Consideration of Asymmetrical Heat Transmission and Distribution Using Numerical Methods

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Outline

- Introduction
- Effects
- Superposition
- Influences on Accident Conditions
- Conclusions
Motivation

• Simplified analysis models usually neglect asymmetrical effects
• Asymmetrical effects add temperature gradients
• Gradients has to be taken into account to get min/max temperatures
Examples

- Basket off-centring due to horizontal transport
- Air flow caused by natural convection
- Air flow caused by thermal barriers as canopies
- Different absorption of solar insolation
Scope

- Routine transport conditions
- Different initial temperature distribution for the fire test
Basket Out of Center

Centred

Off-Centered

- Basic principle: gravity influence during horizontal transport
- Preferred method: FEA
- Gradient size: Usually 5 K to 10 K
- Temperature maximum: at 0° (bottom of cavity wall)
Solar Insolation

Temperatures

- Blue: without solar insolation
- Yellow: with solar insolation

- Basic principle: orientation to the sun during horizontal transport
- Preferred method: FEA or CFD
- Gradient size: depends on solar insolation to heat load ratio
- Temperature maximum: at 180° (top of external package surface)
Natural Convection

Temperatures

- Basic principle: natural convection law for constant heat dissipation
- Preferred method: CFD
- Gradient size: depends on internal heat load
- Temperature maximum: at 180° (top of cavity wall)
Effects Canopies Temperatures

- blue: free air stream
- yellow: canopy

- Basic principle: air stream between package and canopy due to buoyant force
- Preferred method: CFD
- Gradient size: depends on package and canopy geometry, about 5 K
- Temperature maximum: near 0° (bottom area of external package surface)
Canopies

Symmetric

\[ \Delta p = 0.1 \, Pa \]

\[ \Delta p = 0.5 \, Pa \]

- Special effect: air stream behaviour at the lower part of the package/canopy system due to small pressure differences
Effects

Canopies

Temperatures

- black: measured
- yellow: symmetrical conditions
- pink: $\Delta p = 0.1 \text{ Pa left/right}$
- blue: $\Delta p = 0.5 \text{ Pa left/right}$

- Message: analysis results are nearer to measured ones assuming low pressure differences
- Interpretation: realistic effect
- Consequence: subsequent analysis needed to assess symmetrical conditions

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Superposition

Free Air Stream (blue)

Surface temperature of cylindrical cask

- 0_Average
- 1_Free airstream

Temperature [°C]

Cask surface circumference [°]
Superposition

Free Air Stream versus Canopy (yellow)
Superposition

Basket Off-centering and Canopy (pink)
Influences on Accident Conditions

Temperatures over time

- Scenario: canopy loss directly before fire accident starts
- Results: significant time needed (up to 90 hours) until same temperature level is reached as without canopy
- Status: despite scenario seems to be realistic, TS-R-1 does not require to subject thermal barriers to any test

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Conclusions

- Asymmetrical effects and following temperature gradients effect significantly the temperature maxima in the package.
- Therefore, asymmetrical effects has to be addressed sufficiently in package design safety analysis.
- Experimental results needed for validation of numerical models.
- Conformity with requirements and complete temperature distribution can be demonstrated by subsequent numerical analysis considering perfect boundary conditions.
- Superposition of asymmetrical effects gives a rather realistic view on package temperature distribution.
- Use of advanced analysis methods as CFD enables a detailed view on temperature distributions.
- Even for the initial temperature distribution of the fire accident, a look behind TS-R-1 requirements is possible to check rather realistic scenarios.