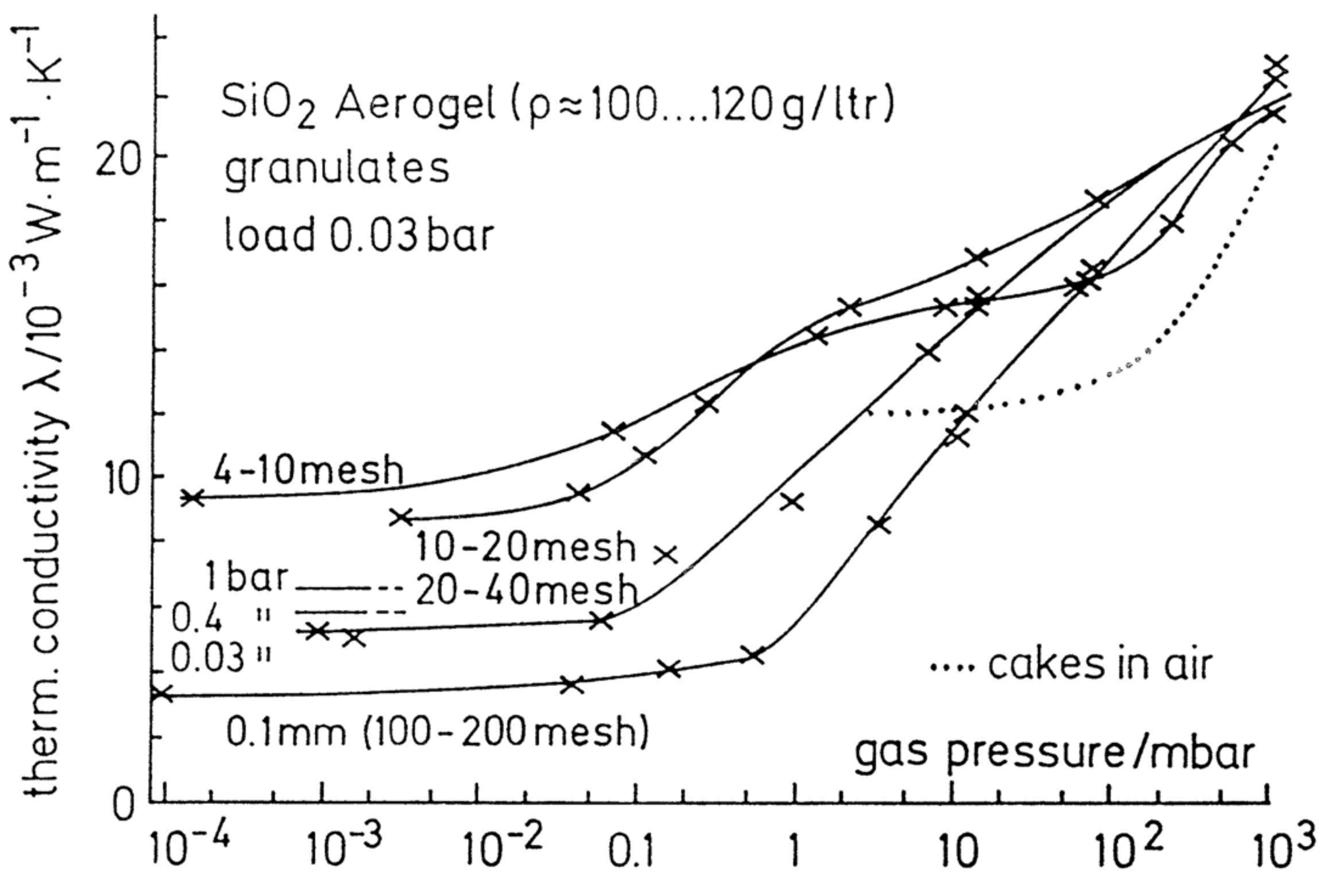
Aerogels

ZAE BAYERN

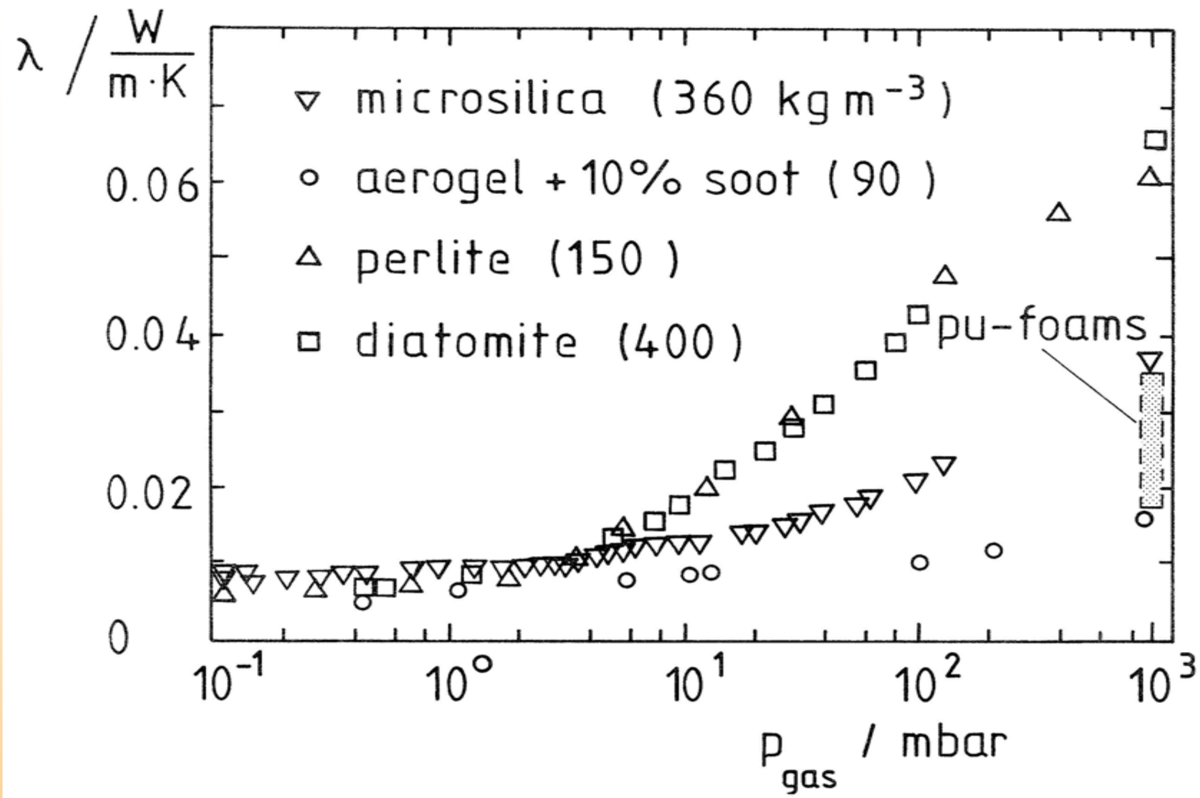
Kistlers´ research in materials sciences in the 1930s led to the first nano-structured insulation materials; for more than 2 decades aerogels were sold by Johns-Manville under the name Santogel.

Lowest conductivities

ZAE BAYERN



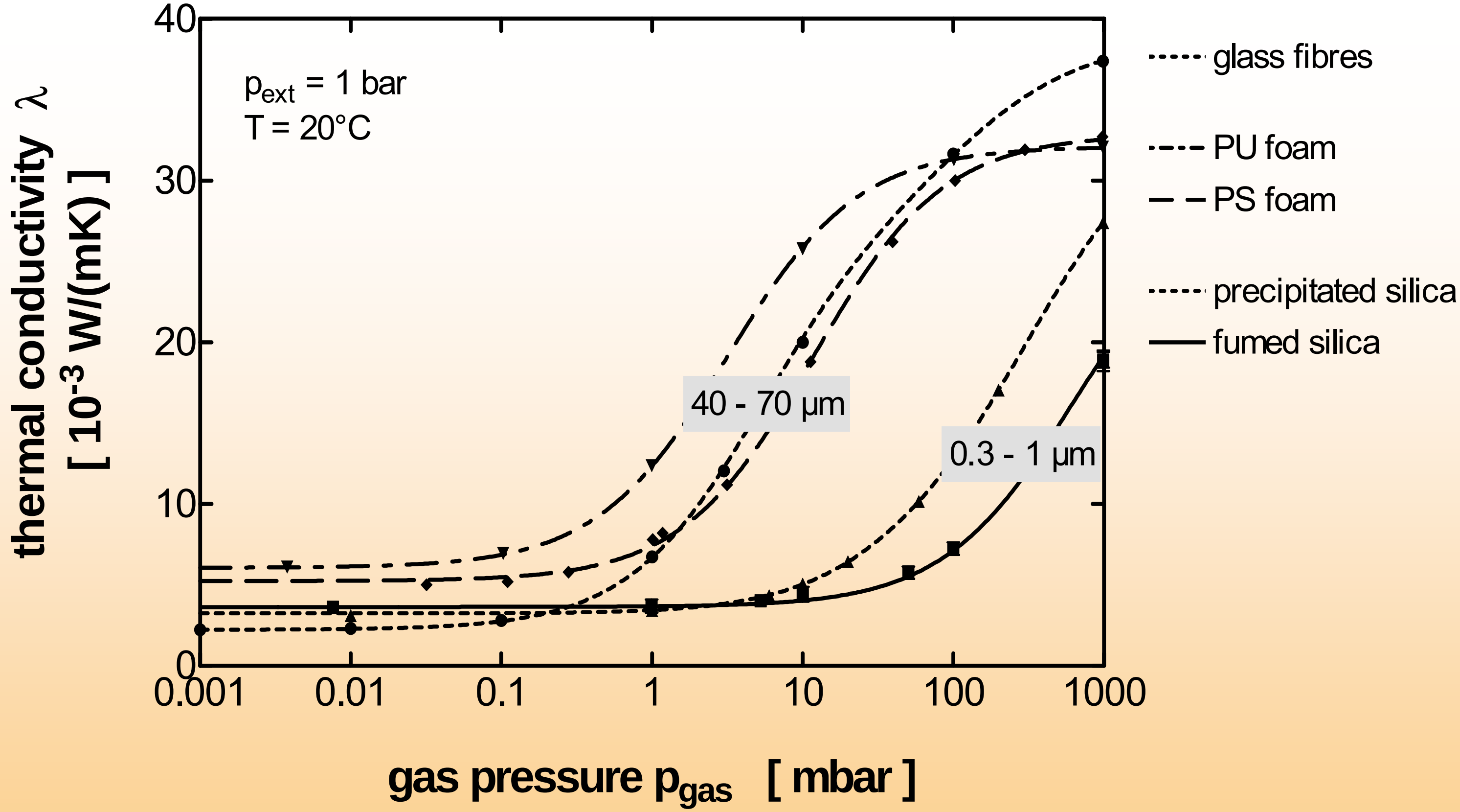
Powder insulations



The thermal conductivity of various silica powders shows a much stronger dependence on gas pressure than the conductivity of aerogels.

Fibers, powders and foams

ZAE BAYERN

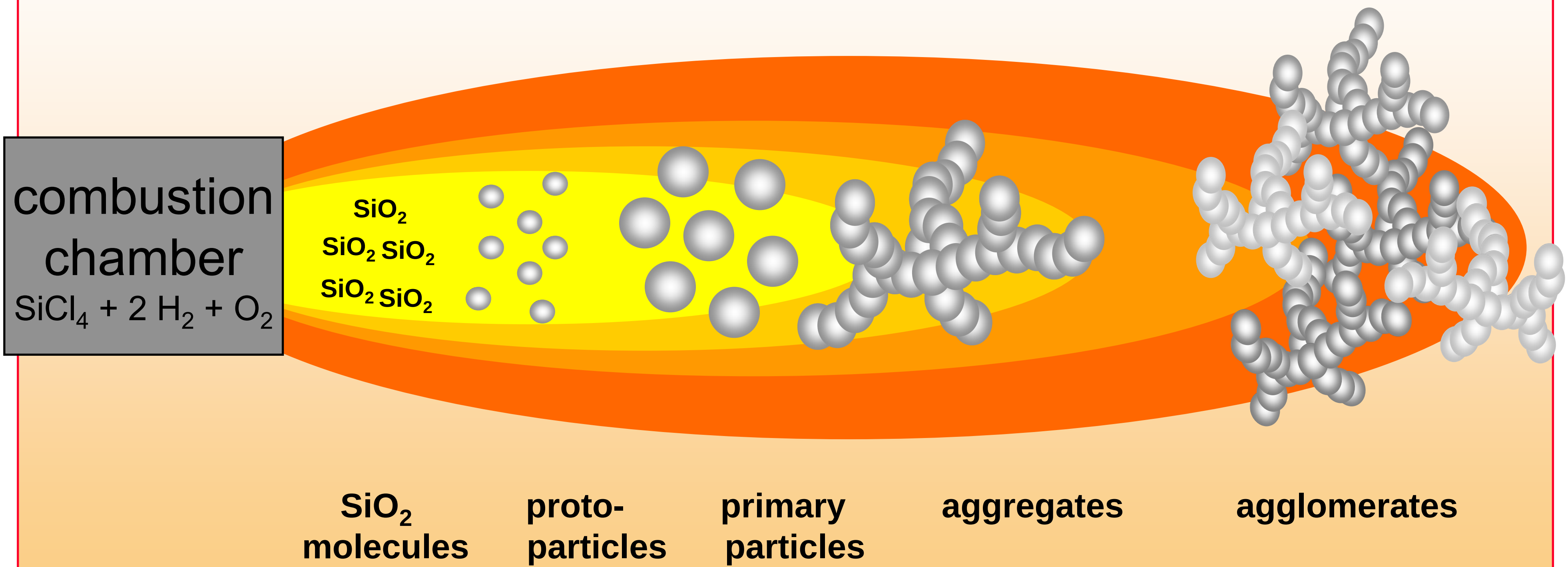


Fumed silica, invented by Harry Kloepfer at Degussa in 1942, and first produced and sold by Degussa under the name Aerosil®, is most suitable for VIP-kernels, however, expensive.

Fumed silica

ZAE BAYERN

$$SiCl_4 + 2\ H_2 + O_2 \rightarrow SiO_2 + 4\ HCl$$



Wacker

CONTENT

ZAE BAYERN

- Introduction
- Materials Research for VIPs
- Progress in Thermophysics Knowhow
- Early VIP-Constructions
- Lessons to heed
- Conclusions and Outlook

3 Heat-Transfer Mechanisms

ZAE BAYERN

solid thermal conductivity λ_{solid}

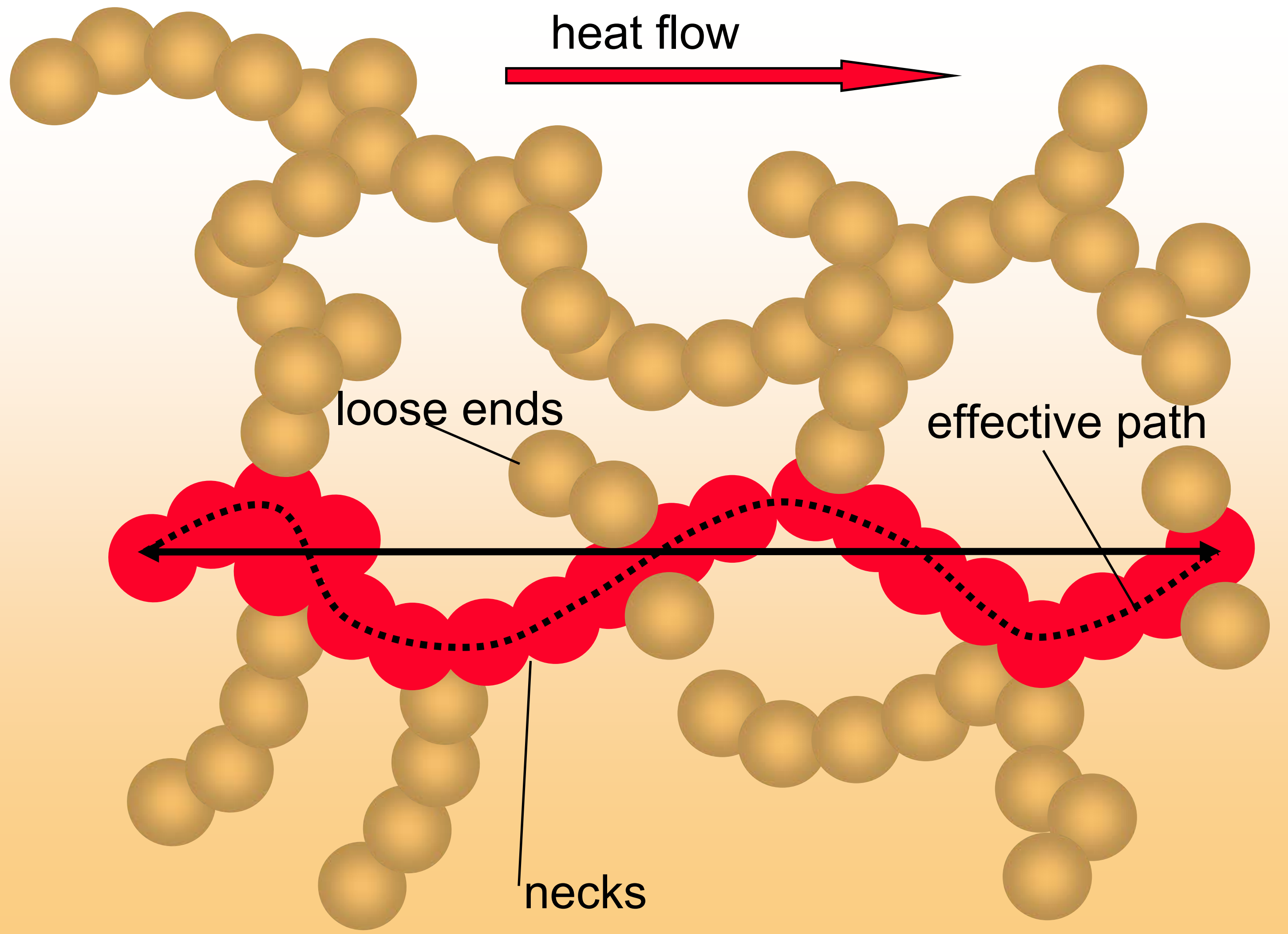
gaseous thermal conductivity λ_{gas}

radiative thermal conductivity λ_{rad}

$$\lambda = \lambda_{solid} + \lambda_{gas} + \lambda_{rad} + \lambda_{coupl}$$

Solid thermal conductivity

ZAE BAYERN



$\lambda_{solid} \sim \rho^{\alpha}$

for foams

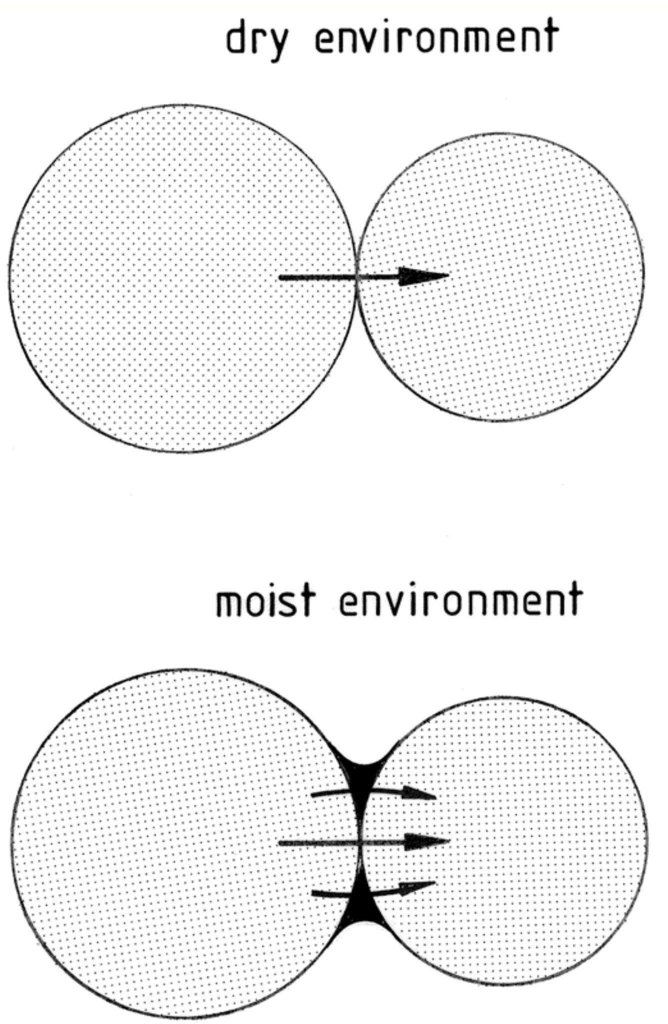
$\alpha \approx 1$

for fractal powders

$\alpha \approx 1.5 \ldots 2$

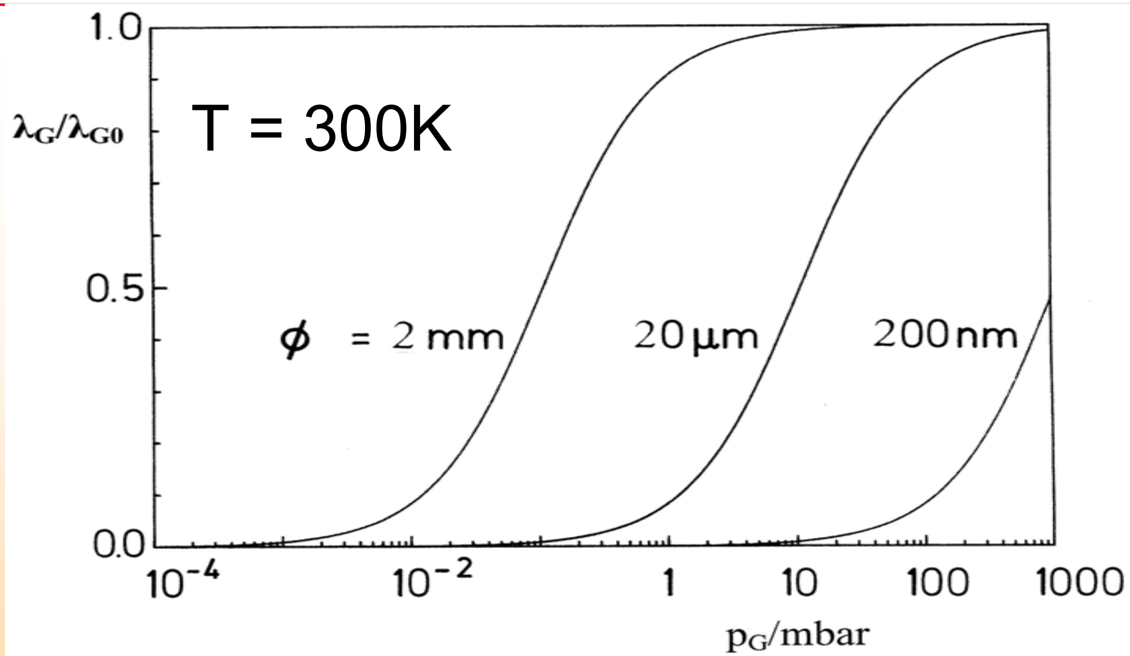
Adsorbed moisture

ZAE BAYERN



Water vapor is adsorbed by the nanostructured porous material, preferential sites are the concave necks; this leads to an increase in solid conductivity

Gaseous thermal conductivity



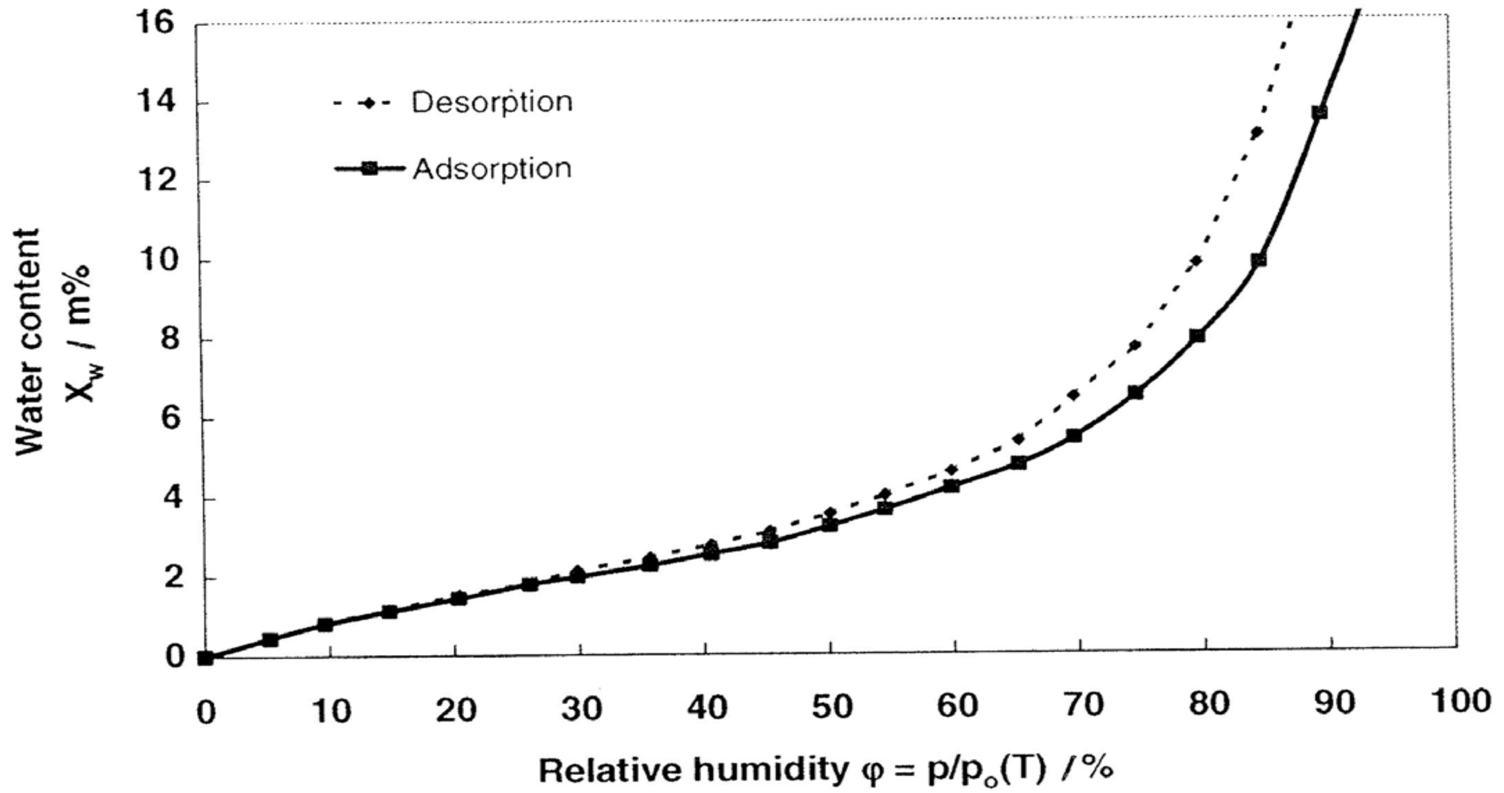
Variation of the relative gaseous thermal conductivity with gas (air) pressure in fumed silica:

$$\lambda_G = \lambda_{G0}/(1+2ßKn)=\lambda_{G0}/(1+p_{1/2}/p_G);$$

Φ=pore width, Kn=Knudsen number, ß=1.6 for air,

$$p_{1/2} \approx 230\ \text{mbar}/(\Phi/\mu m).$$

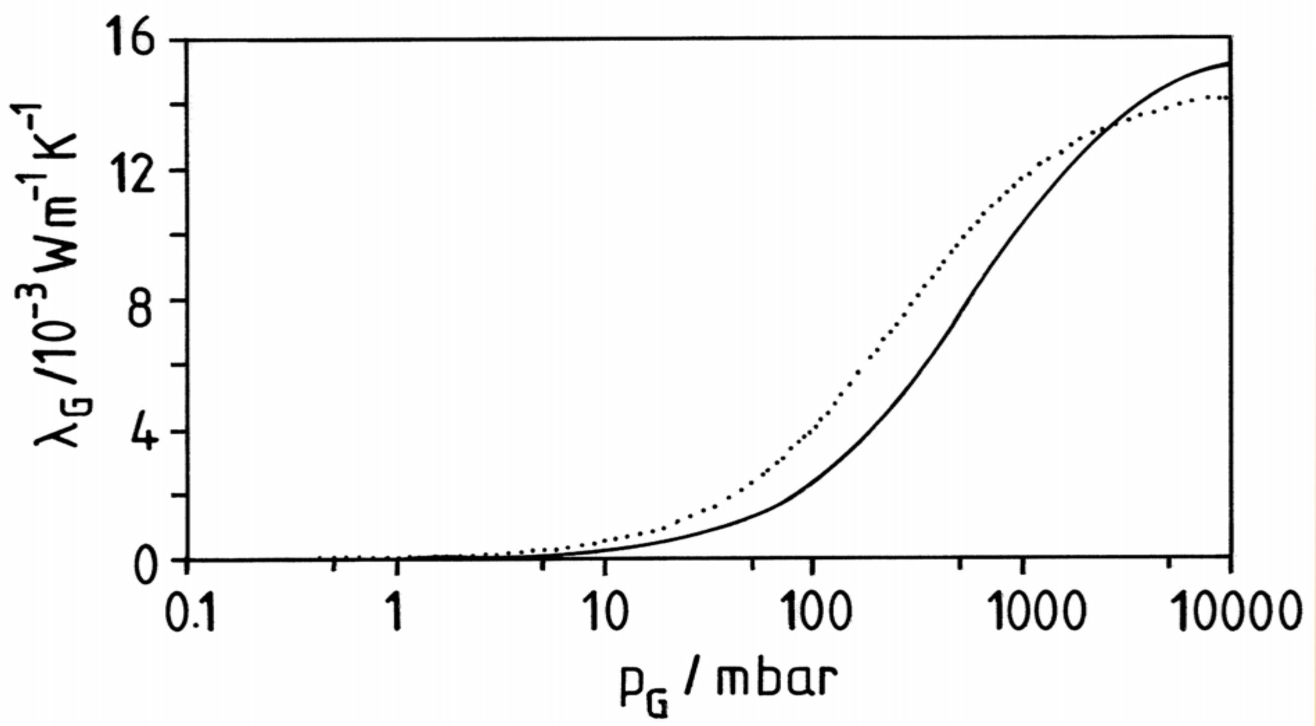
Sorption isotherm



Sorption isotherms for fumed silica kernels at 23°C; for a water content of 3 mass% a rel. humidity of 45 % or a vapor pressure of about 15 mbar results.

Air and water vapor

ZAE BAYERN

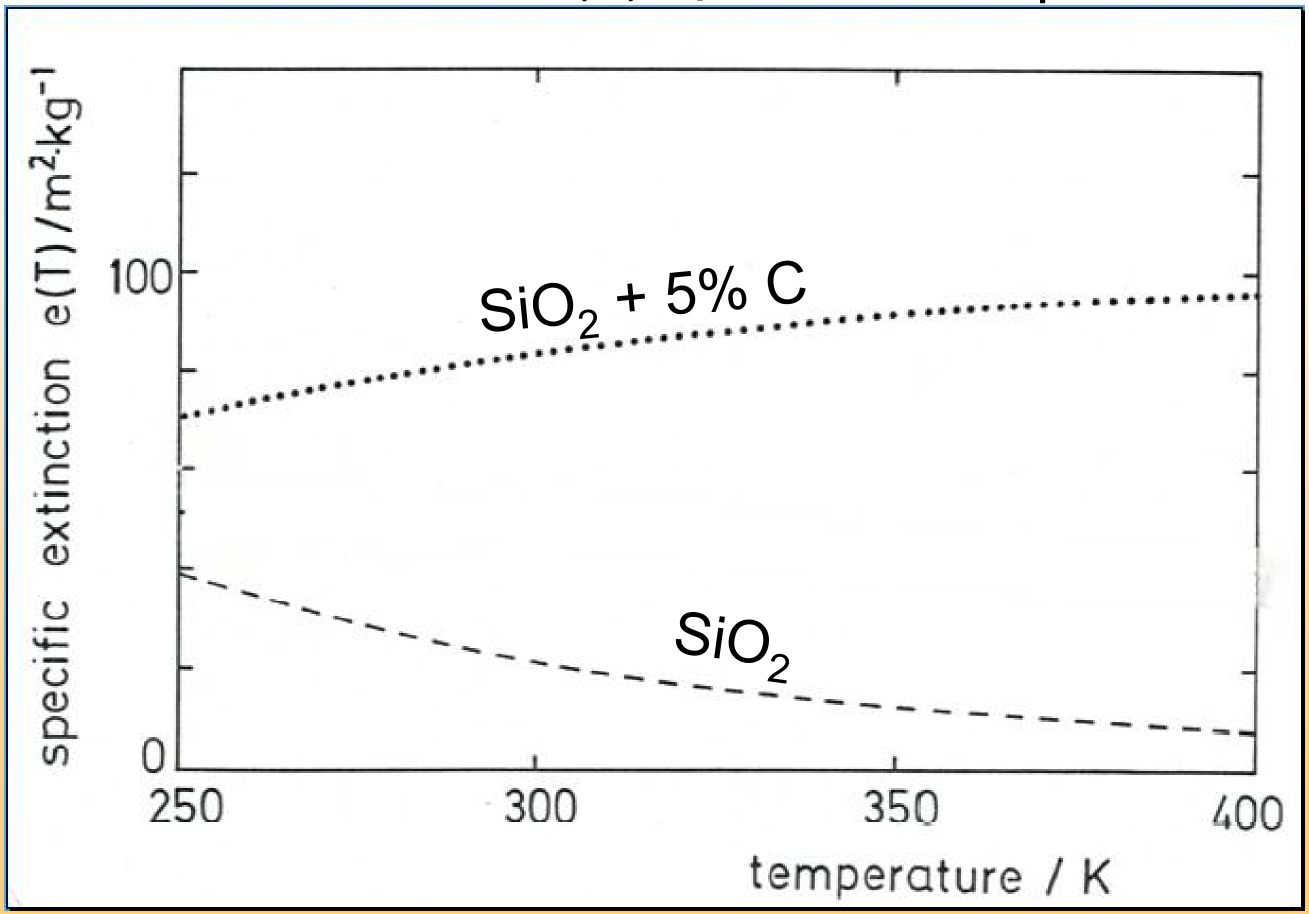


Thermal conductivity of air (—) and of water vapor (…) as a function of pressure within a fumed silica kernel; for a gas pressure of 50 mbar a gaseous conductivity of about 0.002 W/(m·K) results; for a water vapor pressure of 15 mbar a thermal conductivity of less than 0.002 W/(m·K) has to be added to the conductivity of dry air.

Radiative conductivity

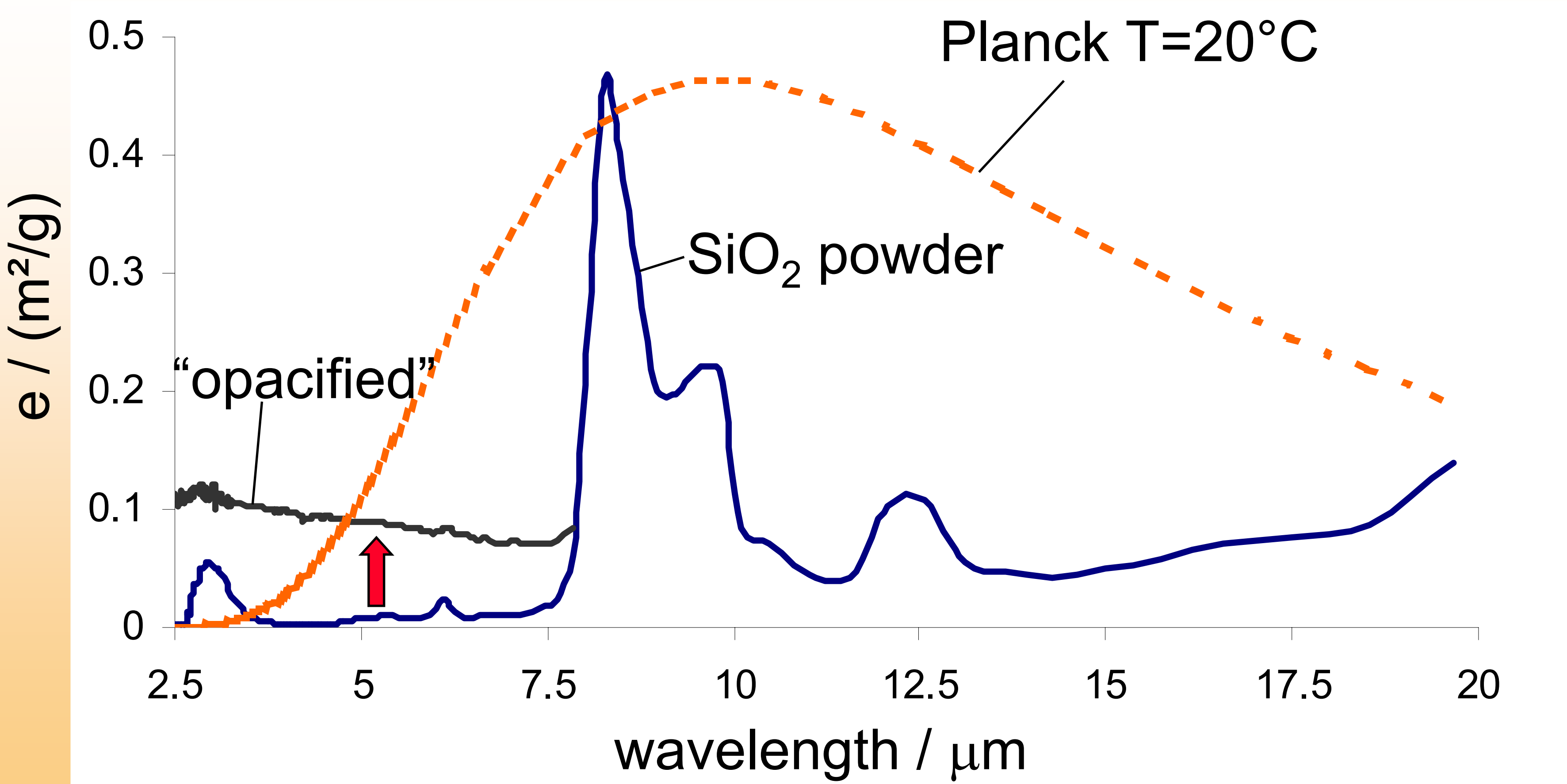
ZAE BAYERN

$$\lambda_{rad} \propto \frac{T^3}{e(T) \cdot \rho} \propto \frac{1}{\rho}$$



Spectral extinction e

ZAE BAYERN



CONTENT

ZAE BAYERN

- Introduction
- Materials Research for VIPs
- Progress in Thermophysics Knowhow
- Early VIP-Constructions
- Lessons to heed
- Conclusions and Outlook

Degussa panel

In the 1990s Degussa/Hanau produced VIPs for refigerator applications with precipitated silica kernel

$\rho \approx 200$ kg/m^3

$\lambda \approx 0.006…0.007$ W/(m·K)

life expectancy 15 years

bottom: bathtub-shaped organic laminate

top: Al-foil (12µm).

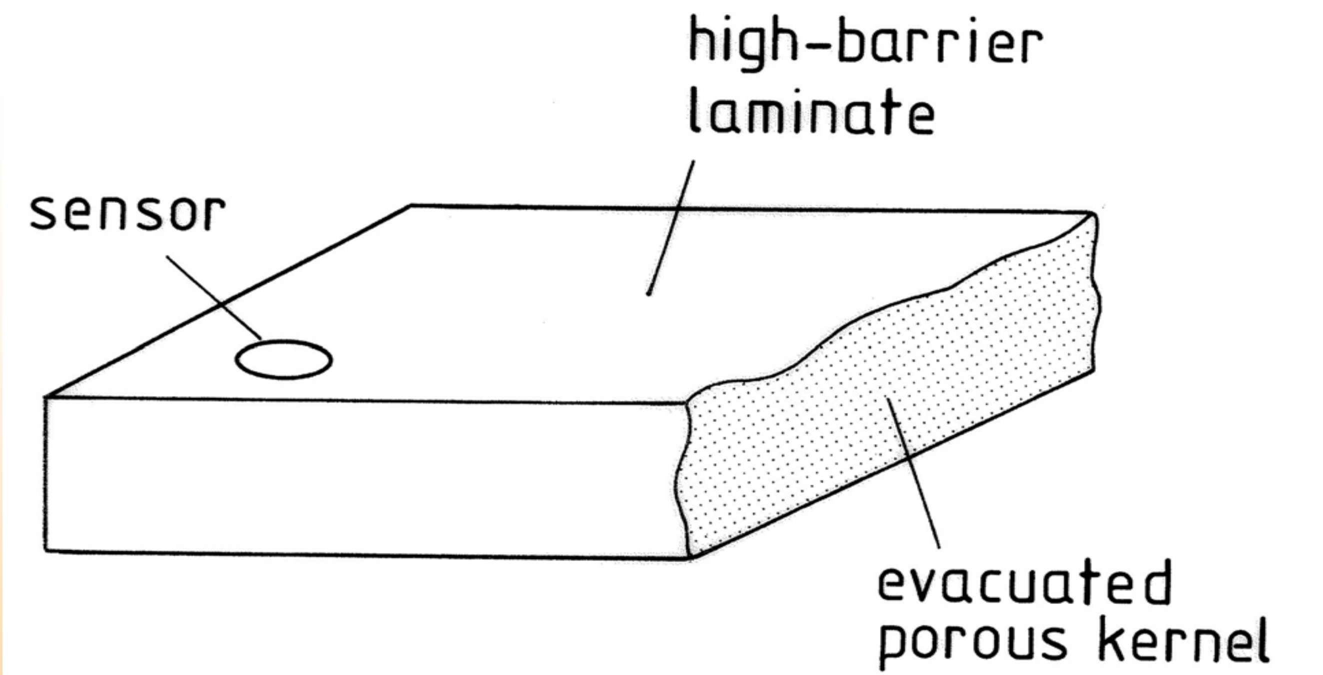
Owens Corning panel

ZAE BAYERN

Owens Corning produced fiber-filled VIPs („Aura“) with a density of 240 kg/m^3, a 75 µm e-beam welded sheet steel envelope and a center-$\lambda \approx 0.002$ W/(m·K).

VIPs nowadays

ZAE BAYERN



Most VIPs today consist of a nanostructured open porous kernel, sealed into a high-barrier laminate or Al-foil; an integrated sensor is important for quality control, i.e. an early detection of leakage.

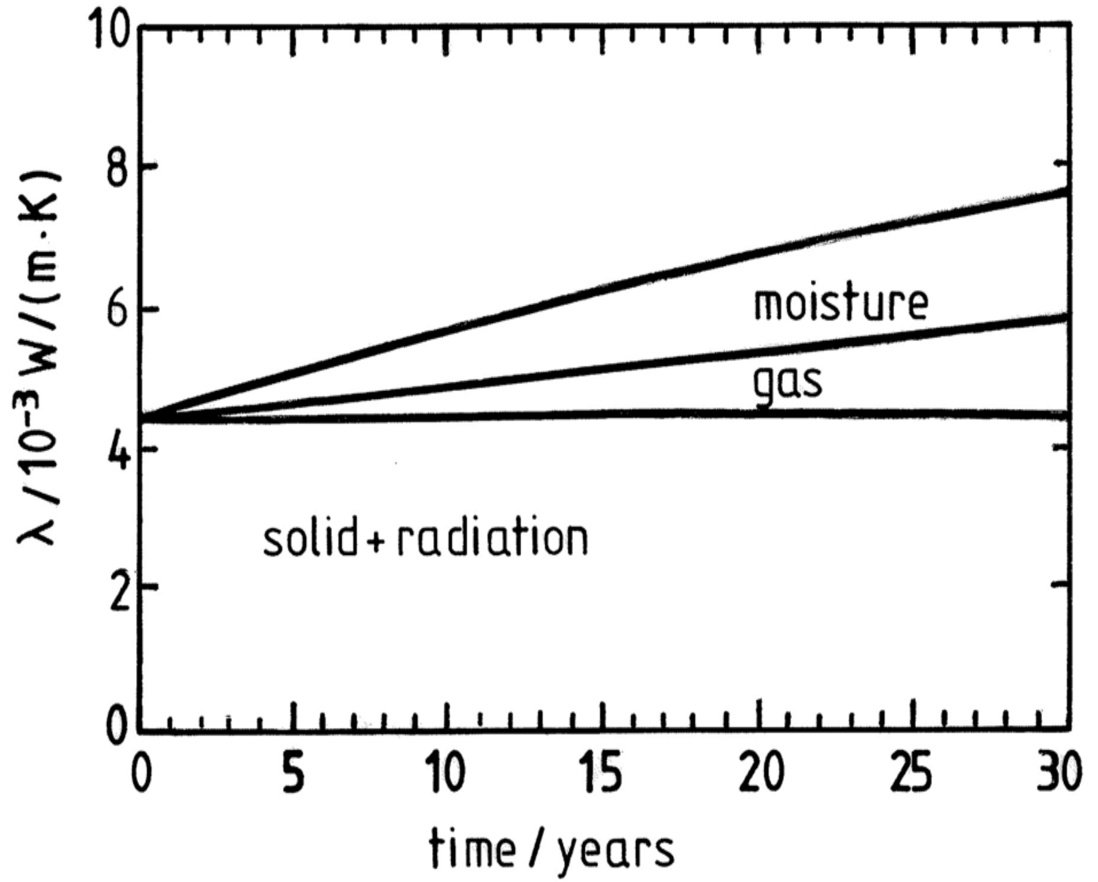
CONTENT

ZAE BAYERN

- Introduction
- Materials Research for VIPs
- Progress in Thermophysics Knowhow
- Early VIP-Constructions
- Lessons to heed
- Conclusions and Outlook

Ageing

ZAE BAYERN



From long-time permeation measurements servive lives of several decades in buildings with thermal conductivities below 0.008 W/(m·K) can be expected for VIPs with fumed silica kernel sealed under stringent quality control in high barrier laminate.

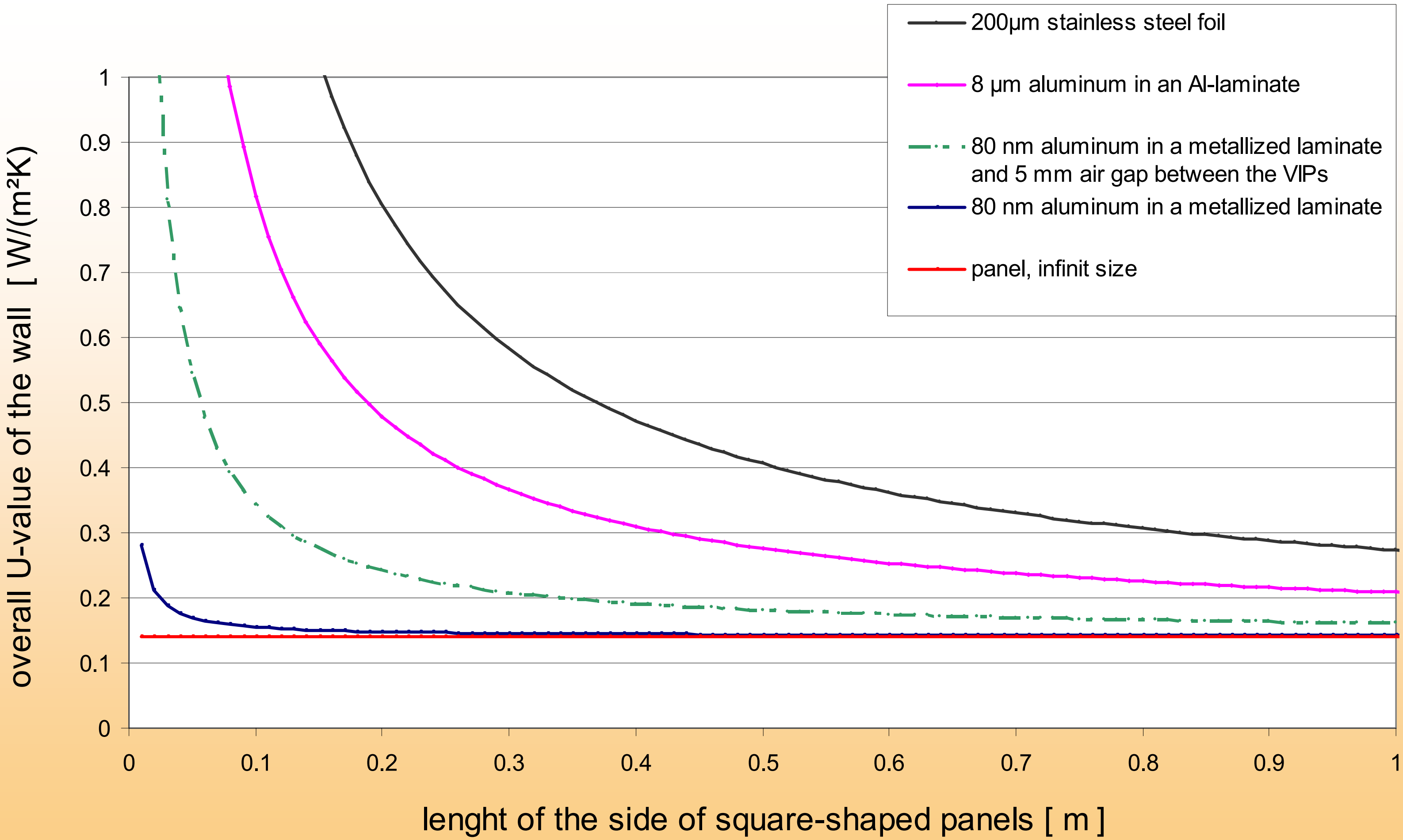
Quality controlled VIPs

ZAE BAYERN

- have a pre-dried kernel – otherwise small pressure increases, which woulds indicate a leaky panel, are masked by the water vapor pressure;
- carry information on the kernel material, the background pressure and the center thermal conductivity upon delivery;
- state the type of envelope, Al-foil or Al-coated laminate, which determine the effective thermal conductivity of the VIP; an upper limit can be calculated as follows:
  $\lambda_{eff}/(W{\cdot}m^{-1}{\cdot}K^{-1}) \approx \lambda_{center}/(W{\cdot}m^{-1}{\cdot}K^{-1}) + 800{\cdot}(d_{Al}/L)$;
  for $\lambda_{center} = 0.005$ W(m·K), $d_{Al} = 8$ µm and L = 0.5 m one obtaines
  $\lambda_{eff} \approx 0.018$ W/(m·K).

Thermal bridging (envelope and gaps)

ZAE BAYERN



Wall: 17.5 cm sand-lime brick, 3cm VIP + 3 cm PS

Conclusion and Outlook

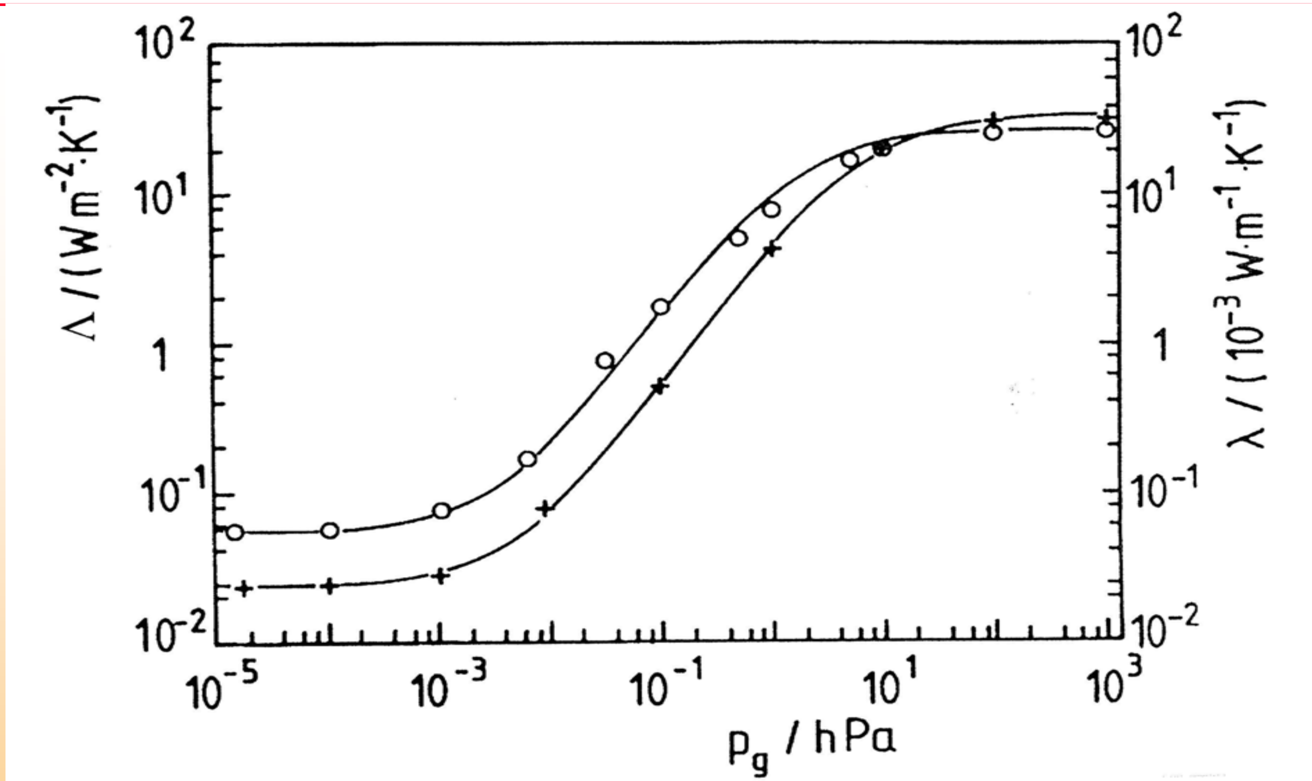
ZAE BAYERN

- Extensive R&D over more than one century has made VIPs reliable, high performance insulation systems, provided that stringent quality control is adopted and guaranteed;
- an integrated sensor (goal: RFID) improves the faith in the reliability of VIPs considerably;
- ongoing R&D aims at the further improvement of the barrier efficiency, enabling the use of cheaper kernel materials.

ZAE BAYERN

Vacuum foil insulation

ZAE BAYERN



Evacuated foil insulations for cryogenic applications provide extremely low heat transfer coefficients and apparent thermal conductivities; T = 303 K, d = 1mm; o = 1 reflective layer, + = 7 reflective layers.

Sol-gel process

ZAE BAYERN

hydrolysis of tetramethoxysilane:

$$Si(OCH_3)_4 + 4\,H_2O \xrightarrow{\text{kat.}} Si(OH)_4 + 4\,CH_3OH$$

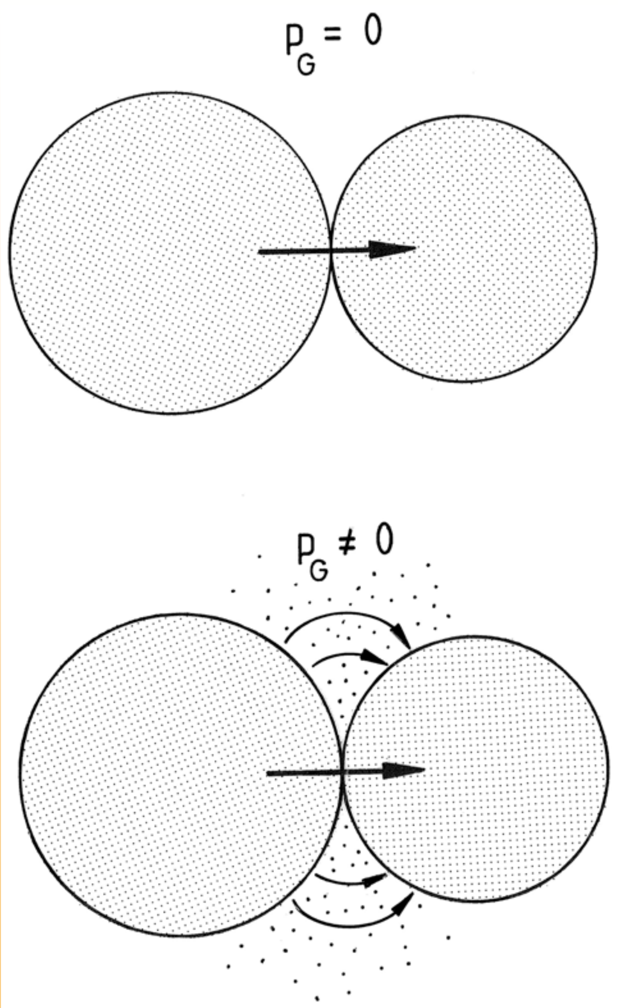
polycondensation:

$$n\ Si(OH)_4 \xrightarrow{\text{kat.}} [SiO_2]_n + 2n\ H_2O$$

The wet gel is either supercritically dried in an autoclave or – after hydrophobization of the inner surface – under ambient conditions.

Coupling

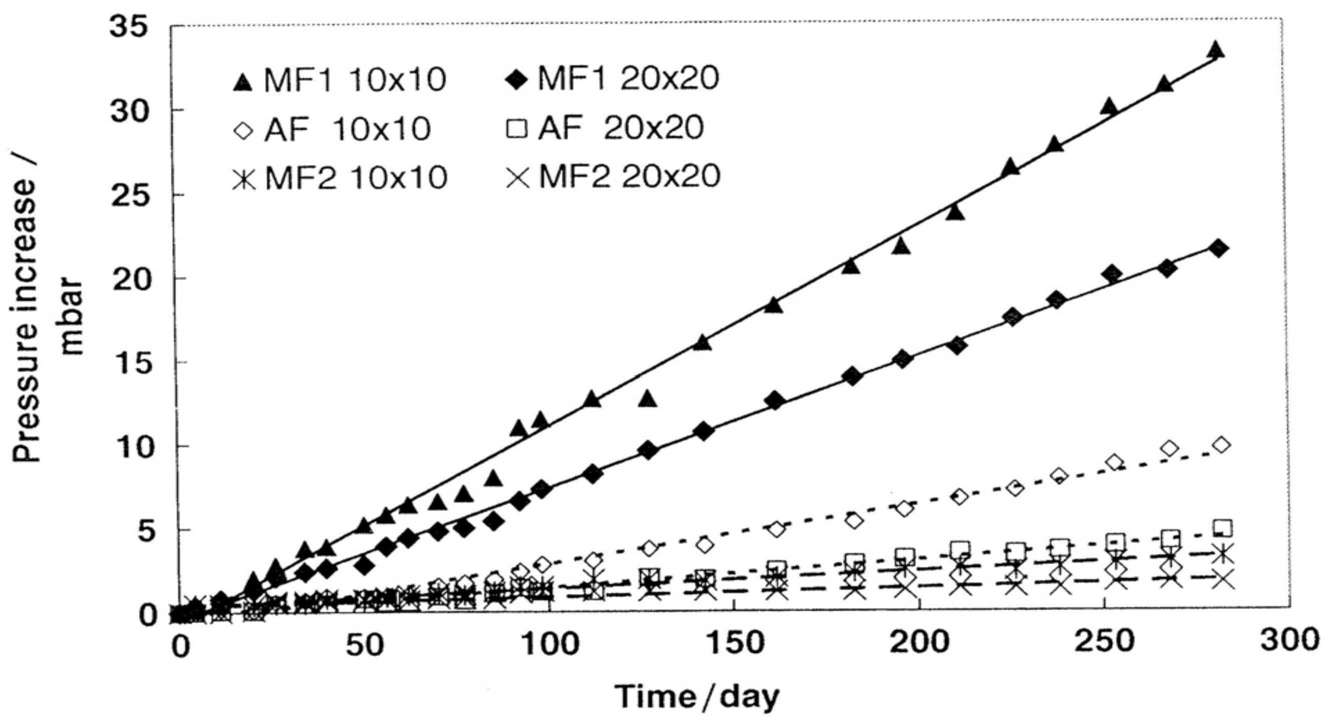
ZAE BAYERN



In vacuum the point contacts between adjacent beads provide high thermal resistances, which in air are more or less are shorted out; the higher the conductivity of the solid beads, the stronger is the coupling effect.

Pressure increase

ZAE BAYERN



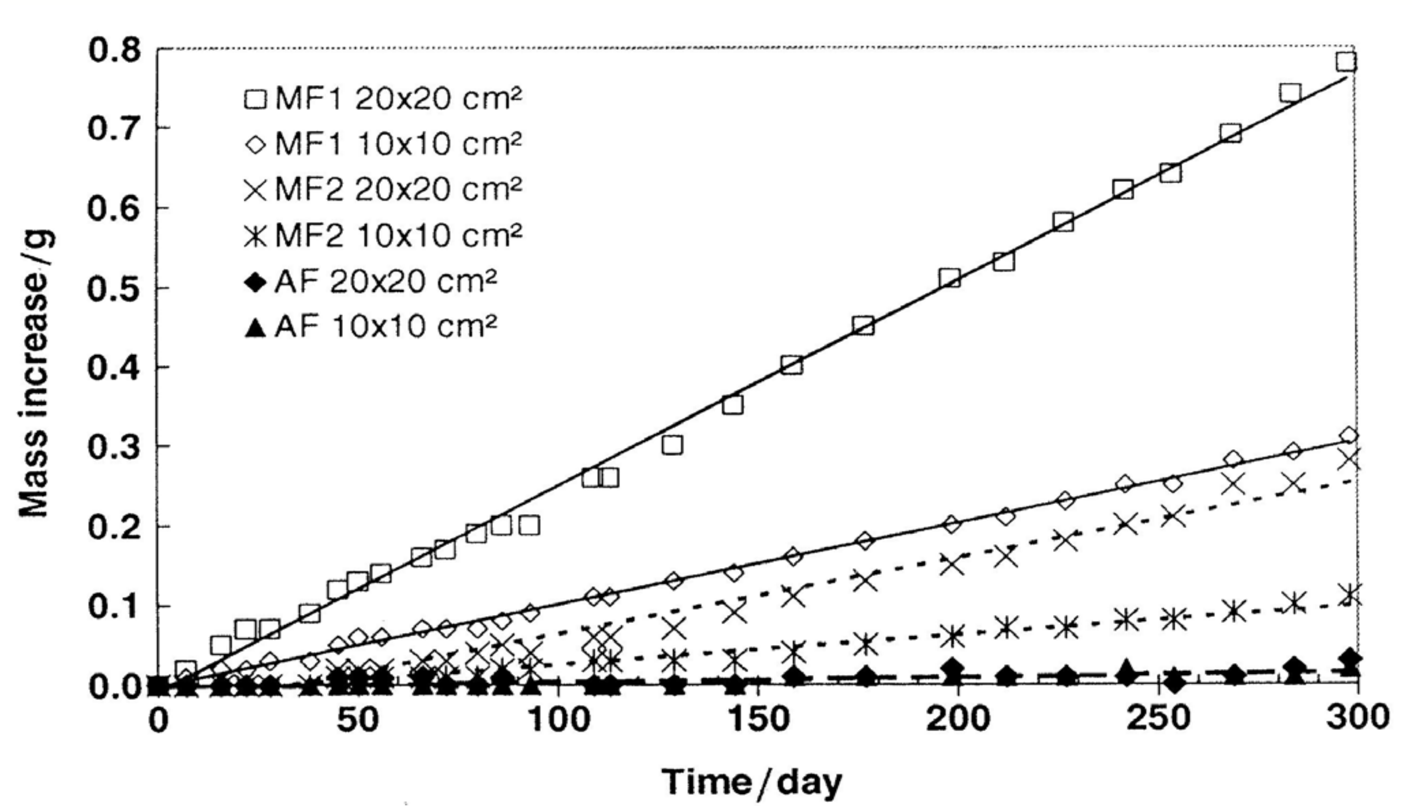
$dp_G/dt =$
$\Theta_A \cdot 2A/(A \cdot d) =$
$2\Theta_A/d$

$dp_G/dt =$
$\Theta_L \cdot 4L/(L^2 \cdot d) =$
$4\Theta_L /(L \cdot d)$

Measured pressure increase with time for VIPs of different size with fumed silica kernels in a dry atmosphere; AF = Al-foil laminated with PE; MF1, MF2 = Al-coated multilayer laminates.

Mass increase

ZAE BAYERN



dm/dt = $\Theta_A \cdot 2A$

dm/dt = $\Theta_L \cdot 4L$

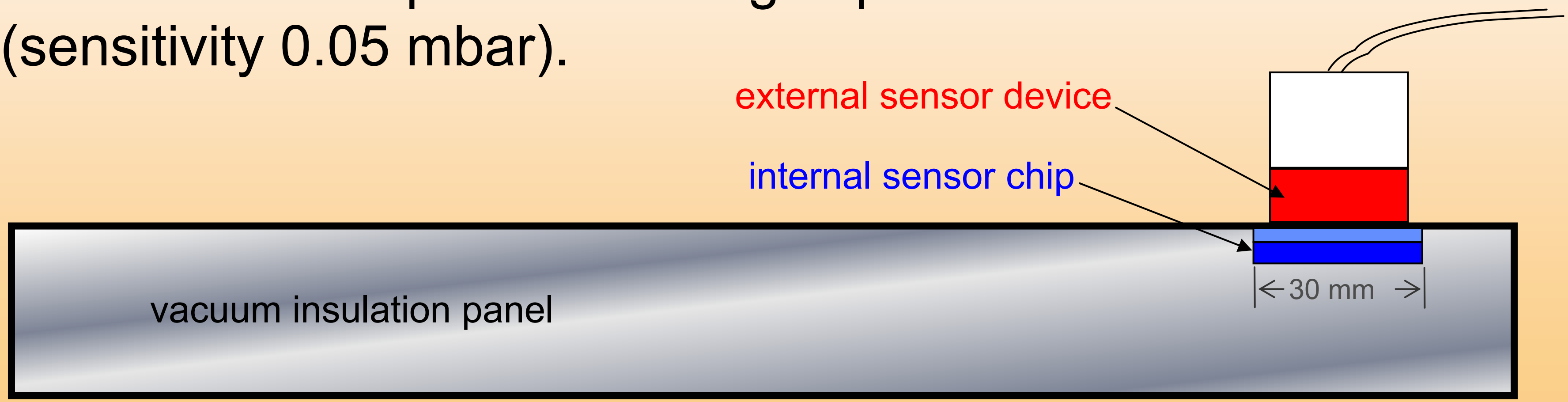
Measured mass increase over time for VIPs of different size with fumed silica kernels in a moist atmosphere.

Sensor

ZAE BAYERN

va-Q-check sensor :

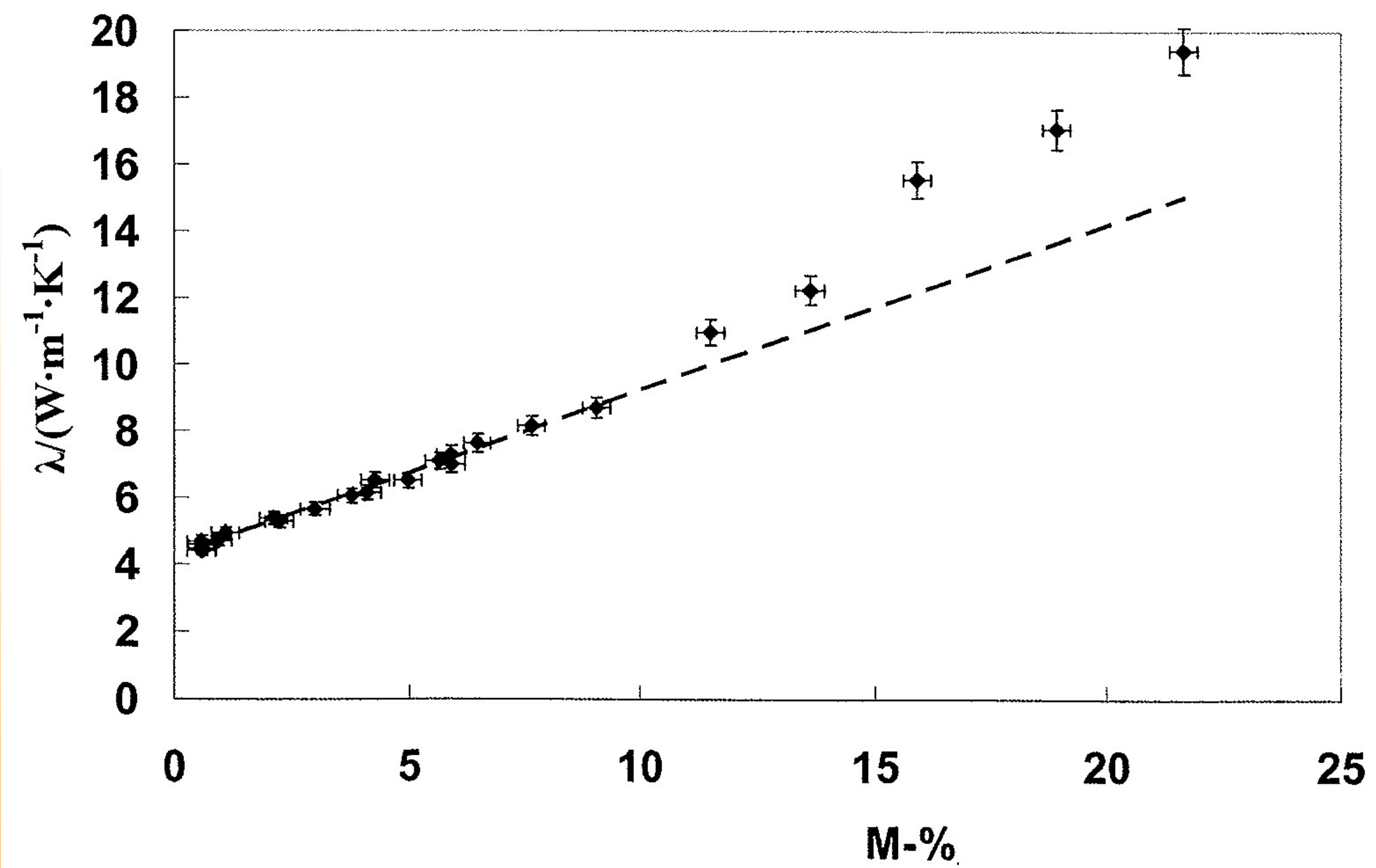
A preheated sensor head is pressed onto the VIP above the sensor chip.
The heat flux through the laminate into the internal sensor chip is measured for T = const. within typically 10 s.
The heat flux depends on the gas pressure within the VIP (sensitivity 0.05 mbar).



www.va-Q-tec.com

Moisture-related conductivity

ZAE BAYERN



Thermal conductivity of evacuated moisturized VIPs as a function of the water content at 10°C.