Vacuum Super-Insulated Heat Storage for High Solar Fraction

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Objectives

Development of a high efficient sensible heat storage for solar applications:

- Reduction of heat losses
- Increase energy density by increasing the operational temperature range e.g. 40/95 °C to …/130-150 °C
- Improve the performance by stratification
**Thermal Insulation**

**Heat transport mechanisms:**
- Conduction
- Convection
- Radiation

![Diagram showing conduction, convection, and radiation]

**Conventional insulation materials** reduce this heat transport significantly

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity (20 °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a rock / glass wool</td>
<td>0.032 … 0.045 W/(m*K)</td>
</tr>
<tr>
<td>b polyurethane</td>
<td>0.024 … 0.035 W/(m*K)</td>
</tr>
<tr>
<td>c polystyrene</td>
<td>0.030 … 0.050 W/(m*K)</td>
</tr>
<tr>
<td>d foam glass</td>
<td>0.040 … 0.050 W/(m*K)</td>
</tr>
</tbody>
</table>
Conventional Insulation and Humidity

- Thermal conductivity up to 30 times higher, even above \( \lambda_{\text{water}} \), even for low humidity, extremely critical above 70°C - 90°C
**Vacuum Insulation (VI) („Thermos Flask“)**

- double walled container
- evacuation of the annular space below $10^{-3}$ mbar
- no convection, no gas thermal conductivity

\[
\dot{Q} = A \sigma \left( \frac{T_1^4 - T_2^4}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} \right)
\]

- only heat transport by radiation (dependent on emission $\varepsilon$ of the walls and independent of the wall distance $d$)
- advantage with respect to conventional insulation only for small gaps
Comparison of Insulation Techniques

```plaintext
conv. insulation, \( \lambda = 0.03 \text{ W/mK} \)

VSI, \( \lambda = 0.01 \text{ W/mK} \)

VI, \( \varepsilon = 0.3 \)

VI, \( \varepsilon = 0.1 \)

VI, \( \varepsilon = 0.05 \)
```
Comparison VSI vs. Conventional Insulation

Source: VDI-Wärmeatlas, own measurements for VSI insulation

⇒ reduction of thermal conductivity by a factor of 5 - 7

⇒ avoid problems with humidity and aging
Heat Transport in VSI

- convection
- gas therm.
- conduction
- evacuation
- therm.
  radiation
- absorption + scattering
- solid state conductivity
- smallest contact area, “deviation”
- vacuum super insulation
  - foam
  - fibers
  - foils
  - powder
Construction of a VSI Solar Storage

- Inner tank
- Outer tank
- Vacuum flange
- Heating/DHW supply
- Solar stratification unit
- Solar supply
- Annular gap with Perlit and Vacuum 0.05 mbar
- Stratification unit heating
- Heating/DHW return
- Solar return
- Air purging
Measurement Result: Thermal Conductivity

After 20 years 1,4 mbar -> Perlit: $\lambda = 0,020 \text{ W/mK}$, pyrogenous silica acid: $0,005 \text{ W/mK}$
3 times better than dry mineral wool, re-evacuation easy possible
Heat Losses Measurements

\[
\frac{dT}{dt} = 0.23 \frac{K}{d}
\]

UA-value = 1.98 W/K, including pipes, connections and support of the inner tank
\(\lambda\) of the insulation = 0.009 W/mK, potential to 0.007 W/mK
Temperature Stratification

Two ways of heat supply to the storage:

- Indirect supply via heat exchanger (left)
- Direct heat supply by charging the fluid layer wise (right)
Temperature Stratification

Stratification:

1. Development of a temperature stratification during charging

2. Supply the fluid in a stratified storage to the layer of the same temperature without destroying of the stratification
Temperature Stratification

- **Temperature stratification has operational advantages**
  Ideal case: discharge the total heat content at a high temperature level

- **Operational advantages** (higher efficiency) for heat supply by solar collectors, heat pumps or condensing boilers
  - Increases the direct use of solar heat
  - Important feature for VSI storage because of low losses
Test of Various Stratification Units
Experimental Results

SB1

OK

SB 1a, V= 70 l/h, "Beladung"

ideal behavior

poor – mixing of the upper 2/3

SB 1a, V= 70 l/h, "Einschichtung"

ideal behavior
Experimental Results

SB4

SB 4, V= 90 l/h, "Beladung"

OK

ideal behavior

SB 4, V= 90 l/h, "Einschichtung"

almost perfect

ideal behavior
Pilot Storages Produced According to AD2000
Solar Space Heating Application
Solar Space Heating Application
Applications of VSI-Technology

- Seasonal storage: up to 100 °C
- Industrial process heat: 100 - 300°C
- Solar power plants: 400 - 700°C

Conclusions

VSI storage is applicable for
- sensible
- latent
- thermo-chemical storage

VSI storage allows
- long-term storage with low heat losses
- solar space heating and DHW with high solar fraction

It is especially interesting for higher storage temperatures and interesting for industrial applications
- process heat e.g. food industry
- waste heat and heat recovery
- district heating
Thank you very much for your attention

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