Introduction

Powder insulation materials:
- Expanded perlite: one of the most commonly used powder insulation materials
- Glass microspheres: an alternative insulator to expanded perlite (developed by 3M)
- Expanded polystyrene (EPS) beads: a newly tested thermal insulation material

Advantages:
- Low cost
- Simplicity of installation
- High thermal performance
- Low density
- Porous structure
- Small particle size

Objectives

- The effective thermal conductivity dramatically reduces to 0 in a high vacuum condition.
- A fitting equation of the deformation factor was presented for expanded perlite, glass microspheres and EPS beads as a function of bulk density.
- The effective thermal conductivity of expanded perlite, glass microspheres and EPS beads, with the empirical equation of deformation factor. However, the further research is necessary to verify the applicability to other powder insulation materials.

Calculation model

\[ k_{eff} = k_s + k_r, \alpha = 0 \]
\[ k_{eff} = k_s + k_r, \alpha = 0.0034 \]

Experimental Procedures

- Target:
  1. Powder insulation
  2. Glass microspheres
  3. Expanded perlite
  4. EPS beads
  5. Vacuum insulation
  6. Multi-layer insulation

- Experimental Apparatus:
  - Powder packing unit
  - Powder packing
  - Vacuum pump line
  - LN2 charging
  - Vacuum measurement
  - Multi-layer insulation

- Conduction shape factor model (Hervin et al., 2005)

\[ \varepsilon = \frac{\pi}{\sin(\varepsilon)} \times \frac{2}{\varepsilon^2} \times \frac{\varepsilon^2}{2} \]

Conclusion

- The thermal performance of EPS beads is better than other insulators at soft vacuum conditions.
- Area-contact model is applicable to predict the effective thermal conductivity of powder insulation at soft vacuum conditions without considering \( k_s \) and \( k_r \).
- The calculation results well match the experimental data.

Experimental Apparatus

- Both of the inner LN2 chamber and the outer vacuum chamber were made by copper.
- Thermocouples were attached to the wall of LN2 supply line, LN2 chamber, vacuum chamber and the copper plate above the LN2 chamber.
- Before the vacuum pump, a 5 \( \mu \)m filter was installed to protect the turbine from powder suction.
- A mass flow controller was installed on LN2 supply line to measure the quantity of evaporated nitrogen.

Experimental Results

- The deformation factor of expanded perlite, glass microspheres, EPS beads were calculated.
- The bulk densities of tested powders range from 4.3 kg/m\(^3\) – 160 kg/m\(^3\).
- The value of deformation factor decreases with increasing bulk density. Because the particles have a higher crush strength when the bulk density is larger.
- The fitting equation of deformation factor for expanded perlite, glass microsphere, and EPS beads is as follow:

\[ \alpha = \exp(-2.4 - 2.7 \times 10^{-3} \rho_{bulk} + 7.3 \times 10^{-2} \rho_{bulk}^2) \]