Alternative core materials for vacuum insulation

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

<table>
<thead>
<tr>
<th>Insulation</th>
<th>R-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiberglass &amp; Cellulose</td>
<td>3-4</td>
</tr>
<tr>
<td>Expanded Polystyrene</td>
<td>4-5</td>
</tr>
<tr>
<td>Urethane Foams</td>
<td>5-8</td>
</tr>
<tr>
<td>VIP</td>
<td>30-50</td>
</tr>
</tbody>
</table>
DOE target value for building applications is <$3 /sq.ft

<table>
<thead>
<tr>
<th>Insulation</th>
<th>Cost ($/sq.ft)</th>
<th>Cost ($/sq.ft/R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiberglass &amp; Cellulose</td>
<td>0.4</td>
<td>0.13-0.1</td>
</tr>
<tr>
<td>Expanded Polystyrene</td>
<td>1.5</td>
<td>0.38-0.3</td>
</tr>
<tr>
<td>Urethane Foam</td>
<td>1.5</td>
<td>0.3-0.19</td>
</tr>
<tr>
<td><strong>VIP</strong></td>
<td><strong>5</strong></td>
<td><strong>0.17-0.1</strong></td>
</tr>
</tbody>
</table>
Fumed silica (FS) is the material of choice because of its low sensitivity to pressure.
**THERMAL CONDUCTIVITY OF AIR**

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

- \( k_{\text{gas}} \) = effective gaseous thermal conductivity, written as a function of \( k \).
- \( k_0 \) = gaseous thermal conductivity at ambient pressure
- \( \beta \) = constant ranges from 1.5 to 2
- \( l_p \) = mean free path of gas particles at ambient pressure
- \( D \) = effective pore diameter
- \( P \) = pressure
- \( P_0 \) = atmospheric pressure


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 ($\text{SiCl}_4$)
ALTERNATE CORE MATERIALS: GLASS BUBBLES (GB)

- Soda-lime borosilicate glass, Average particle size ~ 60 µm
- Particle density: 0.15 g/cm³ (K15), 0.20 g/cm³ (K20), 0.25 g/cm³ (K25)
ALTERNATE CORE MATERIALS: DIATOMACEOUS EARTH (DE)

✅ Skeletal remains of diatoms (algae)
POWDER CHARACTERIZATION

- BET Surface Area Plot
- FTIR

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific surface area, m²/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS</td>
<td>165</td>
</tr>
<tr>
<td>DE</td>
<td>39</td>
</tr>
<tr>
<td>GB</td>
<td>0.6</td>
</tr>
</tbody>
</table>
SAMPLE COMPACTION

1. Mix
2. Dry press

Interstitial space (inter-particle pores)
Glass bubbles
Fumed silica

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EXPERIMENTAL SETUP

Sample chamber

Vacuum setup

Hot disk sensor

Sample

TPS Sensor acts as a
- Heat source
- Resistance Thermometer

College of Engineering
Diatomaceous earth has higher intrinsic thermal conductivity and large pore size.

THERMAL CONDUCTIVITY OF GLASS BUBBLES (GB)

Thermal conductivity, W/m.K (BTU/hr.ft.F)

Pressure, Pa (psi)

10 (1.45·10⁻³)  10² (1.45·10⁻¹)  10³ (1.45·10⁻¹)  10⁴ (1.45·10⁰)  10⁵ (1.45·10¹)

- K15 (0.96)
- K20 (0.95)
- K25 (0.94)
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*
Landauer's relation

Thermal Conductivity, W/m.K

Porosity

Experimental data