Improvements to RELAP5-3D Conduction Model

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Outline of Presentation

- Two modifications to the conduction model
- Each model will be discussed separately
  - Background
  - Implementation in code
  - Verification testing
  - Conclusions

Alternate Heat Structure – Fluid Coupling Model

- Current model uses volume temperature as sink temperature for heat flux computation
- Underestimates heat transfer for fluids of low heat capacity or at low flow rates where there can be large change in fluid temperature in volumes
- New model uses estimate of average temperature in volume for heat flux computation
- Restricted to single phase vapor/gas conditions
- Activated by user on heat structure boundary condition input cards

Alternate Heat Structure – Fluid Coupling Model

– **Estimate of volume outlet temperature from steady state energy equation for constant heat capacity fluid**

$$WC_p(T_{out} - T_{in}) = Q = hA(T_s - T_{avg})$$

– **Integrate differential form of energy equation from inlet to outlet assuming constant surface temperature and variable fluid temperature**

$$T_{out} = T_{in} + (T_s - T_{in})(1 - e^{-\frac{hA}{WC_p}})$$

Alternate Heat Structure – Fluid Coupling Model

- **Equate two forms of energy equation and solve for average fluid temperature**

$$T_{avg} = aT_{out}^{n(n+1)} + (1-a)T_{in}^{n}$$

where

$$a = \frac{(T_s - T_{in})}{(T_{out} - T_{in})}[1 - \frac{WC_p}{hA}(1 - e^{\frac{-hA}{WC_p}})]$$

Alternate Heat Structure – Fluid Coupling Model

- Compute coefficient ‘a’ from beginning of advancement data
- Use T_{out} from beginning of advancement for explicit coupling of heat structure and fluid
- Use T_{out} from end of advancement for implicit coupling of heat structure and fluid
- Use heat transfer coefficient and surface area weighted average of surface temperatures for multiple heat structures attached to volume

Alternate Heat Structure – Fluid Coupling Model

- **Verification Testing**
  - Intermediate HX from lead-bismuth cooled Gen IV reactor – Brayton cycle BOP
  - Lead-bismuth on primary (shell side) and supercritical CO2 on secondary side (tube side)
  - Vary number of heat structures connecting primary and secondary from 10 to 80 with and without alternate heat structure – fluid coupling model

Alternate Heat Structure – Fluid Coupling Model

Number of heat structures	Heat transfer rate with default coupling model (MW)	% deviation	Heat transfer rate with alternate coupling model (MW)	% deviation
10	564.33	5.2	583.21	2.0
20	580.23	2.5	590.32	0.85
40	588.51	1.1	593.72	0.28
80	592.73	0.44	595.37	NA

Alternate Heat Structure – Fluid Coupling Model

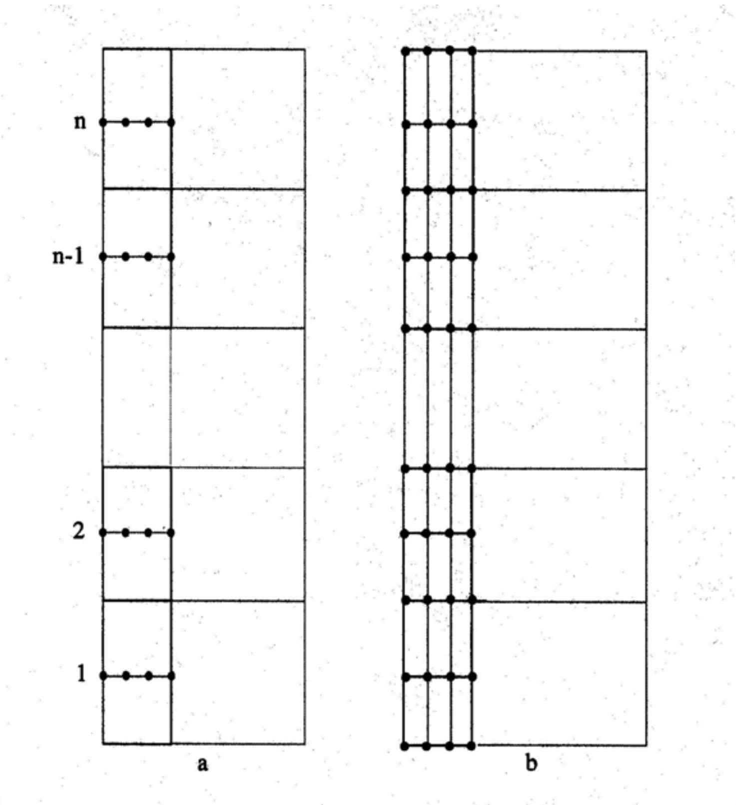
- **Alternate coupling model implemented in code**
- **Improves accuracy of coupled solid – fluid model**
- **Restricted to single phase vapor/gas coolants**

2D Conduction Model

- 2D conduction model is part of reflood model – uses ADI solution technique
- Other features of reflood model are moving, adaptive, fine mesh model and reflood heat transfer correlation package
- 2D conduction model separated from reflood model
- Uses fixed fine mesh model with 2 subdivisions per heat structure

2D Conduction Model

2D conduction mesh



2D Conduction Model

- New option on heat structure geometry information card – word 6
- 2D conduction model activated during initialization
- Initial 2D temperature distribution computed from initial 1D temperature distribution

2D Conduction Model

Verification testing

- **Two sided Cartesian heat structure geometry with 20 heat structures**
- **Test case used to verify implementation of reflood model on left surface of heat structure geometry**
- **Rising liquid level on reflood side of heat structure geometry and single phase vapor on non-reflood side**

2D Conduction Model

Test cases

- **Reflood model with reflood on right surface**
- **Reflood model with reflood on left surface**
- **2D model based on right reflood deck**

2D Conduction Model

Test Cases

- **2D model based on left reflood deck**
- **Figure of merit is similarity of surface temperatures, i.e. temperatures of reflood surface should be the same regardless of whether the 'reflood' surface is the left or right surface of the heat structure**

2D Conduction Model

Test Cases

- 1D and 2D adiabatic test cases – Cartesian and cylindrical geometry
- Non-uniform initial radial/lateral temperature distribution
- Figure of merit is similarity of volume average temperatures – demonstrates conservation of energy

2D Conduction Model

- 2D conduction model separated from reflood model
- Results of reflood test cases give confidence that 2D conduction solution, i.e. the ADI solution technique, is working correctly
- 2D conduction test cases exhibit exact symmetry
- Adiabatic test cases exhibit exact conservation of energy for Cartesian test cases but small error for cylindrical test case