AEROGEL BASED PRODUCTS FOR THERMAL INSULATION OF BUILDINGS

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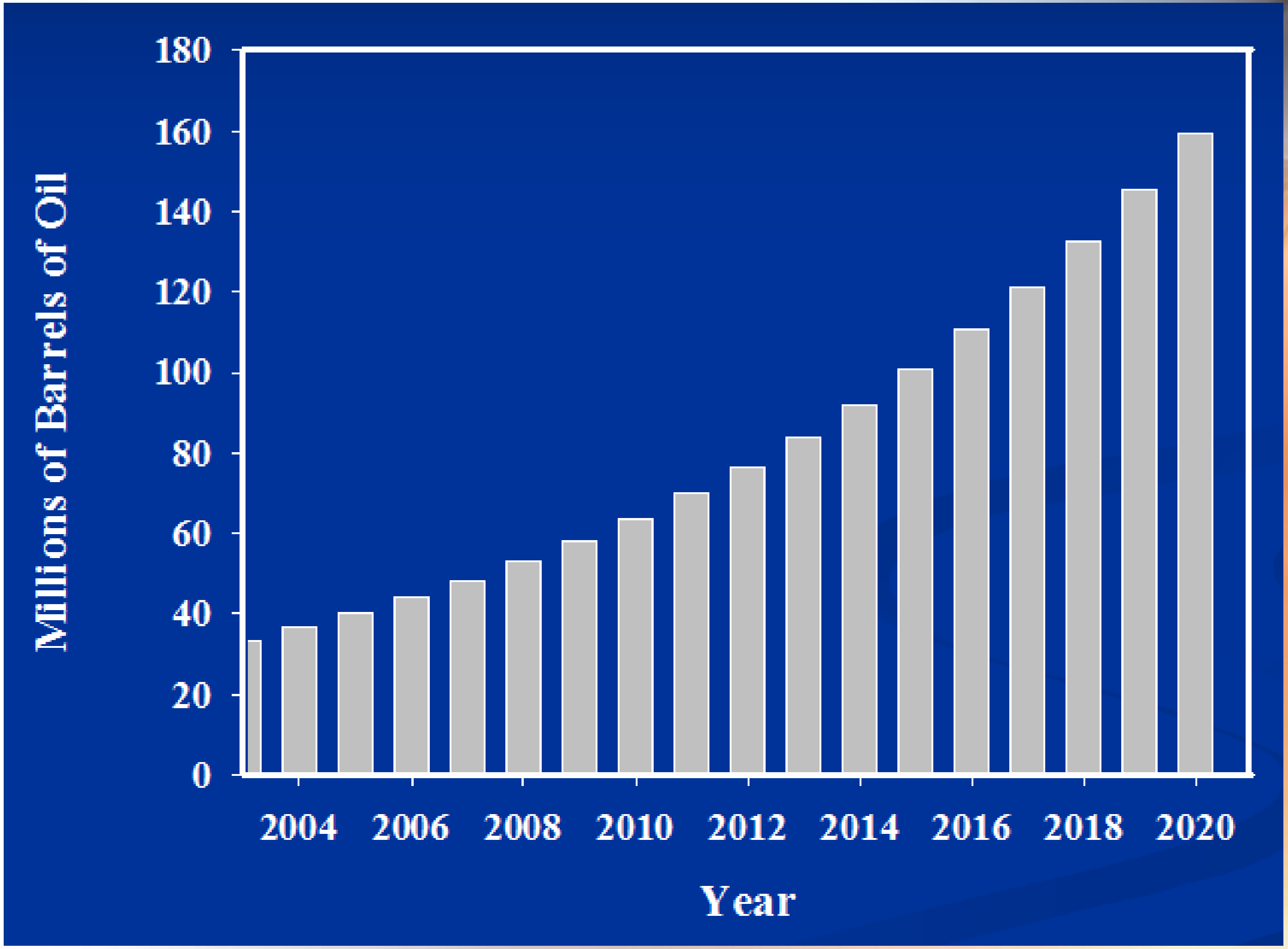
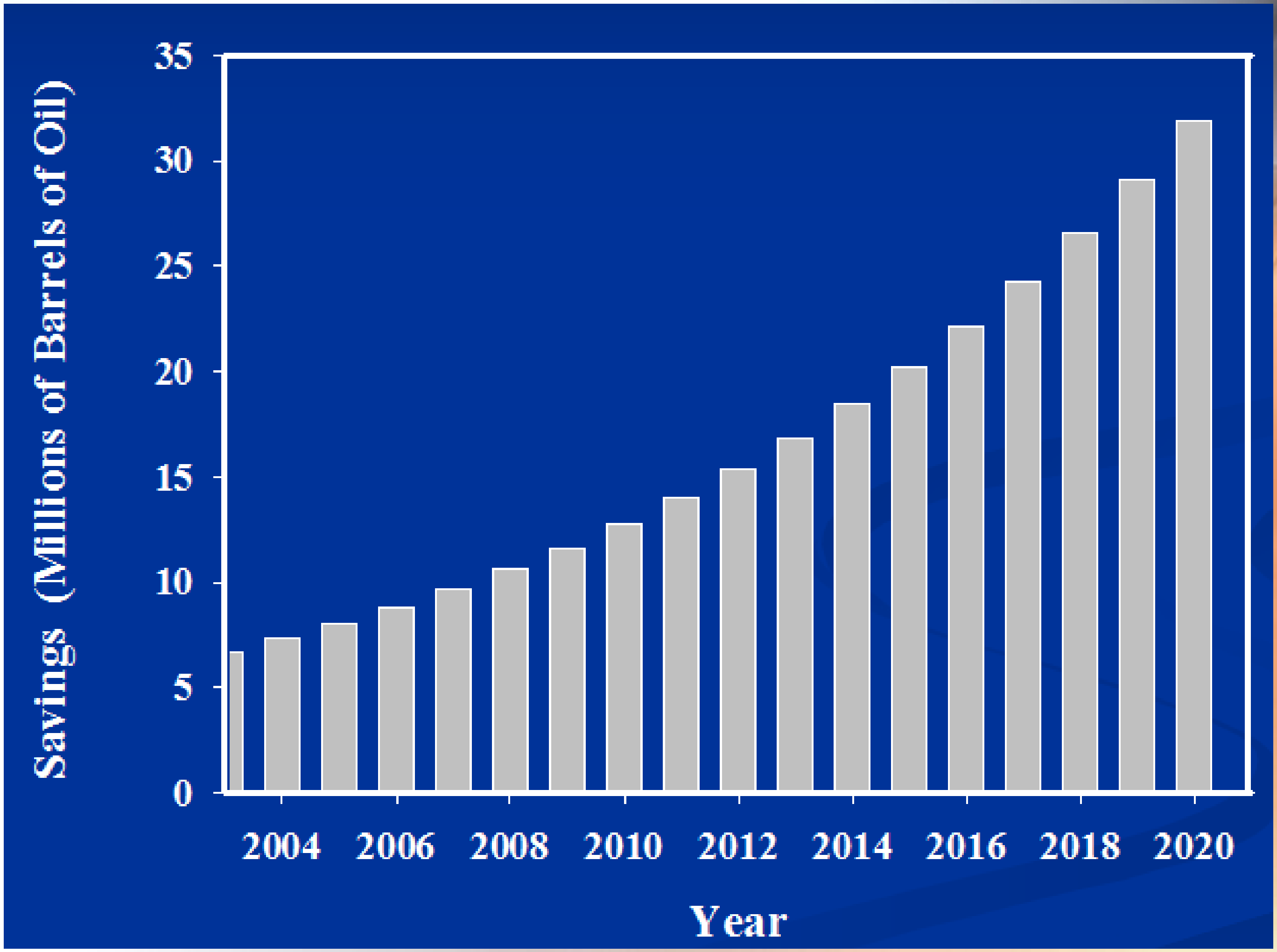
Projections of Residential Energy Consumption in Turkey



Forecasting of Turkey's net electricity energy consumption on sectoral bases
Coşkun Hamzaçebi, Energy Policy, 35, 2009 (2007)

Savings of Turkey by Reducing Residential Energy Consumption by 20% by Insulation



1 Barrel of Oil ➔ ~$50

Heat Losses from Windows of Buildings

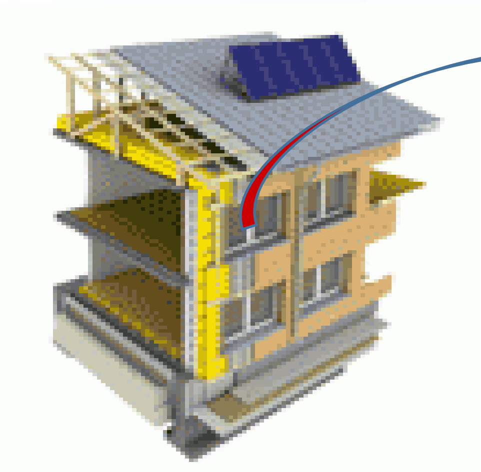
Ref: Retrieved from http://www.imagingnotes.com (image courtesy of FLIR Systems, Inc.)

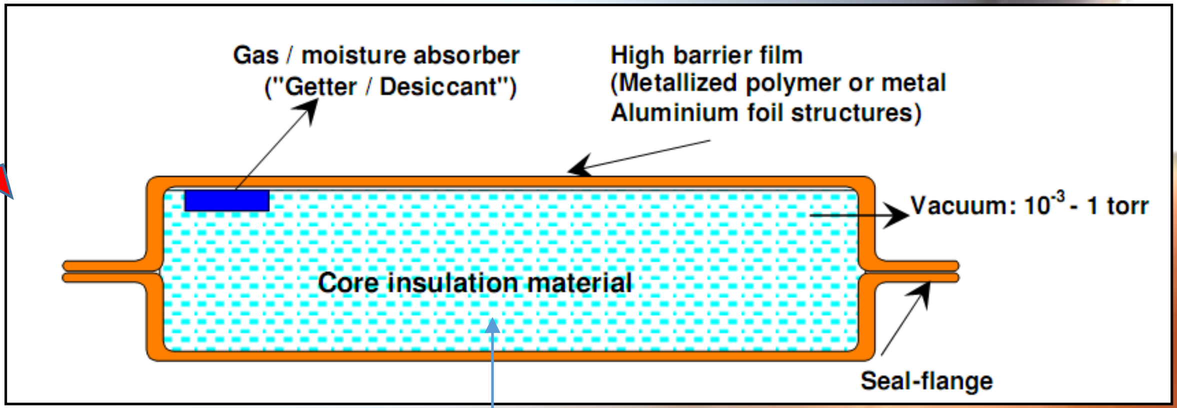
Transparent Thermal Insulation Systems

Possible Solutions:

- Instead of argon or air, use a transparent insulator
- Replace glass with a transparent insulator

Vacuum Insulation Panels

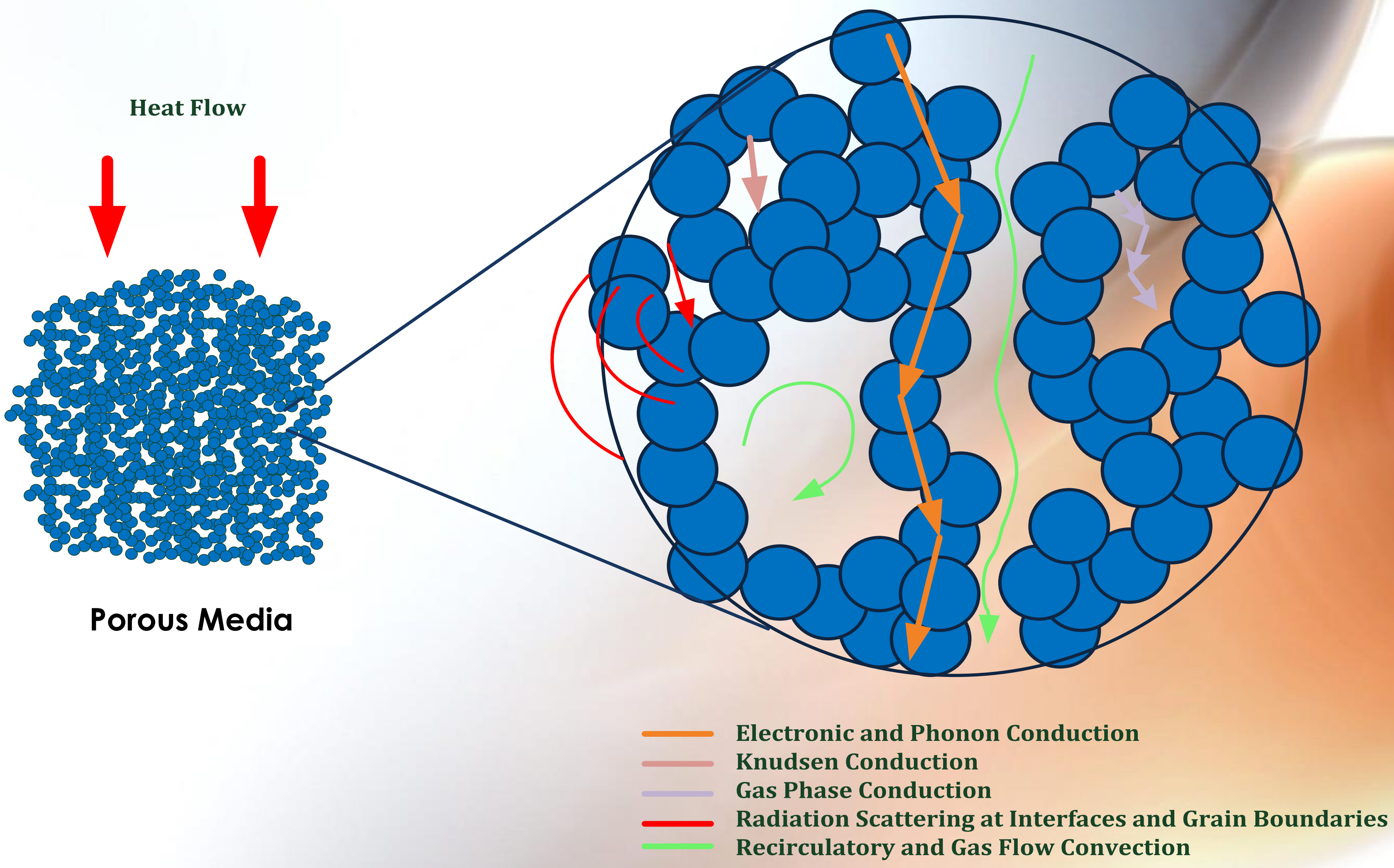




Fumed silica, glass fiber

NOT TRANSPARENT

Heat Transfer in Porous Materials



Fundamental Mechanisms of Heat Transfer

- Conduction
- Convection
- Radiation
- Coupling Terms

Circuit in Series

$$\lambda_{total} = \lambda_{conduction} + \lambda_{convection} + \lambda_{radiation} + \lambda_{coupling\ terms}$$

Fundamental Mechanisms of Heat Transfer

$$\lambda_{total} = \lambda_{conduction} + \lambda_{convection} + \lambda_{radiation} + \lambda_{coupling\ terms}$$

FLOW OF THE GAS MOLECULES WITHIN THE PORES ARE SUPPRESSED OWING TO THE FINE PORE SIZES OF THE AEROGEL STRUCTURE

NEGLIGIBLE

Fundamental Mechanisms of Heat Transfer

$$\lambda_{total} = \lambda_{conduction} + \lambda_{radiation}$$

Solid Conduction
Gaseous (Knudsen) Conduction

Scattering at Interfaces &
Grain Boundaries

Solid Conduction

Depends on the structural parameters of the porous material:

- Density
- Porosity
- Interconnectivity of the pores

Hrubesh et.al. & Fricke et.al.;

$$\lambda_s = \lambda_s^o V_s \left(\frac{\upsilon_p}{\upsilon_d} \right)$$

λ_s : Solid network conductivity

λ_s^o : Intrinsic conductivity of network material

V_s : Volume fraction of the solid

υ_p , υ_d : Sound velocities in porous and dense bodies

Solid Conduction

$$\lambda_s = \lambda_s^o V_s \left(\frac{\upsilon_p}{\upsilon_d} \right)$$

Solid conduction can be reduced by:

- reducing the intrinsic conductivity of network material λ_s^o
- and reducing the volume fraction of the solid V_s (increasing the porosity)

Gaseous Conduction: *Knudsen Conduction*

Knudsen equation:

$$\lambda_g = \frac{\lambda_g^o V_g}{(1+\beta K_n)}$$

λ_g^o : Thermal conductivity of free air

β : Parameter considering energy transfer between gas molecules & solid matrix (~2)

V_g : Volume fraction of the voids (porosity)

K_n : Knudsen number

Gaseous Conduction: *Knudsen Conduction*

Knudsen number:

$$K_n = \frac{l_g}{\phi}$$

l_g : Mean free path of gas molecules

ϕ : Pore diameter

From Kinetic Theory of Gases:

$$l_g = \frac{k_B T}{\sqrt{2}\pi d_g^2 P}$$

k_B : Boltzmann constant

d_g : Average size of gas molecules

T, P : Temperature & Pressure

Gaseous Conduction: *Knudsen Conduction*

For air at ambient conditions:

$$\lambda_g^o = 2.534 \times 10^{-2} W / mK$$

$$\beta \approx 2$$

$$K_n = \frac{70}{\phi}$$

$$\lambda_g = \frac{2.534 \times 10^{-2} V_g}{\left(1 + \frac{140}{\phi}\right)}$$

Gaseous Conduction: *Knudsen Conduction*

For air at ambient conditions:

$$\lambda_g = \frac{2.534\times10^{-2}V_g}{\left(1+\frac{140}{\phi}\right)} \quad \Bigg\} \quad \lambda_g \approx 1.7\times10^{-5}V_g\phi \quad \text{for} \quad \phi << 140nm$$

Knudsen conduction can be reduced by:

- reducing the average pore size
- reducing the porosity

Radiation: *Scattering at Interfaces & Grain Boundaries*

Becomes significant for transparent porous materials: affected by the scale of the pore structure

Rosseland approximation:

$$\lambda_r = \frac{16}{3}\frac{\sigma n^2 T^3}{\rho e(T)}$$

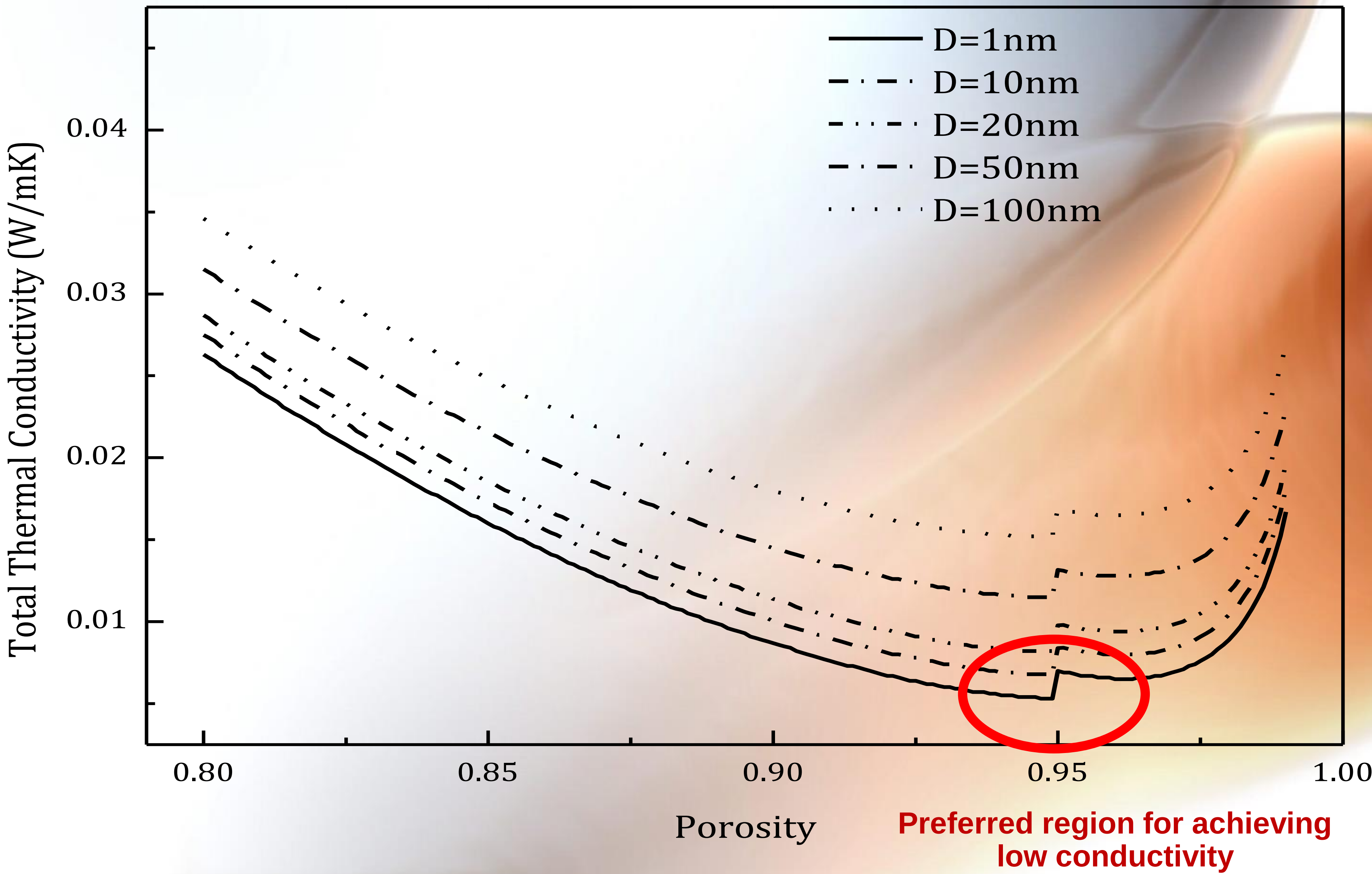
σ : Stephen-Boltzmann constant

ρ : Density of the material

$e(T)$: Mass-specific extinction coefficient

T : Absolute temperature

Effect of Porosity and Pore Size on Total Thermal Conductivity



Total Thermal Conductivity

Desired material properties for low thermal conductivity:

- Low density
- High porosity
- Small pore sizes

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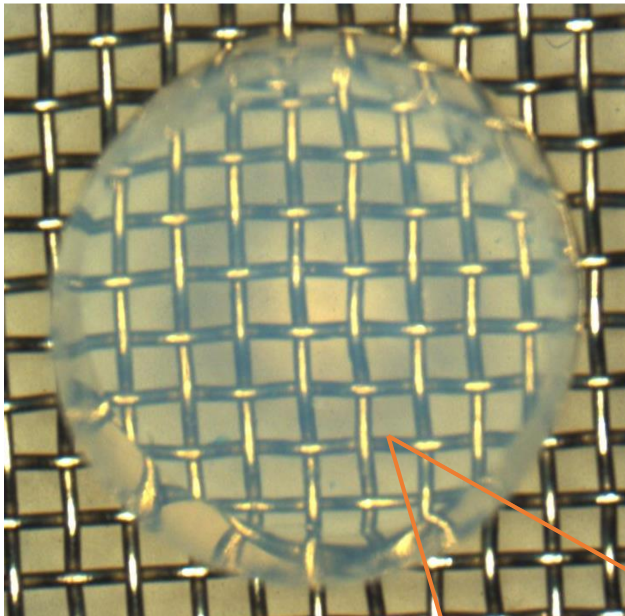
AEROGELS

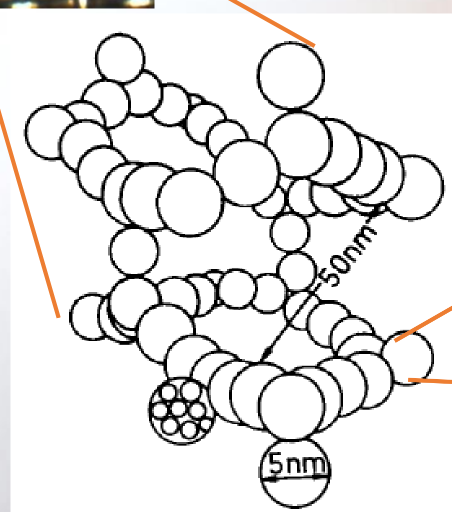
Silica Aerogels & Insulation

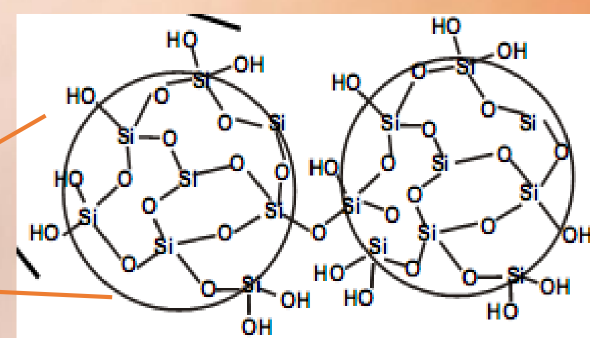


Why Silica Aerogels?

- ✓ monolithic
- ✓ high porosity (80-99%)
- ✓ transparent
- ✓ low density (as low as 3 kg/m^3)
- ✓ pore sizes smaller than 50 nm

AEROGELS ARE PERFECT CANDIDATES FOR TRANSPARENT INSULATION SYSTEMS

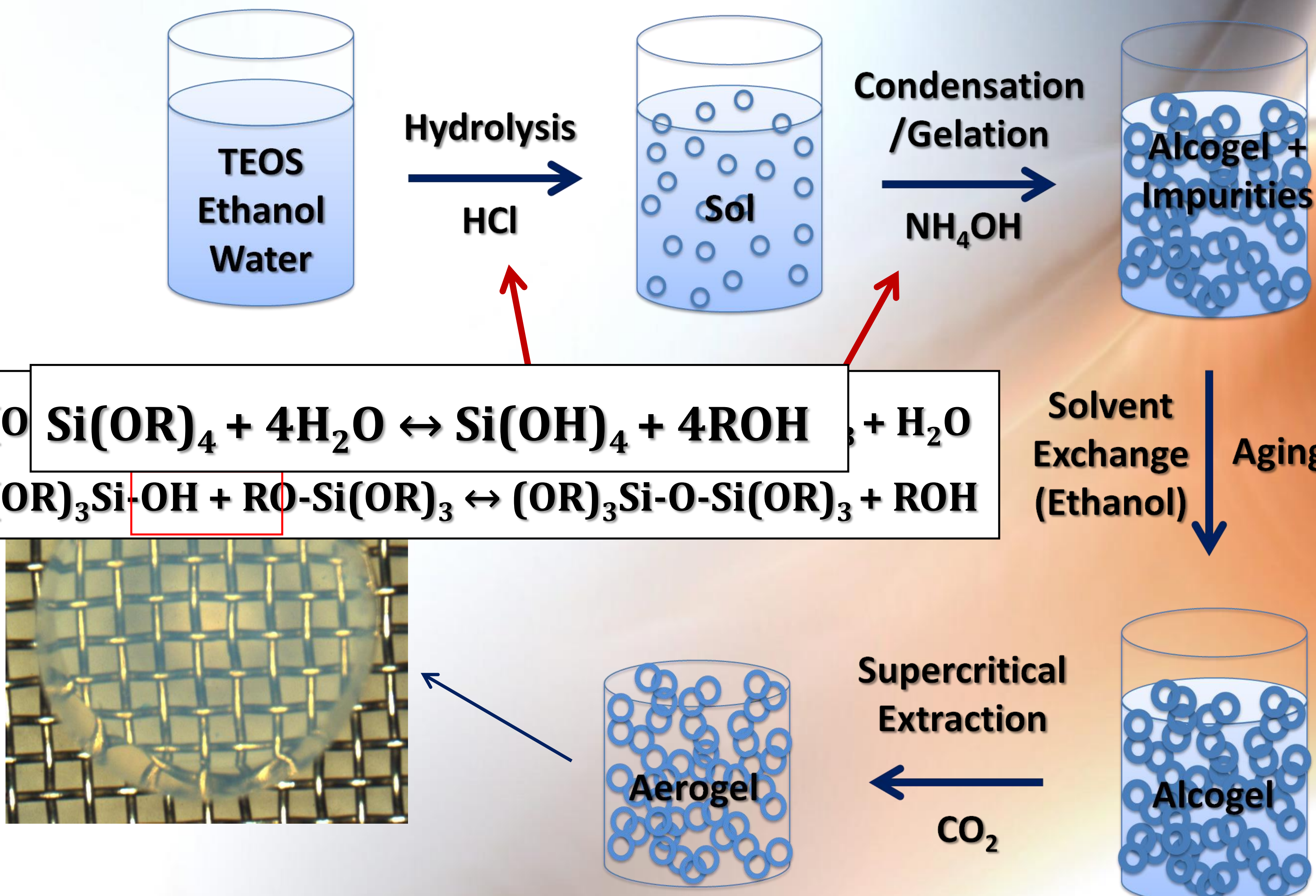




OBJECTIVE: DEVELOP AEROGEL BASED TRANSPARENT VACUUM INSULATION PANELS

No.	Beneficiary		Country	Activity in project
1	KINGSPAN	Kingspan	IE	Project co-ordination. Design of large VIP, pilot plant development and end user
2	PERA	PERA The Innovation Network	UK	Process manufacture/pilot scale up Project management and administration
3	HANITA	Hanita Coatings	IL	Barrier films and VIP production
4	VA-Q-TEC	va-Q-tec vacuum insulation	DE	Materials, design of VIP prototype and process development
5	FRAUNHOFER†	Fraunhofer	DE	Transparent and opaque barrier films, characterisation and development, VIP production, simulation and modelling of the building envelope and VIPs
6	KOÇ	KOÇ UNIVERSITY	TR	Development of aerogels and aerogel-polymer composites
7	AIRGLASS	Airglass	SE	Aerogel-polymer composite producers; production of aerogel-polymer composite panels, up-scaling, cost reduction
8	BASF	BASF The Chemical Company	DE	Nanofoam development and process up-scaling
9	GAIKER	GAIKER ik4 research alliance	ES	Lifecycle assessment, cost analysis, safety assessment, end-of-life studies
10	ACCIONA	acciona Pioneros en desarrollo y sostenibilidad	ES	Component assessment and demonstration in building applications

Synthesis of Aerogels

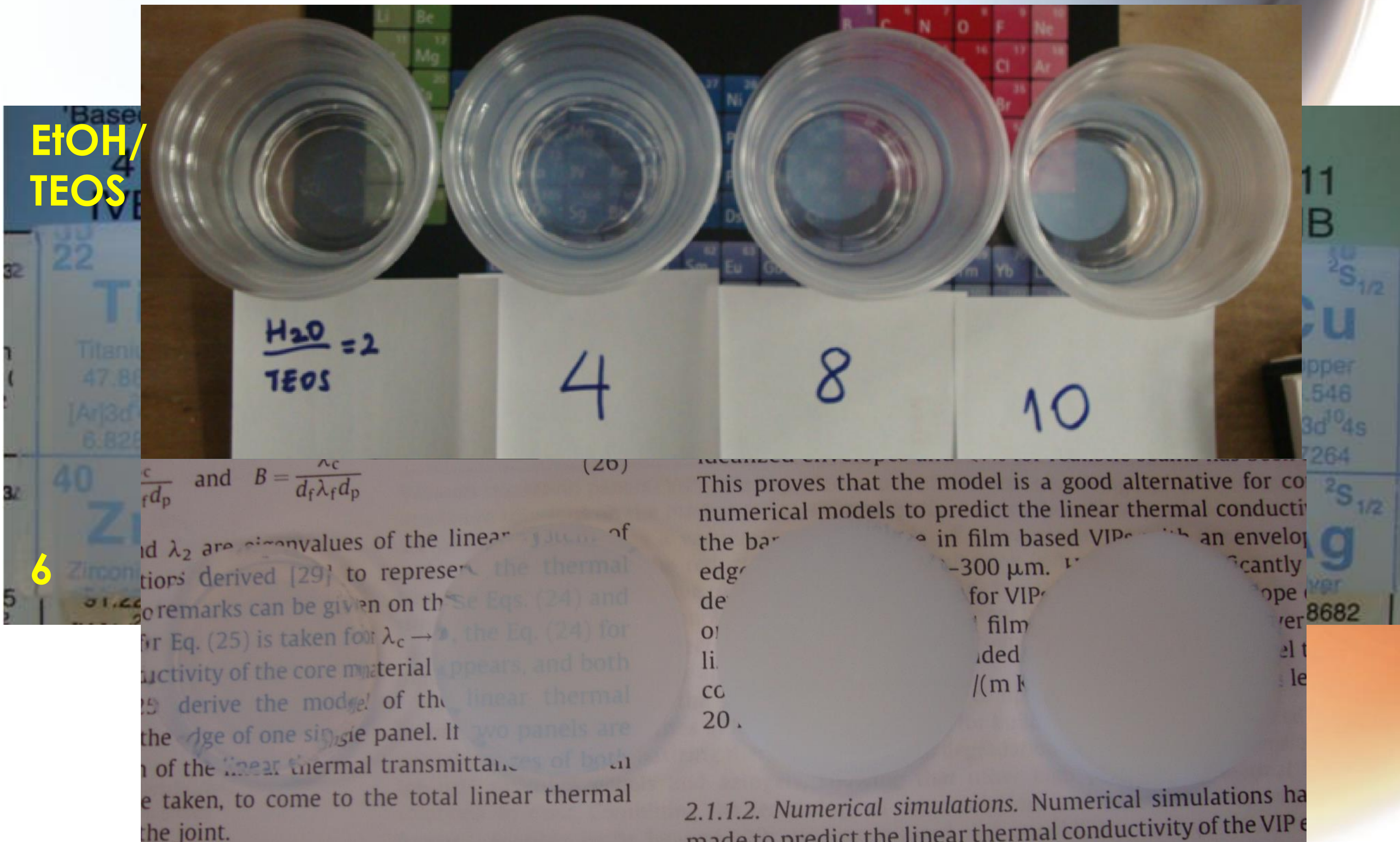


$$Si(OR)_4 + 4H_2O \leftrightarrow Si(OH)_4 + 4ROH$$

(O … $+ H_2O$

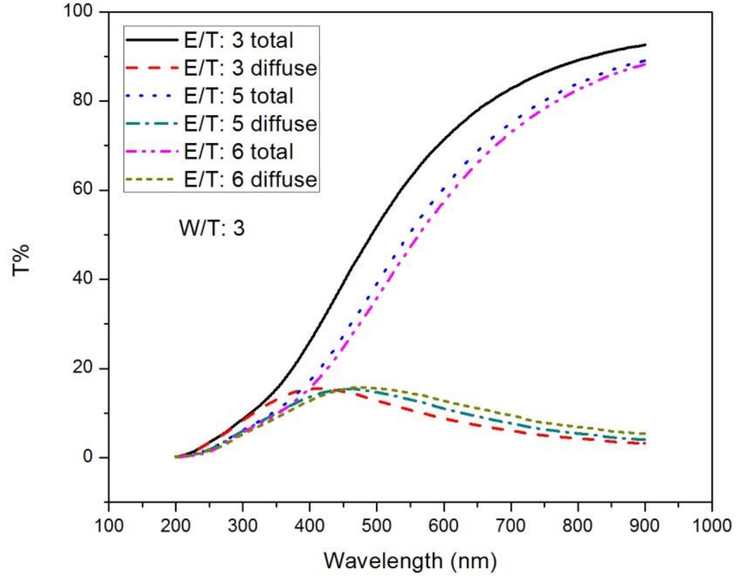
$$(OR)_3Si\text{-}OH + RO\text{-}Si(OR)_3 \leftrightarrow (OR)_3Si\text{-}O\text{-}Si(OR)_3 + ROH$$

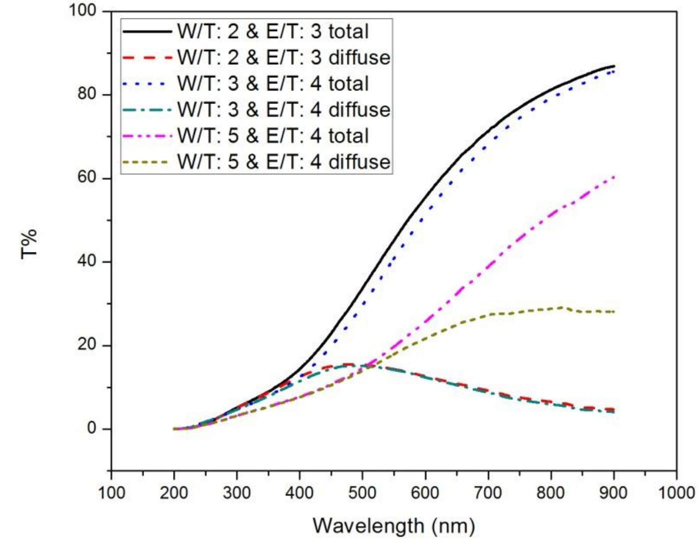
Effect of Reactant Concentration on Transparency



H_2O/TEOS molar ratios: 2, 4, 8, 10 (constant EtOH/TEOS: 4)

Effect of Reactant Concentration on Transparency





EtOH/TEOS molar ratios

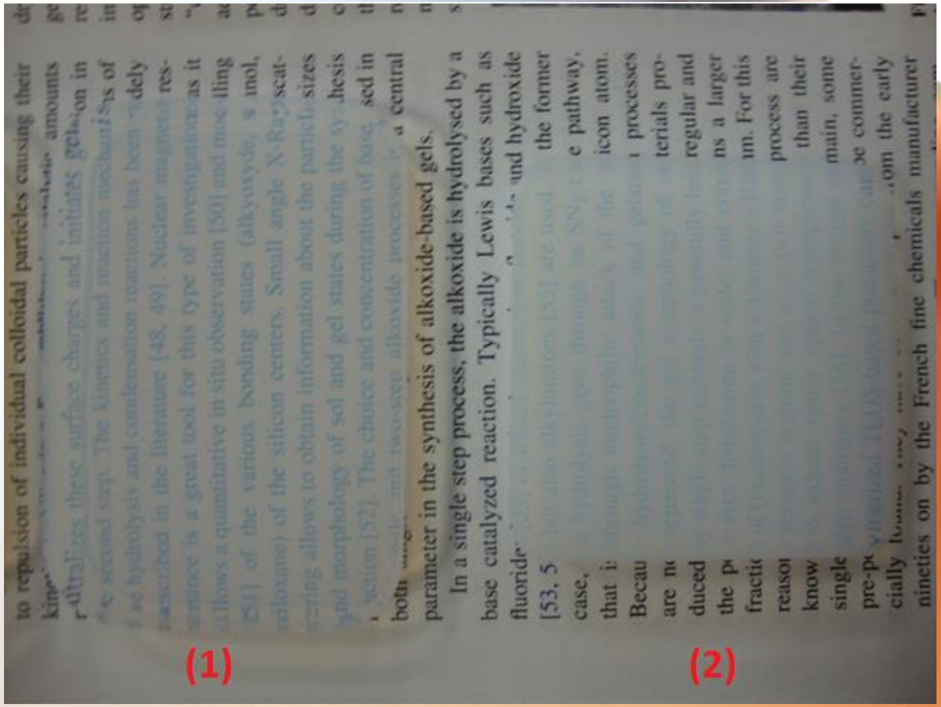
Water/TEOS molar ratios

E/T Rati nm)	@ 600
3	87.7
5	81.8
6	77.8

Effect of Mold Materials on Surface Scattering

- **Types of molds**
  - **Glass**
  - **Teflon**
  - **Polypropylene (PP)**
  - **Plexiglass (polymethylmethacrylate)**

Teflon and PP Molds



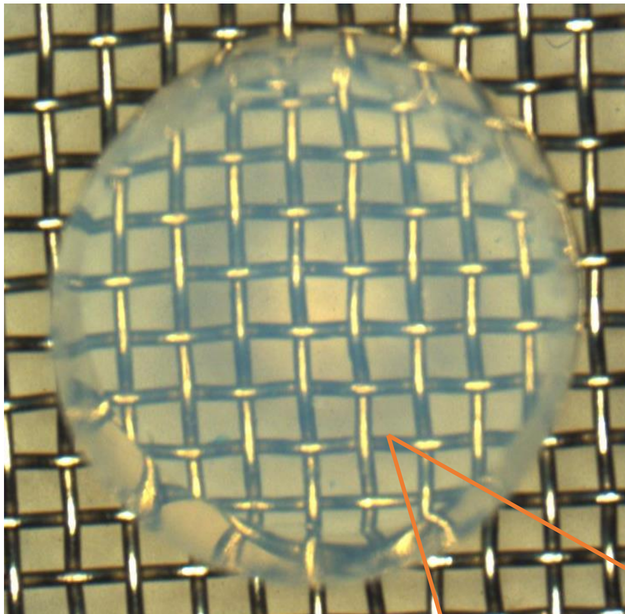
Aerogel synthesized in PP mold (1) and in Teflon mold (2)

Drawbacks:

- High surface roughness due to manufacturing

- Manufacturing of large scale Teflon and PP molds is not easy.

One Drawback of Silica Aerogels



- ✓ Fragile & brittle
- ✓ Poor mechanical properties

WAYS TO IMPROVE MECHANICAL PROPERTIES

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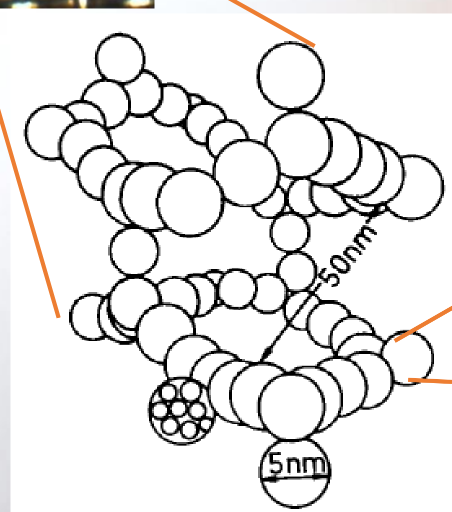
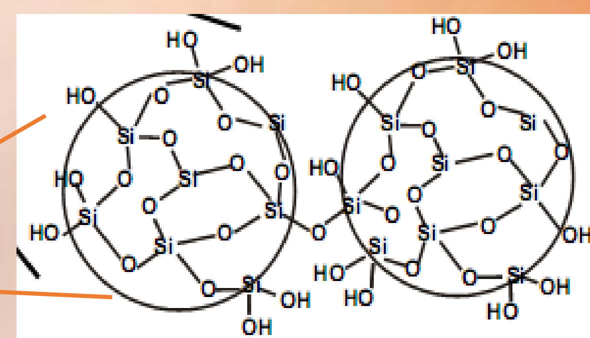
AEROGEL COMPOSITES



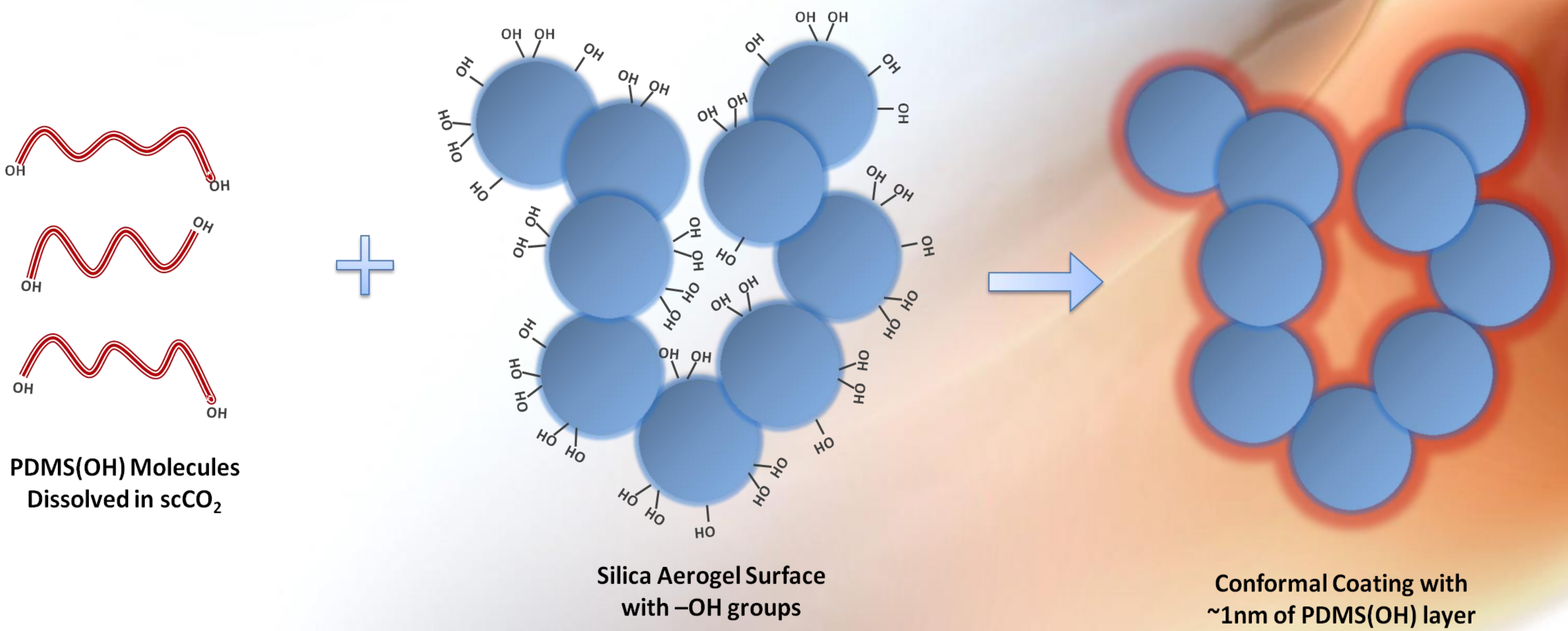


Typical Approaches to Produce Aerogel Composites with Polymers

1. **Blend with the silica network**
2. **Chemically linked to the silica network**
3. **H-bonding with the surface groups**
4. **Entagled within the pore**
5. **Reactive supercritical deposition of polymer**

Reactive Supercritical Deposition of PDMS(OH)

Conformal coating of the silica aerogel surface with a thin layer of polymer



Large Scale Production

50x35x2.2 cc plexiglas mold

35 L autoclave vessel

A Large Scale Transparent Silica Aerogel

(d: 0.180 g/mL and λ_T: 16 mW/m.K)

Fig.1: transparent VIP-aerogel

Available online at www.sciencedirect.com

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Development of Transparent and Opaque Vacuum Insulation Panels for Energy Efficient Buildings

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Abstract

One reason for heat losses in buildings is inadequate insulation. Vacuum Insulation Panels (VIPs) is emerging as a promising solution, being more energy efficient than conventional insulation materials, thinner and lighter. A VIP is made by placing a core insulation material inside a gas-barrier envelope and evacuating the air from inside the panel. The limitations to wide-scale VIP commercialization lie in lack of low-cost and high-volume processes to turn them into products suitable for use in buildings, and

Conclusion

- **Aerogels are perfect candidates for transparent insulation systems because of their transparency and low thermal conductivity**
- **Density, porosity and average pore size of the aerogels are the major parameters affecting their thermal conductivity**
- **EtOH/TEOS and H_2O/TEOS molar ratios and type of the mold used during gelation affect the transparency.**
- **One drawback of aerogels are their poor mechanical properties which can be improved by incorporation of polymers**
- **Among various routes, supercritical deposition seems to be promising to to obtain polymer-aerogel composites without losing the transparency**

ACKNOWLEDGEMENTS

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KOÇ UNIVERSITY

SEVENTH FRAMEWORK PROGRAMME

NanoInsulate


Thank you…