Chemical Engineering 512

Nuclear Reactor Transient Modeling

Lecture 9

Pump Curves

Spiritual Thought

"You never know whom they will save! It may be the one that on life's billows is tempest tossed or it may even be the one that had been reported missing at life's sea. And when someone is saved through their rescue mission, oh how great shall be their joy with him or her in the kingdom of our Father."

-Elder Jacob de Jager

Objectives

- Learn about kinetics input into RELAP
- Practice Combination of Volumes in Series

What is Point Kinetics?

- Used to compute reactor power behavior in a nuclear reactor
- Point kinetics is space independent and uses core-average fluid conditions, weighting factors, and feedback coefficients
- Nodal kinetics is the multidimensional neutron kinetics option

- Kinetics type
  - Point
  - Nodal
- Feedback type
  - Separabl
  - Table3
  - Table4
  - Table3A
  - Table4A

```
*****************************************************************************************
*                                                                                       *
*                                    Kinetics                                           *
*                                                                                       *
*****************************************************************************************
*
*           KineticsType        FeedbackType
30000000    point               separabl
*           Decay  Power        React  NFrac
30000001    gamma  1200e+6  0.0    300.
*           ModeratorDensity      Reactivity
30000501    6.37250               0.006
30000502    46.8710               0.100
30000503    70.3065               0.250
*           Temperature           Reactivity
30000601    32.0                  0.0
30000602    4500.0                0.0
*           VolNum       Incr  WeightFact  LiqTempCoef
30000701    514010000    0     0.07391     0.0
30000702    514020000    0     0.18250     0.0
30000703    514030000    0     0.24359     0.0
*           HSNum        Incr  WeightFact  FuelTempCoef
30000801    5141001      0     0.07391     0.0
30000802    5141002      0     0.18250     0.0
30000803    5141003      0     0.24359     0.0
*
```

- Fission product decay type
  - No-gamma
  - Gamma
  - Gamma-ac
- Total Reactor Power
- Initial reactivity
- Delayed

```
*****************************************************************************************
*                                                                                       *
*                                    Kinetics                                           *
*                                                                                       *
*****************************************************************************************
*
*           KineticsType        FeedbackType
30000000    point               separabl
*           Decay   Power       React   NFrac
30000001    gamma   1200e+6     0.0     300.
*           ModeratorDensity    Reactivity
30000501    6.37250               0.006
30000502    46.8710               0.100
30000503    70.3065               0.250
*           Temperature           Reactivity
30000601    32.0                  0.0
30000602    4500.0                0.0
*           VolNum        Incr    WeightFact    LiqTempCoef
30000701    514010000     0       0.07391       0.0
30000702    514020000     0       0.18250       0.0
30000703    514030000     0       0.24359       0.0
*           HSNum         Incr    WeightFact    FuelTempCoef
30000801    5141001       0       0.07391       0.0
30000802    5141002       0       0.18250       0.0
30000803    5141003       0       0.24359       0.0
*
```

- Moderator density vs reactivity table
- Fuel temperature vs reactivity table

```
*****************************************************************************************
*                                                                                       *
*                                      Kinetics                                         *
*                                                                                       *
*****************************************************************************************
*
*            KineticsType        FeedbackType
30000000     point               separabl
*            Decay   Power       React   NFrac
30000001     gamma   1200e+6     0.0     300.
*            ModeratorDensity    Reactivity
30000501     6.37250             0.006
30000502     46.8710             0.100
30000503     70.3065             0.250
*            Temperature         Reactivity
30000601     32.0                0.0
30000602     4500.0              0.0
*            VolNum      Incr    WeightFact  LiqTempCoef
30000701     514010000   0       0.07391     0.0
30000702     514020000   0       0.18250     0.0
30000703     514030000   0       0.24359     0.0
*            HSNum       Incr    WeightFact  FuelTempCoef
30000801     5141001     0       0.07391     0.0
30000802     5141002     0       0.18250     0.0
30000803     5141003     0       0.24359     0.0
*
```

- Volume weighting factors
  - Increment same as heat structure increment
  - If WeightFact is non-zero, LiqTempCoef = 0

```
*****************************************************************************************
*                                                                                       *
*                                    Kinetics                                           *
*                                                                                       *
*****************************************************************************************
*
*           KineticsType        FeedbackType
30000000    point               separabl
*           Decay   Power     React   NFrac
30000001    gamma   1200e+6   0.0     300.
*           ModeratorDensity      Reactivity
30000501    6.37250               0.006
30000502    46.8710               0.100
30000503    70.3065               0.250
*           Temperature           Reactivity
30000601    32.0                  0.0
30000602    4500.0                0.0
*           VolNum        Incr    WeightFact    LiqTempCoef
30000701    514010000     0       0.07391       0.0
30000702    514020000     0       0.18250       0.0
30000703    514030000     0       0.24359       0.0
*           HSNum         Incr    WeightFact    FuelTempCoef
30000801    5141001       0       0.07391       0.0
30000802    5141002       0       0.18250       0.0
30000803    5141003       0       0.24359       0.0
```

- Card 1CCCG701
  - Source type
    - If 1000-1004, then point kinetics is used

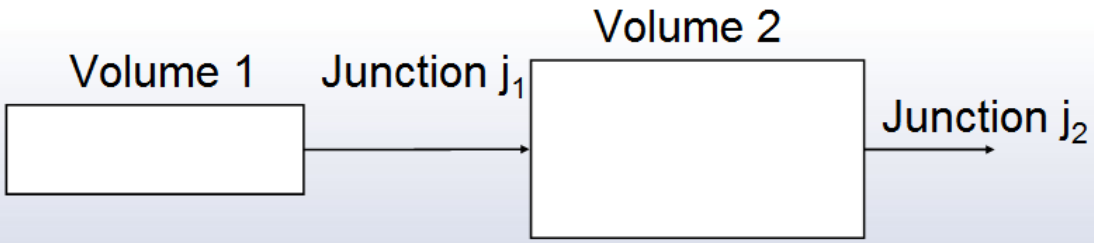
```
*****************************************************************************
*                                                                           *
*                              Heat Structures                              *
*                                                                           *
*****************************************************************************
*
*           AxialHS  RadMesh  GeoType  SSFlag  LeftBound  Reflood
11000000    6        8        2        1       5.74       0
*           MeshLocation      MeshFormat
11000100    0                 1
*           NumOfIntervals    RightCoordinate
11000101    7                 6.5
*           CompositionNum    IntervalNum
11000201    5                 7
*           SourceValue       IntervalNum
11000301    0.0               7
*           InitialTemp       MeshPointNum
11000401    500.              8
*           BoundaryVol/Table  Incr  BCType  SACode  SA/Factor  HSNum
11000501    150010000          0     1       1       10.0       6
*           BoundaryVol/Table  Incr  BCType  SACode  SA/Factor  HSNum
11000601    0                  0     1       1       10.0       6
*           SourceType  Pf          LeftBoundMult  RightBoundMult  HSNum
11000701    1000        0.001791    0.0            0.0             6
*           WordFormat
11000800    0
*           HydDiam  HLFor  HLRev  GSLFor  GSLRev  GLCFor  GLCRev  Boil  HSNum
11000801    0.0      3.0    3.0    0.0     0.0     0.0     0.0     1.0   6
*           WordFormat
11000900    0
*           HydDiam  HLFor  HLRev  GSLFor  GSLRev  GLCFor  GLCRev  Boil  HSNum
11000901    0.0      3.0    3.0    0.0     0.0     0.0     0.0     1.0   6
*
```

Combining Volumes

- Reduce the number of control volumes
- Avoid having control volumes that are too small

- Can combine in series or parallel

Combining in Series



Hydrodynamic:				
Length:	Dx_1		Dx_2	
Elevation change:	Dz_1		Dz_2	
Hydraulic diameter:	D_{h1}		D_{h2}	
Area:	A_1	A_{j1}	A_2	A_{j2}
Volume:	V_1		V_2	
Form losses:		K_{j1}		K_{j2}
Heat structures:				
Inner radius:	R_{i1}		R_{i2}	
Thickness:	t_1		t_2	
Length:	L_1		L_2	

Combining Hydrodynamic Components

$Dx_m = Dx_1 + Dx_2$	

Combining Hydrodynamic Components

$Dx_m = Dx_1 + Dx_2$	$Dx_m = 2.0 + 2.0 = 4.0$
$Dz_m = Dz_1 + Dz_2$	

Combining Hydrodynamic Components

$Dx_m = Dx_1 + Dx_2$	$Dx_m = 2.0 + 2.0 = 4.0$
$Dz_m = Dz_1 + Dz_2$	$Dz_m = 0.0 + 0.0 = 0.0$
$V_m = V_1 + V_2$	

Combining Hydrodynamic Components

$Dx_m = Dx_1 + Dx_2$	$Dx_m = 2.0 + 2.0 = 4.0$
$Dz_m = Dz_1 + Dz_2$	$Dz_m = 0.0 + 0.0 = 0.0$
$V_m = V_1 + V_2$	$V_m = 0.00789*2+0.01863*2 = 0.05304$
$A_m = V_m/Dx_m$	

Combining Hydrodynamic Components

$Dx_m = Dx_1 + Dx_2$	$Dx_m = 2.0 + 2.0 = 4.0$
$Dz_m = Dz_1 + Dz_2$	$Dz_m = 0.0 + 0.0 = 0.0$
$V_m = V_1 + V_2$	$V_m = 0.00789*2+0.01863*2 = 0.05304$
$A_m = V_m/Dx_m$	$A_m = 0.05304/4.0 = 0.01326$
$D_{hm} = \left[\frac{\left(\frac{Dx_m}{A_m}\right)^{1.75}}{\frac{Dx_1}{D_{h1}^{1.25} A_1^{1.75}} + \frac{Dx_2}{D_{h2}^{1.25} A_2^{1.75}}} \right]^{0.80}$	

Combining Hydrodynamic Components

$Dx_m = Dx_1 + Dx_2$	$Dx_m = 2.0 + 2.0 = 4.0$
$Dz_m = Dz_1 + Dz_2$	$Dz_m = 0.0 + 0.0 = 0.0$
$V_m = V_1 + V_2$	$V_m = 0.00789*2+0.01863*2 = 0.05304$
$A_m = V_m/Dx_m$	$A_m = 0.05304/4.0 = 0.01326$
$D_{hm} = \left[\frac{\left(\frac{Dx_m}{A_m}\right)^{1.75}}{\frac{Dx_1}{D_{h1}^{1.25}A_1^{1.75}} + \frac{Dx_2}{D_{h2}^{1.25}A_2^{1.75}}}\right]^{0.80}$	$D_{hm} = \left[\frac{\left(\frac{4}{0.01326}\right)^{1.75}}{\frac{2}{0.102^{1.25}0.00789^{1.75}} + \frac{2}{0.154^{1.25}0.01863^{1.75}}}\right]^{0.80} = 0.0777$
$K_{jmf}=[(K_{j1}/A_{j1}^2)+(K_{j2}/A_{j2}^2)]A_{jm}^2$ $K_{jmr}=[(K_{j1}/A_{j1}^2)+(K_{j2}/A_{j2}^2)]A_{jm}^2$	

Combining Hydrodynamic Components

$Dx_m = Dx_1 + Dx_2$	$Dx_m = 2.0 + 2.0 = 4.0$
$Dz_m = Dz_1 + Dz_2$	$Dz_m = 0.0 + 0.0 = 0.0$
$V_m = V_1 + V_2$	$V_m = 0.00789*2+0.01863*2 = 0.05304$
$A_m = V_m/Dx_m$	$A_m = 0.05304/4.0 = 0.01326$
$D_{hm} = \left[\frac{\left(\frac{Dx_m}{A_m}\right)^{1.75}}{\frac{Dx_1}{D_{h1}^{1.25}A_1^{1.75}} + \frac{Dx_2}{D_{h2}^{1.25}A_2^{1.75}}}\right]^{0.80}$	$D_{hm} = \left[\frac{\left(\frac{4}{0.01326}\right)^{1.75}}{\frac{2}{0.102^{1.25}0.00789^{1.75}} + \frac{2}{0.154^{1.25}0.01863^{1.75}}}\right]^{0.80} = 0.0777$
$K_{jmf}=[(K_{j1}/A_{j1}^2)+(K_{j2}/A_{j2}^2)]A_{jm}^2$ $K_{jmr}=[(K_{j1}/A_{j1}^2)+(K_{j2}/A_{j2}^2)]A_{jm}^2$	$K_{jmf}=[(0.33/0.00789^2)]0.01863^2 = 1.840$ $K_{jmr}=[(0.29/0.00789^2)]0.01863^2 = 1.617$

Combining Heat Structures

$L_m = L_1 + L_2$	

Combining Heat Structures

$L_m = L_1 + L_2$	$L_m = 2.0 + 2.0 = 4.0$
$A_{im} = A_{i1} + A_{i2}$	

Combining Heat Structures

$L_m = L_1 + L_2$	$L_m = 2.0 + 2.0 = 4.0$
$A_{im} = A_{i1} + A_{i2}$	$A_{im} = 2\pi(0.0501*2+0.0770*2) = 1.597$
$R_{im} = A_{im}/(2\pi L_m)$	

Combining Heat Structures

$L_m = L_1 + L_2$	$L_m = 2.0 + 2.0 = 4.0$
$A_{im} = A_{i1} + A_{i2}$	$A_{im} = 2\pi(0.0501*2+0.0770*2) = 1.597$
$R_{im} = A_{im}/(2\pi L_m)$	$R_{im} = 1.597/(2\pi 4) = 0.0635$
$V_{hs1} = \pi[(R_{i1}+ t_1)^2 - R_{i1}^2)]L_1$	

Combining Heat Structures

$L_m = L_1 + L_2$	$L_m = 2.0 + 2.0 = 4.0$
$A_{im} = A_{i1} + A_{i2}$	$A_{im} = 2\pi(0.0501*2+0.0770*2) = 1.597$
$R_{im} = A_{im}/(2\pi L_m)$	$R_{im} = 1.597/(2\pi 4) = 0.0635$
$V_{hs1} = \pi[(R_{i1}+ t_1)^2 – R_{i1}^2)]L_1$	$V_{hs1} = \pi[(0.0501+ 0.0066)^2 – 0.0501^2)]2.0 = 0.00443$
$V_{hs2} = \pi[(R_{i2}+ t_2)^2 – R_{i2}^2)]L_2$	

Combining Heat Structures

$L_m = L_1 + L_2$	$L_m = 2.0 + 2.0 = 4.0$
$A_{im} = A_{i1} + A_{i2}$	$A_{im} = 2\pi(0.0501*2+0.0770*2) = 1.597$
$R_{im} = A_{im}/(2\pi L_m)$	$R_{im} = 1.597/(2\pi 4) = 0.0635$
$V_{hs1} = \pi[(R_{i1}+ t_1)^2 – R_{i1}^2)]L_1$	$V_{hs1} = \pi[(0.0501+ 0.0066)^2 – 0.0501^2)]2.0 = 0.00443$
$V_{hs2} = \pi[(R_{i2}+ t_2)^2 – R_{i2}^2)]L_2$	$V_{hs2} = \pi[(0.077+ 0.0071)^2 – 0.077^2)]2.0 = 0.00719$
$V_{hsm} = V_{hs1} + V_{hs2}$	

Combining Heat Structures

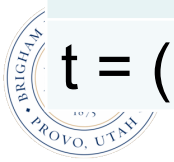
$L_m = L_1 + L_2$	$L_m = 2.0 + 2.0 = 4.0$
$A_{im} = A_{i1} + A_{i2}$	$A_{im} = 2\pi(0.0501*2+0.0770*2) = 1.597$
$R_{im} = A_{im}/(2\pi L_m)$	$R_{im} = 1.597/(2\pi 4) = 0.0635$
$V_{hs1} = \pi[(R_{i1}+ t_1)^2 – R_{i1}^2)]L_1$	$V_{hs1} = \pi[(0.0501+ 0.0066)^2 – 0.0501^2)]2.0 = 0.00443$
$V_{hs2} = \pi[(R_{i2}+ t_2)^2 – R_{i2}^2)]L_2$	$V_{hs2} = \pi[(0.077+ 0.0071)^2 – 0.077^2)]2.0 = 0.00719$
$V_{hsm} = V_{hs1} + V_{hs2}$	$V_{hsm} = 0.00443 + 0.00719 = 0.01162$
$R_{om} = \left[R_{im}^2 + \frac{V_{hsm}}{\pi L_m}\right]^{\frac{1}{2}}$	

Combining Heat Structures

$L_m = L_1 + L_2$	$L_m = 2.0 + 2.0 = 4.0$
$A_{im} = A_{i1} + A_{i2}$	$A_{im} = 2\pi(0.0501*2+0.0770*2) = 1.597$
$R_{im} = A_{im}/(2\pi L_m)$	$R_{im} = 1.597/(2\pi 4) = 0.0635$
$V_{hs1} = \pi[(R_{i1}+ t_1)^2 – R_{i1}^2)]L_1$	$V_{hs1} = \pi[(0.0501+ 0.0066)^2 – 0.0501^2)]2.0 = 0.00443$
$V_{hs2} = \pi[(R_{i2}+ t_2)^2 – R_{i2}^2)]L_2$	$V_{hs2} = \pi[(0.077+ 0.0071)^2 – 0.077^2)]2.0 = 0.00719$
$V_{hsm} = V_{hs1} + V_{hs2}$	$V_{hsm} = 0.00443 + 0.00719 = 0.01162$
$R_{om} = \left[R_{im}^2 + \frac{V_{hsm}}{\pi L_m}\right]^{\frac{1}{2}}$	$R_{om} = \left[0.0635^2 + \frac{0.01162}{\pi 4.0}\right]^{\frac{1}{2}} = 0.07045$
$t = (R_{om} – R_{im})/4$	

Combining Heat Structures

$L_m = L_1 + L_2$	$L_m = 2.0 + 2.0 = 4.0$
$A_{im} = A_{i1} + A_{i2}$	$A_{im} = 2\pi(0.0501*2+0.0770*2) = 1.597$
$R_{im} = A_{im}/(2\pi L_m)$	$R_{im} = 1.597/(2\pi 4) = 0.0635$
$V_{hs1} = \pi[(R_{i1}+ t_1)^2 – R_{i1}^2)]L_1$	$V_{hs1} = \pi[(0.0501+ 0.0066)^2 – 0.0501^2)]2.0 = 0.00443$
$V_{hs2} = \pi[(R_{i2}+ t_2)^2 – R_{i2}^2)]L_2$	$V_{hs2} = \pi[(0.077+ 0.0071)^2 – 0.077^2)]2.0 = 0.00719$
$V_{hsm} = V_{hs1} + V_{hs2}$	$V_{hsm} = 0.00443 + 0.00719 = 0.01162$
$R_{om} = \left[R_{im}^2 + \frac{V_{hsm}}{\pi L_m}\right]^{\frac{1}{2}}$	$R_{om} = \left[0.0635^2 + \frac{0.01162}{\pi 4.0}\right]^{\frac{1}{2}} = 0.07045$
$t = (R_{om} – R_{im})/4$	$t = (0.07045 – 0.0635)/4 = 0.00174$



Combining in Parallel

- DVDs have another example you can work through
- I suggest you make yourself familiar with this process

Assignment

- Watch DVD sections 39-43 before next Class
- Homework 4 is due Tuesday (10/3)