Alternative core materials for vacuum insulation

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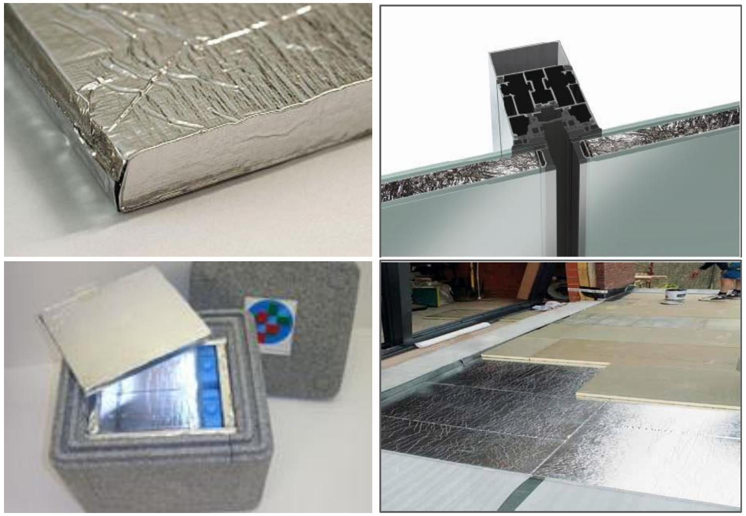
Thermal Performance of the Exterior Envelopes of Whole Buildings XIII International Conference

iowa energy center

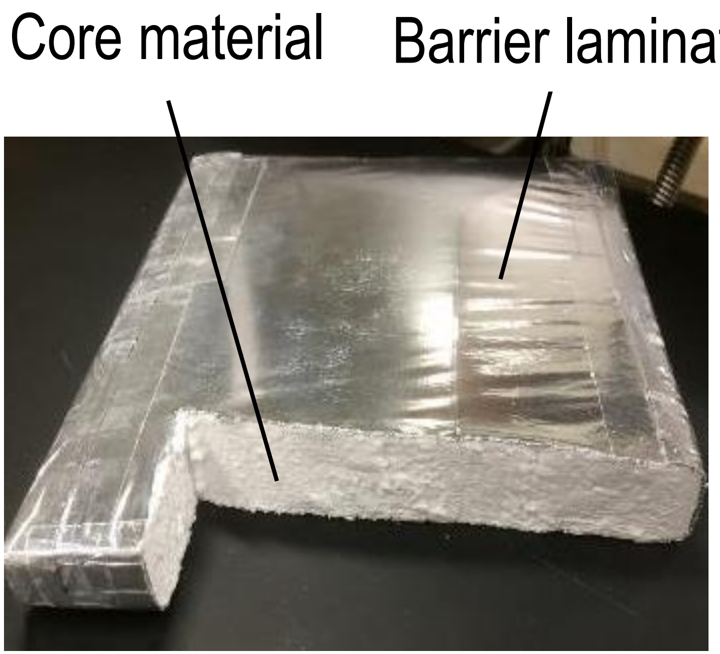
Next Generation Insulation

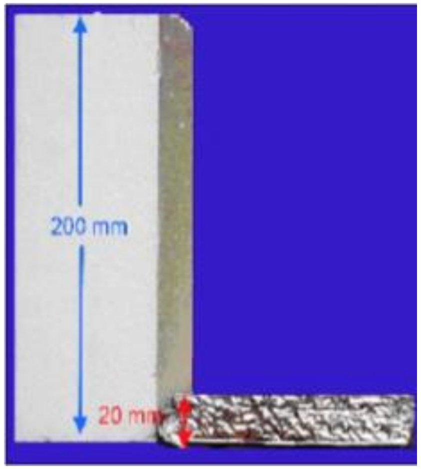
Traditional Insulation



ADVANCED INSULATION MATERIALS

Vacuum Insulation Panel (VIP): Highly porous core material is evacuated and then sealed by the barrier laminate





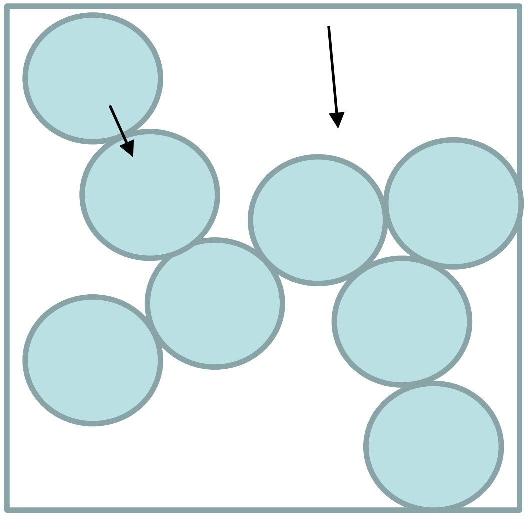
Insulation	R-value
Fiberglass & Cellulose	3-4
Expanded Polystyrene	4-5
Urethane Foams	5-8
VIP	**30-50**

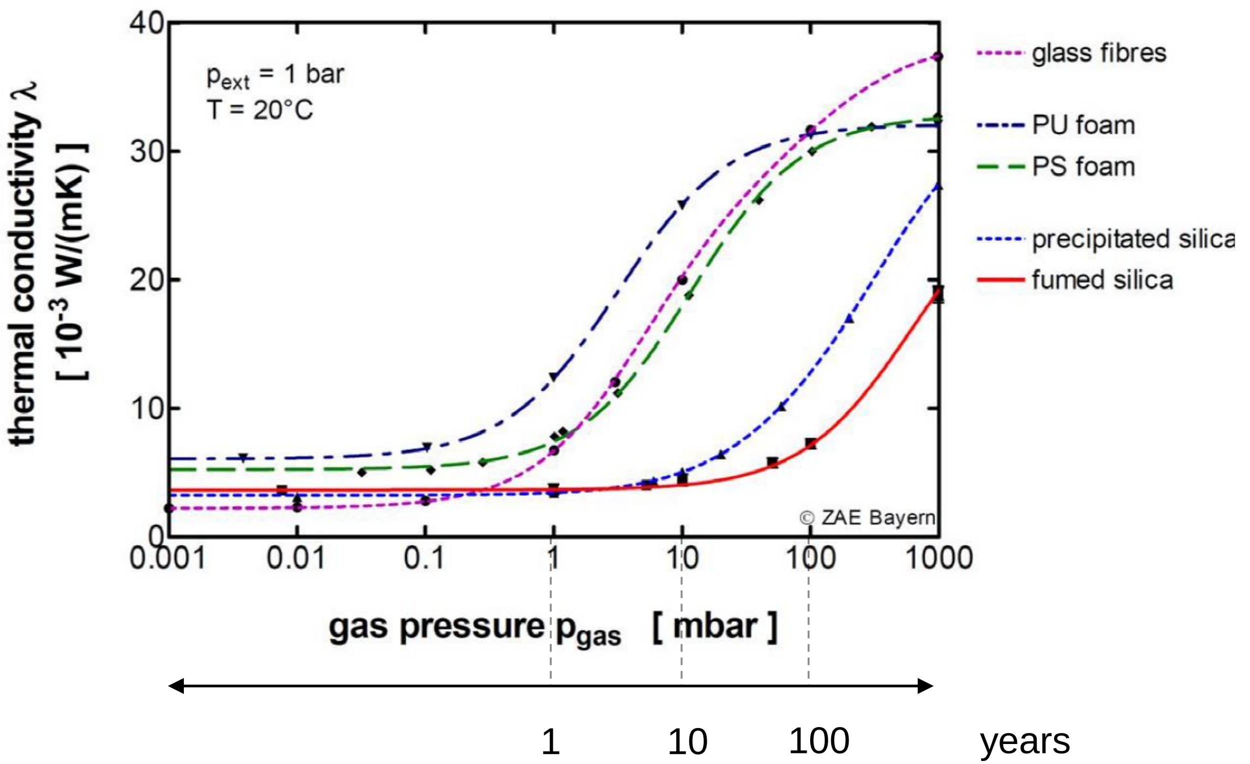
THEN WHY NOT?

Insulation	Cost ($/sq.ft)	Cost ($/sq.ft/R)
Fiberglass & Cellulose	0.4	0.13-0.1
Expanded Polystyrene	1.5	0.38-0.3
Urethane Foam	1.5	0.3-0.19
VIP	**5**	**0.17-0.1**

DOE target value for building applications is <$3 /sq.ft

AVAILABLE CORE MATERIALS



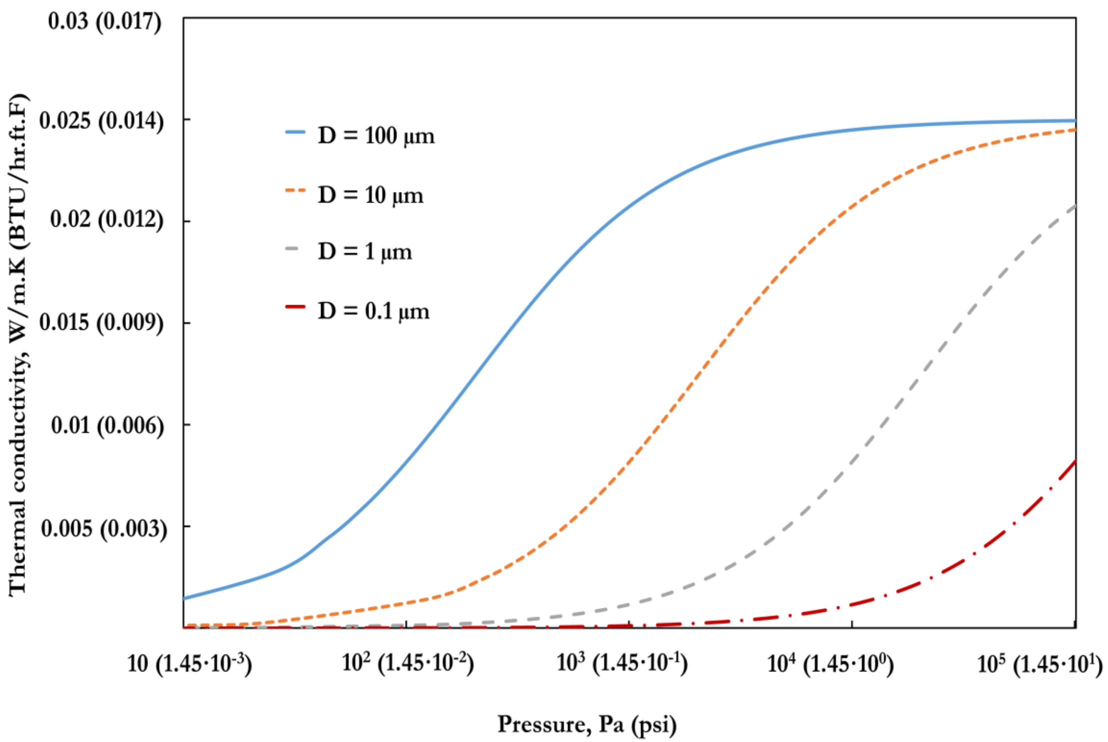


Wakili, K.; Bundi, R.; Binder, B., Effective thermal conductivity of vacuum insulation panels. *Building Research and Information* **2004**, *32* (4), 293-299.

✓ Fumed silica (FS) is the material of choice because of its low sensitivity to pressure

THERMAL CONDUCTIVITY OF AIR

$$k = \frac{k_0}{1+2\beta\left(\frac{P_0 l_p}{PD}\right)}$$

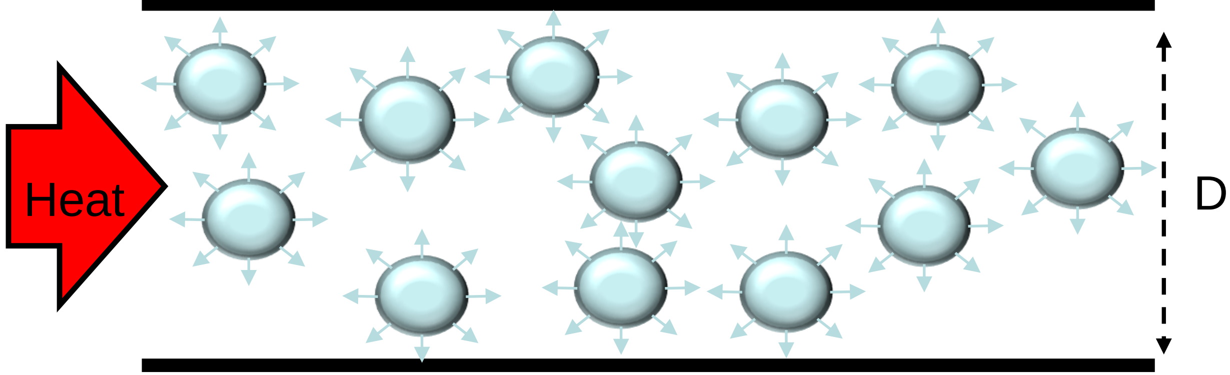


k_{gas} = effective gaseous thermal conductivity, written as a function of k_o
k_o = gaseous thermal conductivity at ambient pressure
β = constant ranges from 1.5 to 2
l_p = mean free path of gas particles at ambient pressure
D = effective pore diameter
P = pressure
P_o = atmospheric pressure

Kaganer, M.G. 1969. Jerusalem: Israel Program for Scientific Translations.
Kennard, E.H. 1938. New York: McGraw-Hill Book Company.

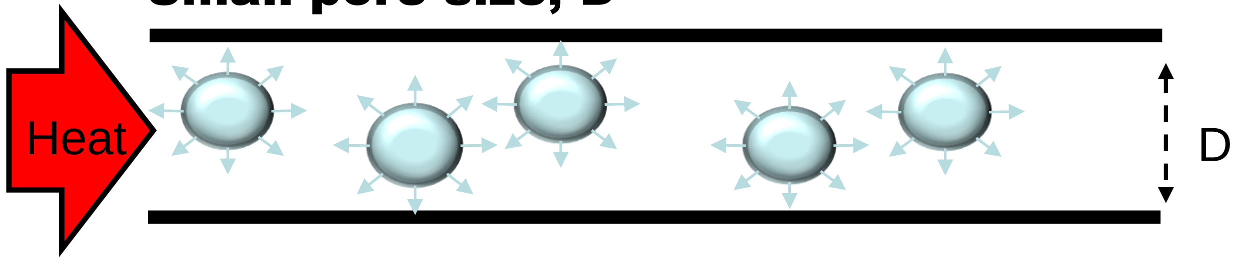
PORE SIZE

Large pore size, D



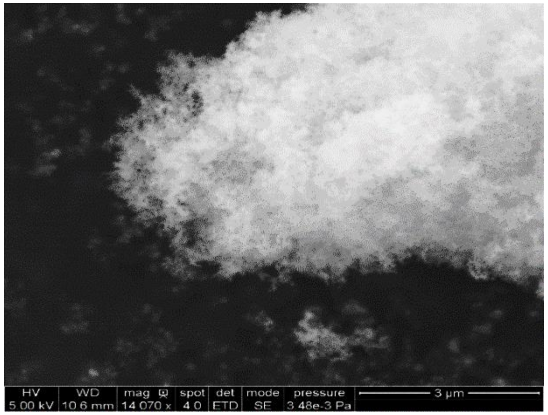
Heat transfer across the gas phase occurs by molecule-molecule kinetic energy transfer

Small pore size, D

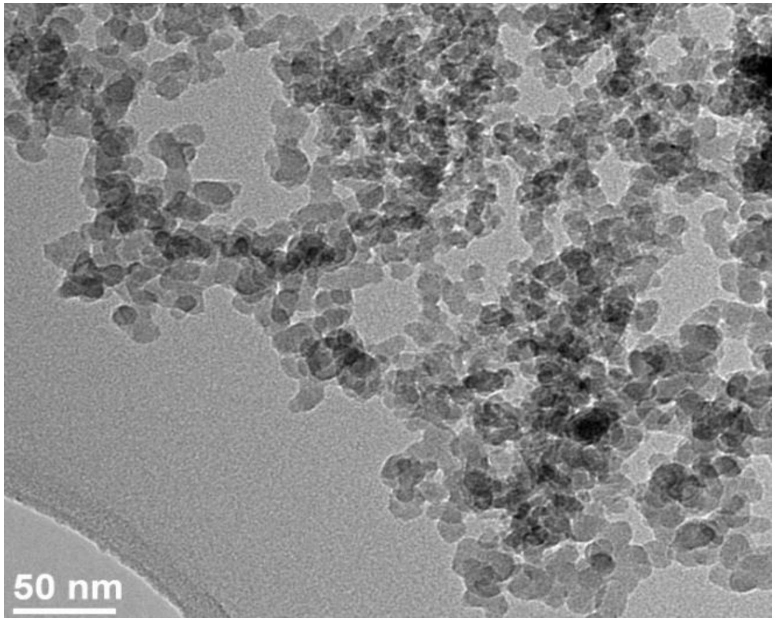


When pore size is smaller than the mean free path of the gas molecules the scattering occurs at the boundary lower thermal conductivity

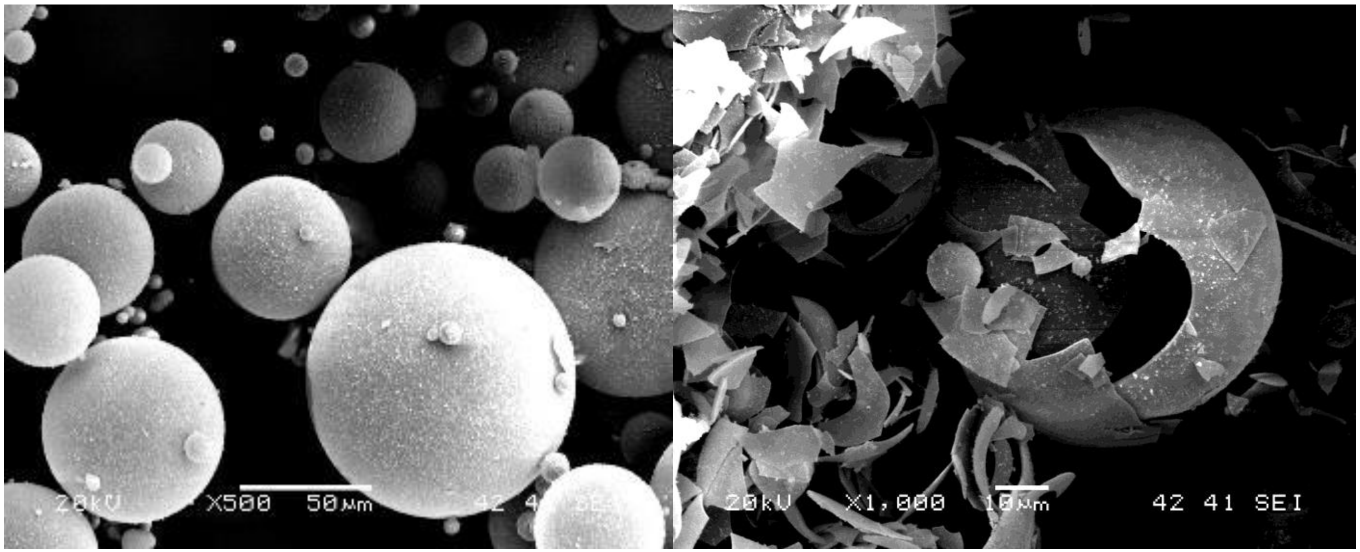
FUMED SILICA (FS)



- ✓ Produced from silicon tetrachloride ($SiCl_4$)



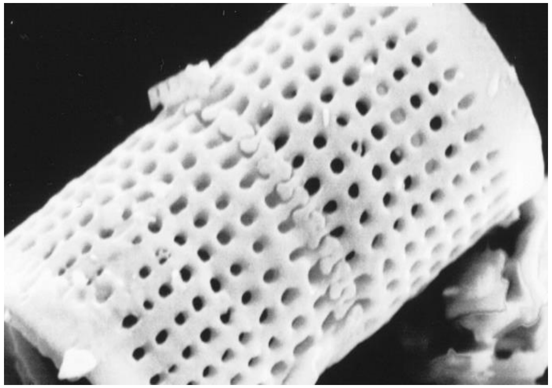
ALTERNATE CORE MATERIALS: GLASS BUBBLES (GB)

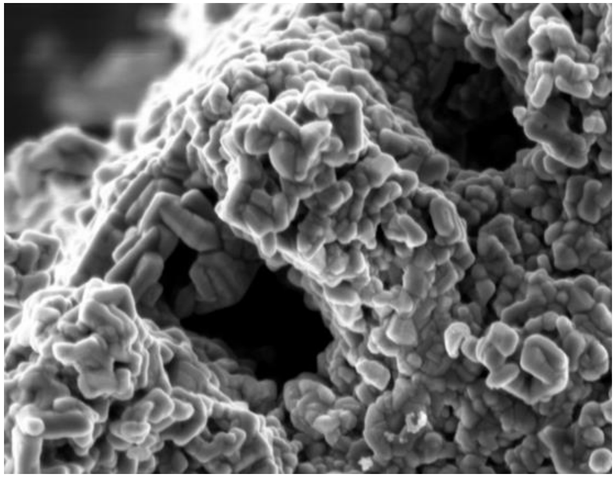


- Soda-lime borosilicate glass, Average particle size ~ 60 µm
- Particle density: 0.15 g/cm^3 (K15), 0.20 g/cm^3 (K20), 0.25 g/cm^3 (K25)

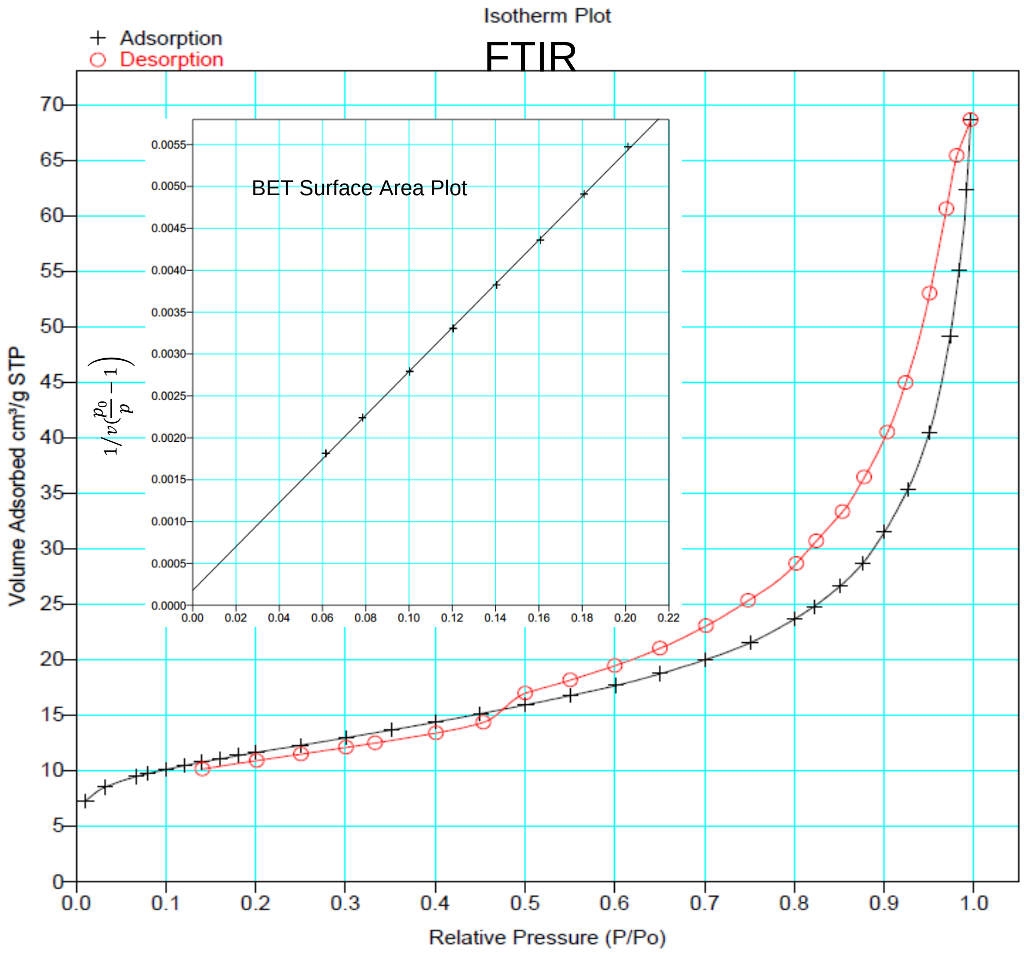
ALTERNATE CORE MATERIALS: DIATOMACEOUS EARTH (DE)

- ✓ Skeletal remains of diatoms (algae)



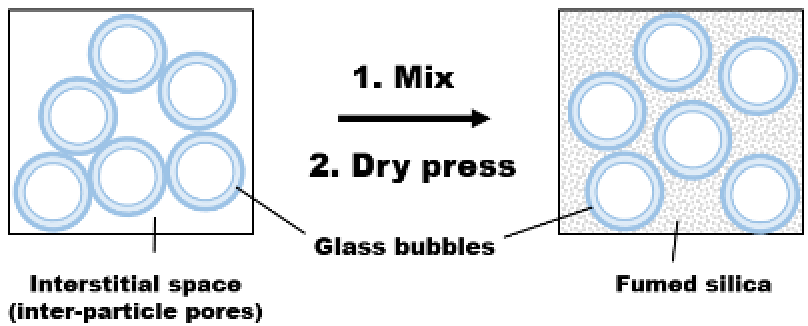


POWDER CHARACTERIZATION



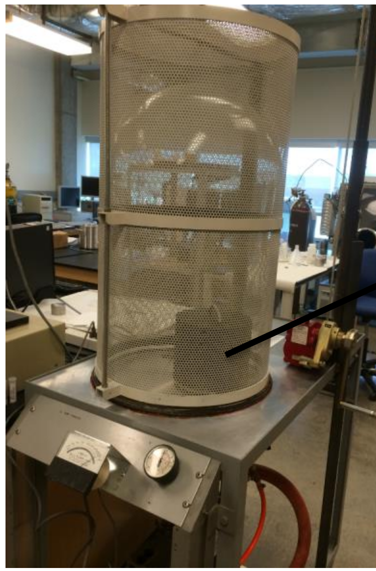
Material	Specific surface area, m^2/g
FS	165
DE	39
GB	0.6

SAMPLE COMPACTION

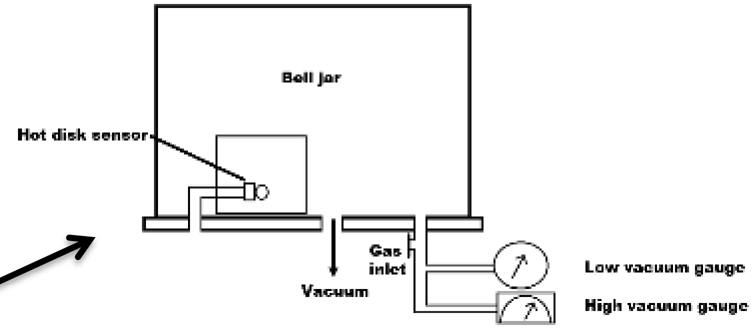


EXPERIMENTAL SETUP

Sample chamber

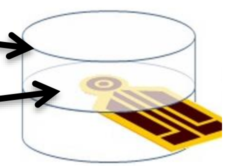


Vacuum setup



Sample

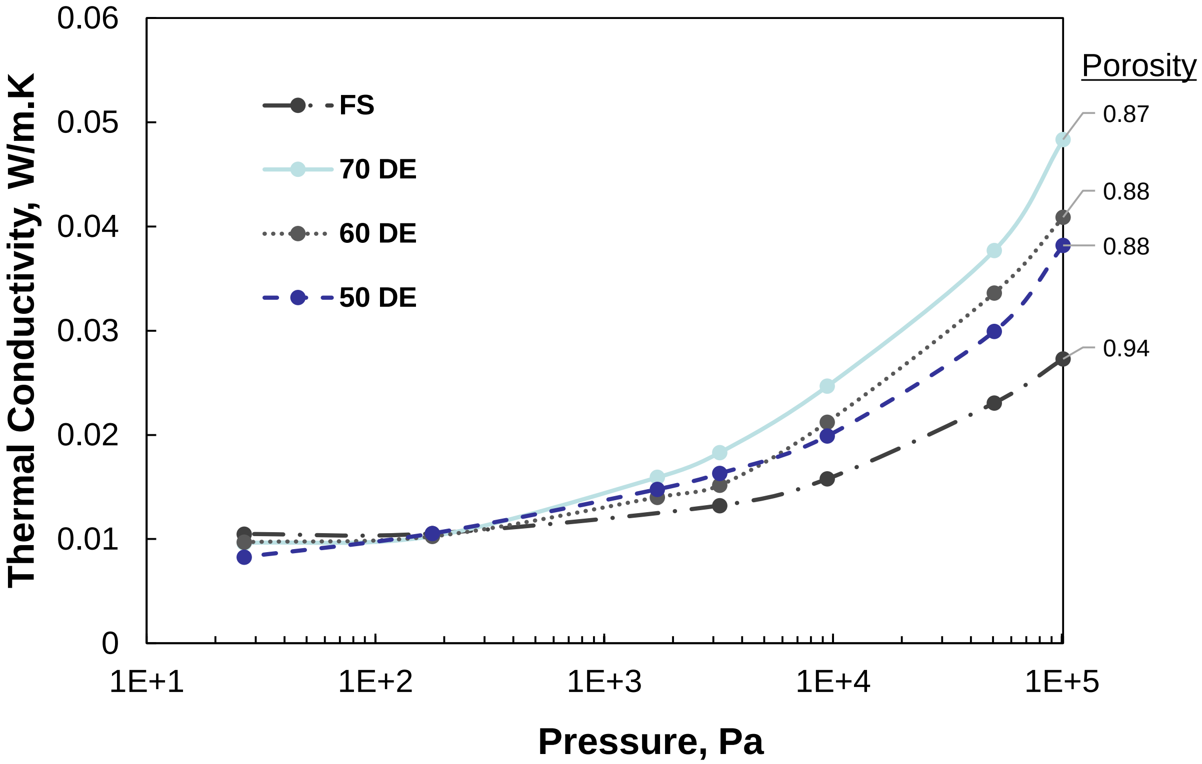
Hot disk sensor



TPS Sensor acts as a

- Heat source
- Resistance Thermometer

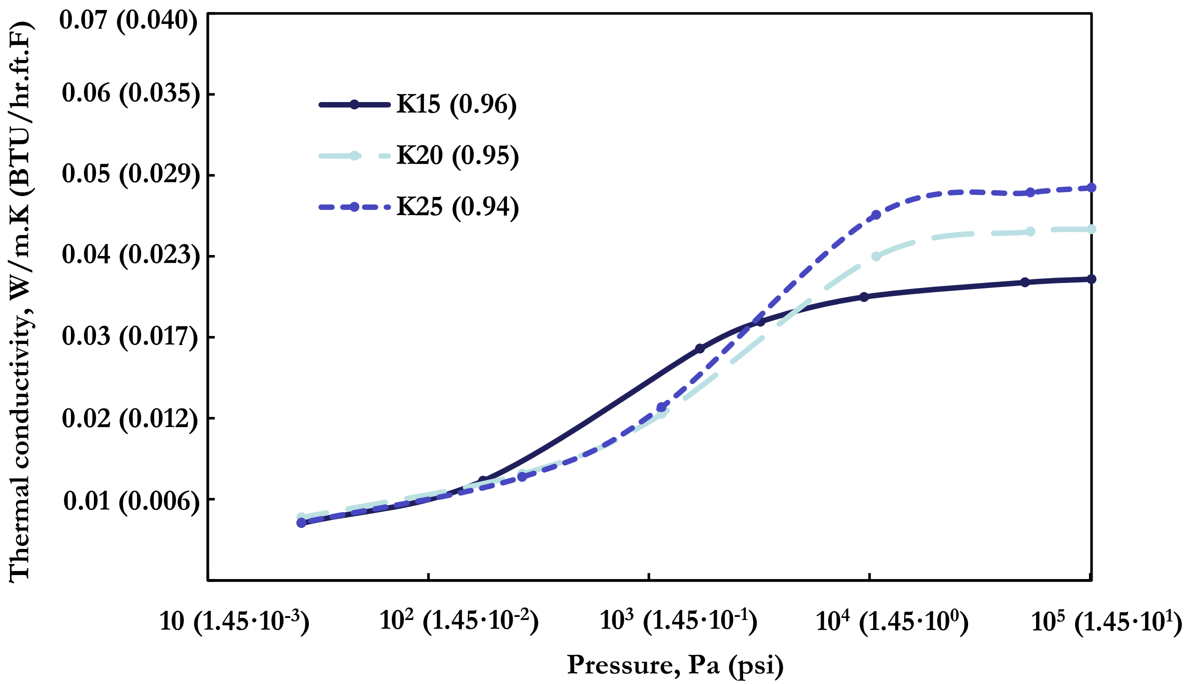
DIATOMITE/FUMED SILICA



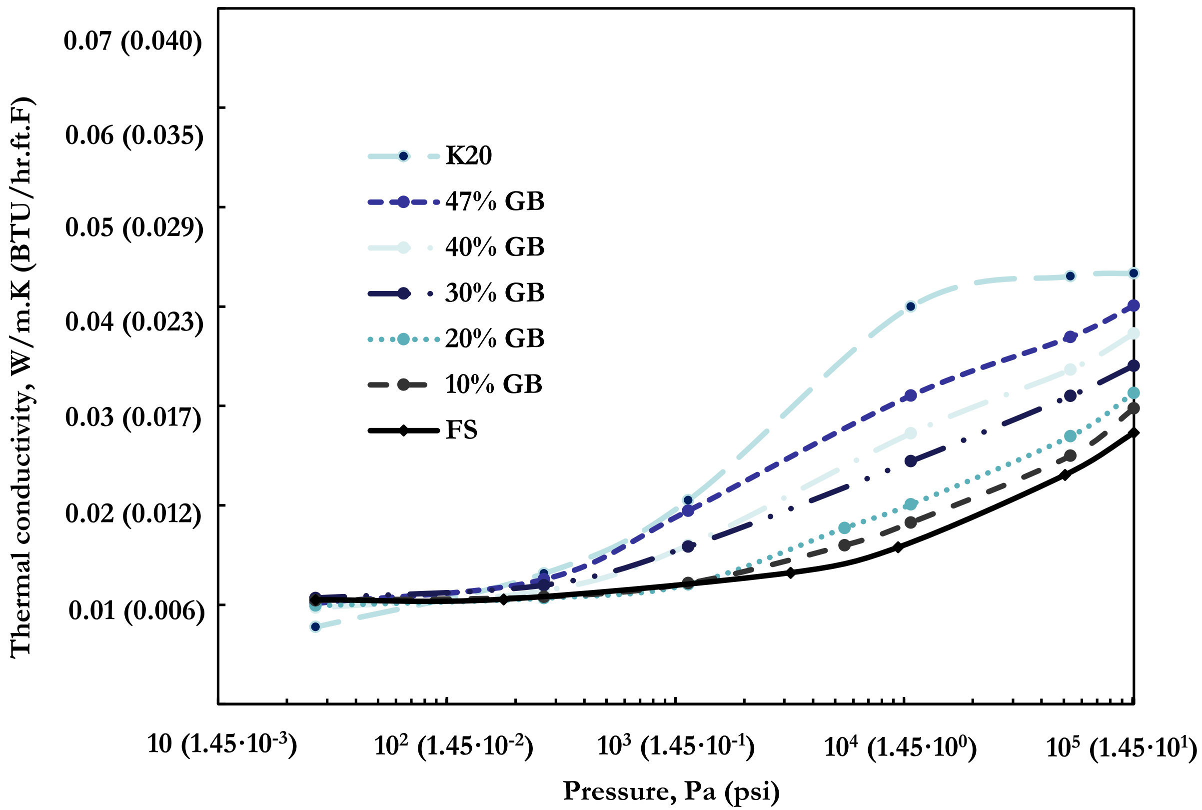
- ✓ Diatomaceous earth has higher intrinsic thermal conductivity and large pore size

Chang, B.S., Zhong, L. and Akinc, M. 2016. Vacuum 131:120-26

THERMAL CONDUCTIVITY OF GLASS BUBBLES (GB)



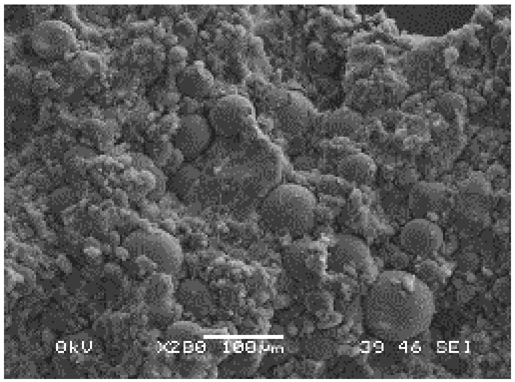
GB/FS COMPOSITE

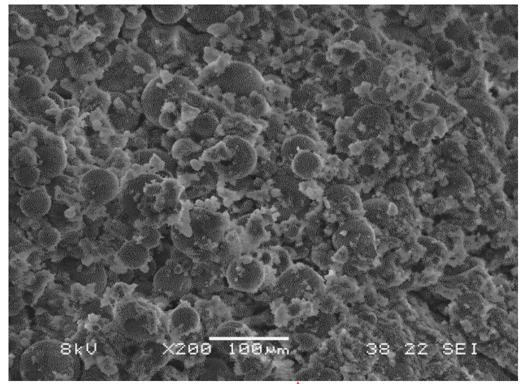


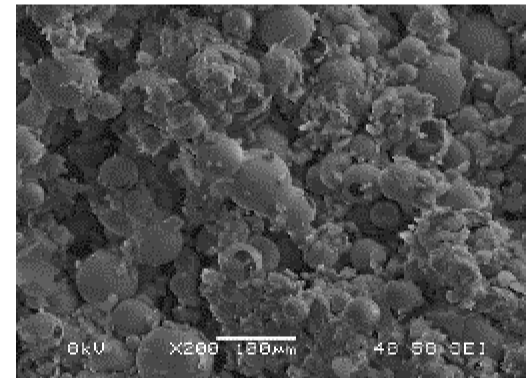
10-20% GB showed almost identical thermal conductivity with FS at low pressure (1000 Pa).

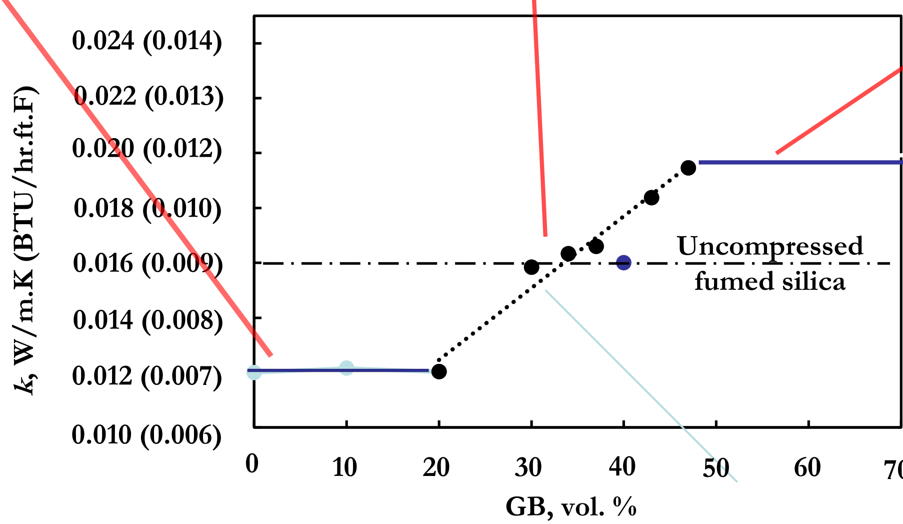
Further addition of GB, increased thermal conductivity.

MORPHOLOGY OF COMPACTS







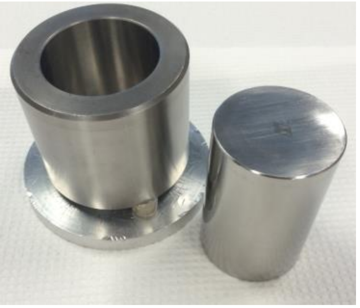


- ✓ Thermal conductivity of all compositions at 1000 Pa

CUT OFF AT 20% GB

- Packing factor of glass bubbles are ca. 60% (theoretical maximum)
- Compared to experiments, there is a 40% discrepancy!

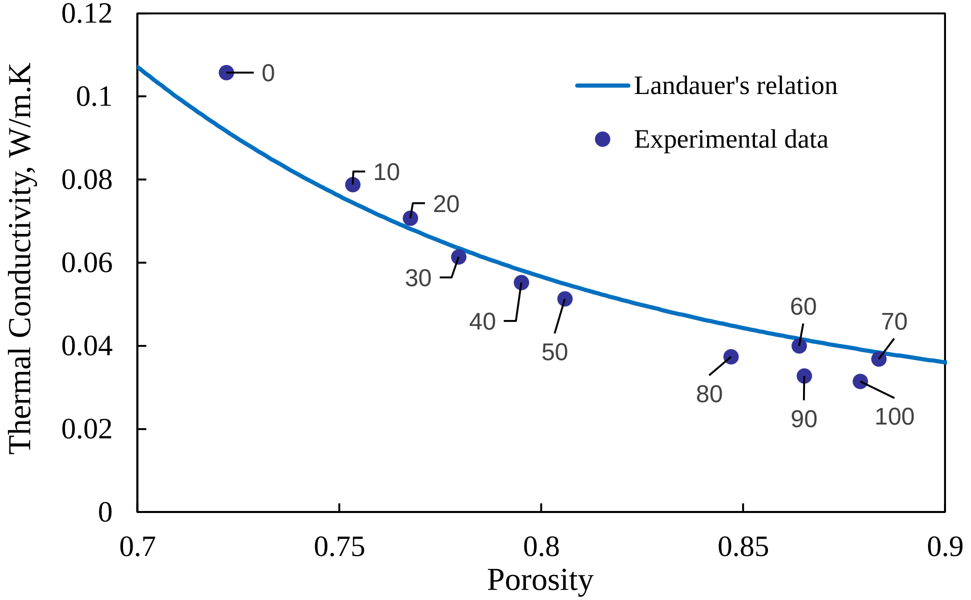
Most likely stem from processing method (unidirectional compression), producing local inhomogeneity



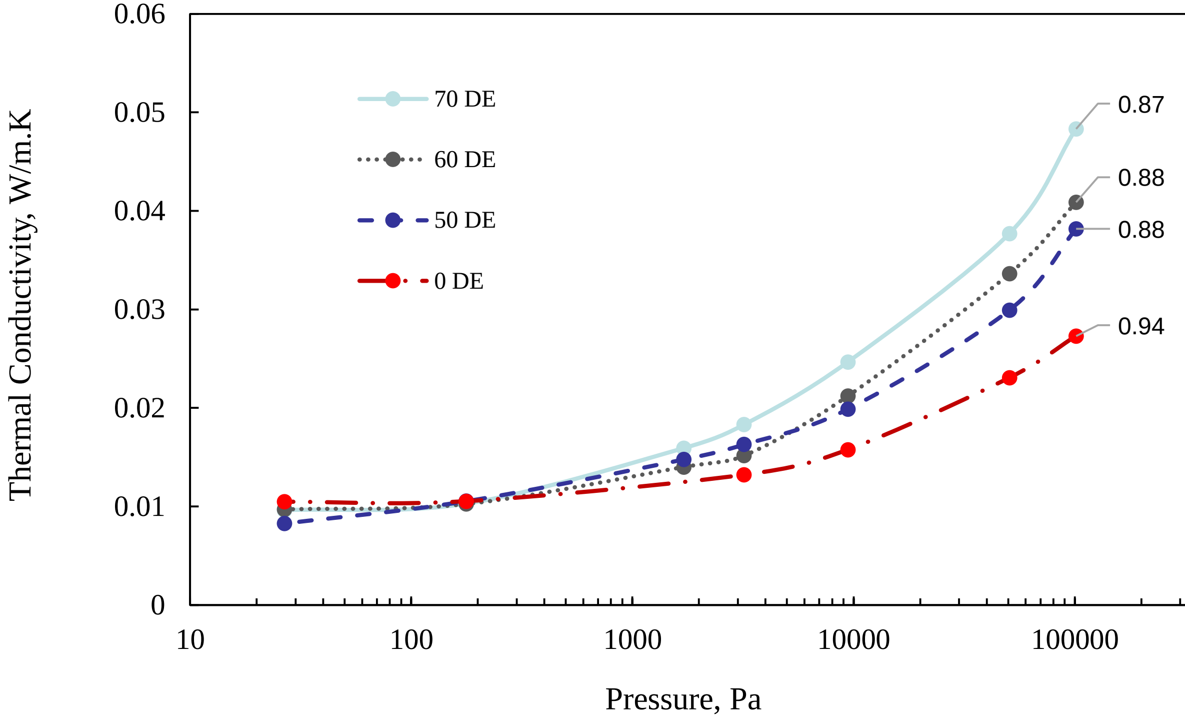
SUMMARY

- Thermal conductivity of fumed silica/glass bubble mixtures was investigated as a function of volume fraction of GB and gas pressure from vacuum to atmospheric pressure
- Total porosity and pore size of the compact play a critical role in thermal conductivity, especially at higher gas pressures
- Up to 20 vol% FS could be replaced with GB with little change in thermal conductivity
- Increase in thermal conductivity with >20% GB was attributed to formation of larger pores due to inhomogeneous mixing
- A more uniform mixing and compaction may retain low thermal conductivity at higher GB contents.

This work was funded by Iowa Energy Center, Grant # 13-04



0.12
0.1
0.08
0.06
0.04
0.02
0
0.7
0.75
0.8
0.85
0.9
Porosity
Thermal Conductivity, W/m.K
Landauer's relation
Experimental data
0
10
20
30
40
50
60
70
80
90
100


0.06
0.05
0.04
0.03
0.02
0.01
0
Thermal Conductivity, W/m.K
10
100
1000
10000
100000
Pressure, Pa
70 DE
60 DE
50 DE
0 DE
0.87
0.88
0.88
0.94