EVOLVE Lithium Tray Boiling Analysis

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Overview

- Issues
  - ♦ Need void fraction distribution in liquid metal tray to:
    - ▪ Determine volumetric energy deposition
    - ▪ Structural thermal loading
    - ▪ Design for vapor removal
  - ♦ MHD effects on voids:
    - ▪ Will MHD radically shift void profile?
      (with “vigorous” boiling appears 2nd order, preliminary)

Preliminary Void Fraction Determination

- Divide 50 cm tray into “channels” and predict void distribution in each channel
- Channel sizing calculation (Taylor length scale)

$$width = 2\pi\sqrt{\frac{3\sigma}{g\Delta\rho}}$$

width = 8cm, is a maximum bubble size (channel should be at least this wide)
(for simplicity a channel size of 10 cm was chosen)
σ = surface tension (N/m)
g = gravity constant
$\Delta\rho$ = liquid-vapor density difference (kg/m^3)

- Mohamed Sawan (UW) provided nuclear heating (W/cm^3) distribution for OB tray which gives generation rates for W and Li
- Uniform void distribution of 17% used for first calculation
- 25 zone Li pool (5 radial channels, 5 vertical positions)

Preliminary Void Fraction Determination

- Nuclear heating (W/cm^3) distribution in OB tray

98.9						
99.4	28.3	22.1	17.6	14.5	12.6	40.4
100.7	28.2	21.9	17.4	14.2	12.2	39.2
101.7	28.2	21.8	17.4	14.2	12.1	38.1
102.5	28.4	21.9	17.4	14.2	12.0	37.1
104.6	28.7	22.2	17.5	14.3	12.2	36.3
103.2	90.3	72.0	58.4	48.2	40.3	34.4
104.0						

FW represented by 0.6 cm thick zone
Trays have 50 cm radial thickness and 15 cm height
Tray bottom and back W plates are 0.5 cm thick
OB neutron wall loading is 10 MW/m^2

- Use energy deposited in Li and W to determine the vaporization rate

Preliminary Void Fraction Determination

- The material (Li) vaporized is used to determine the volumetric vapor flux (jg) and the dimensionless superficial gas velocity used in the churn-turbulent flow model

- Empirical study of void fraction in a pool configuration with upward flowing gas (bubbly or churn-turbulent flow regime, Casas & Corradini)

- Drift-flux model used

$$< void >= \frac{< Jg >}{C_o < Jg > + C_1} \qquad Jg = \frac{jg}{\left[\frac{\sigma_f(\rho_f - \rho_g)g}{\rho_f{}^2}\right]^{1/4}} \qquad Z = \frac{\mu_f}{\left[\rho_f\left(\frac{\sigma_f}{(\rho_f - \rho_g)g}\right)^{1/2}\sigma_f\right]^{1/2}} \qquad jg = \frac{m_g}{\rho_g A}$$

- C_o and C_1 experimentally determined coefficients from tests with mercury, woods metal, water, Freon, dodecane, and silicone oils

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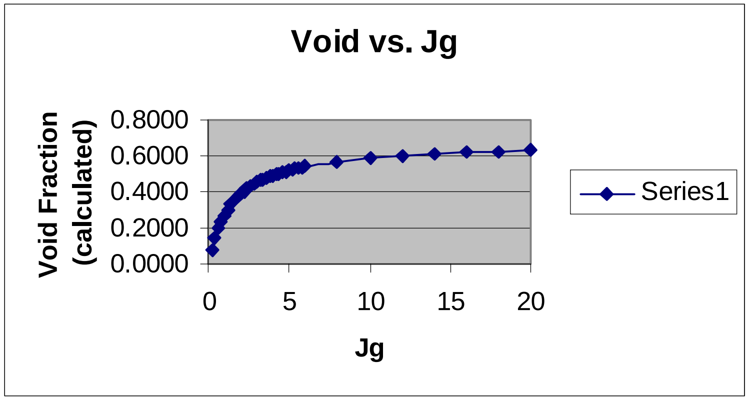
Preliminary Void Fraction Determination

Jg = dimensionless superficial gas velocity
C_o = $0.248 \ln(Z) + 3.52$
C_1 = $0.502\, h^*_o + 7.27\, 10^{-3} \ln(Z) - 0.124\, h^*_o \ln(Z) - 0.0295$
Z = Ohnesorge Number
h^*_o = dimensionless pool depth (height/diameter, 15 cm/10 cm)
m_g = vapor mass flow rate

jg = volumetric vapor flux
σ_f = fluid surface tension
μ_f = fluid viscosity
ρ_f = fluid density
ρ_g = vapor density
A = channel area

- Void fractions are driven by Li vapor density (ideal gas calculation) and by nuclear heat loads applied to the Li and W

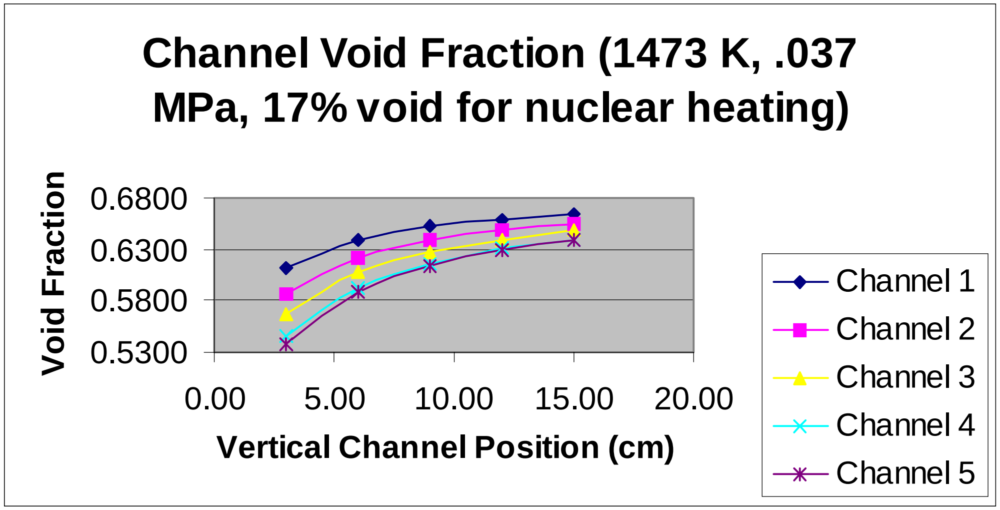
- Provided below is a plot of void fraction versus superficial gas velocity (Jg) at 1473 K and 0.037 MPa (most Jg values are above 5)

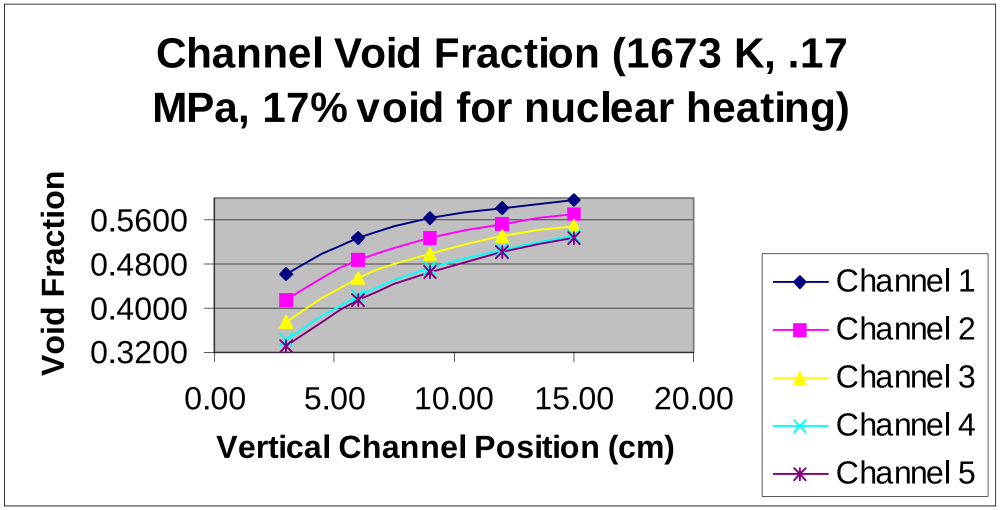


Preliminary Void Fraction Determination

- The superficial gas velocity scales directly to nuclear heating, but you can see that at sufficiently high (~ 5) values changes in nuclear heating minimally affect void fraction
- Assumed void fraction 17% for original nuclear heating values
- As void changes the deposition heating rates will change, ultimately the initial void fraction will be iterated on to converge to some value
- On the next page is the void profile for heating values corresponding to 17 % voids, 1473 K (0.037 MPa) and 1673 K (0.17MPa)
- To accurately assess, void fraction must be matched with heating (iteration necessary)

Preliminary Void Fraction Determination





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Iteration Process for Determining Void Fraction Distribution

- Volumetric heating is lower for higher void fractions

- As first order approximation nuclear heating in the Li is scaled linearly with density
  - Neutron attenuation in Li changes with void fraction affecting nuclear heating in Li at back of tray, W back plate, and W bottom plate

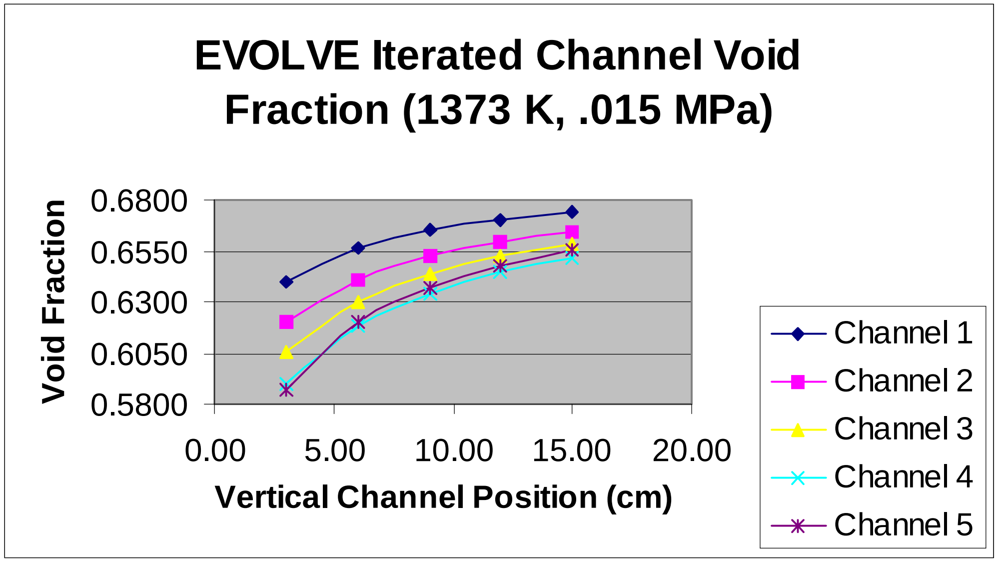
- Calculations repeated till convergence

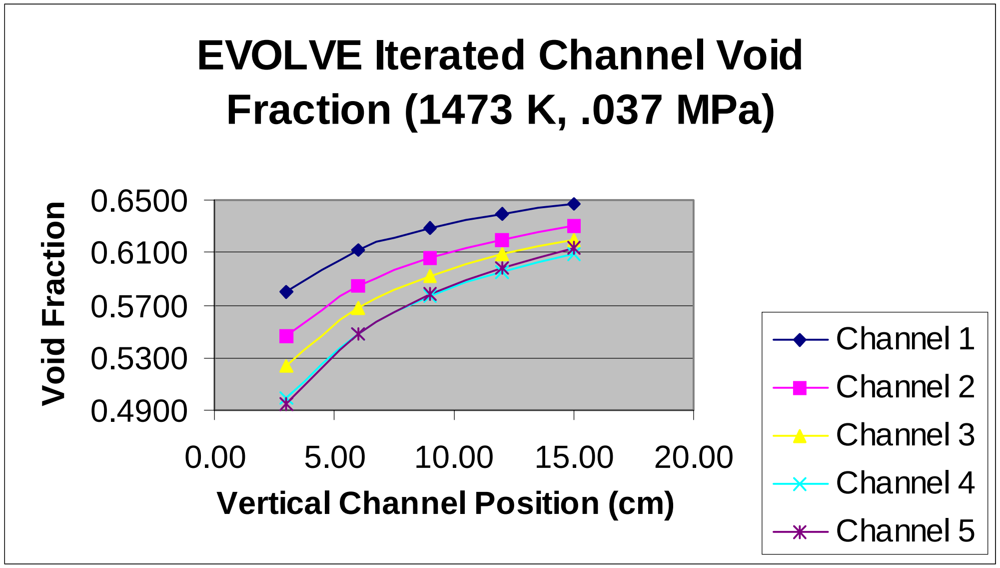
- This approach speeds up the iteration process

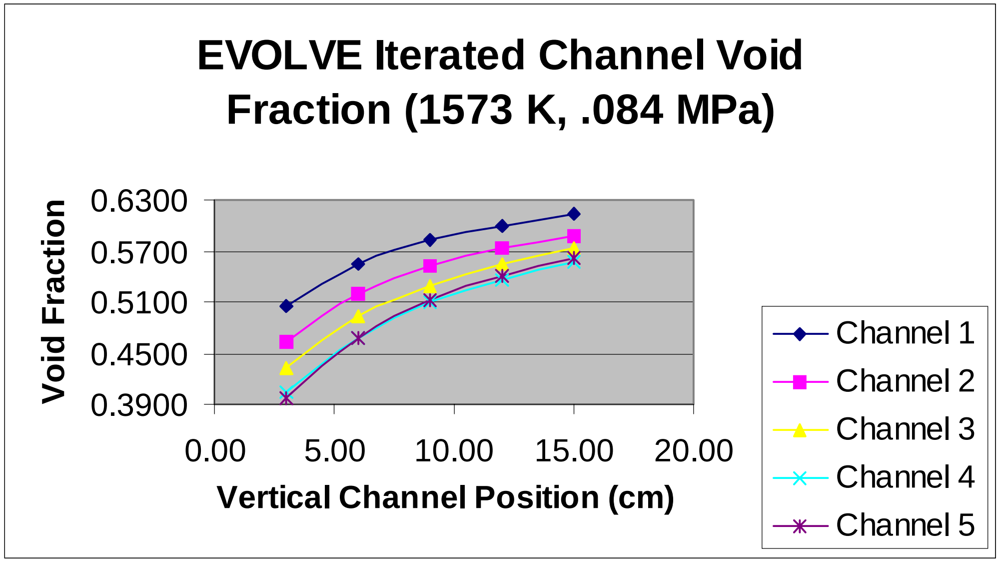
- The higher void fraction (compared to the assumed 17% average value) will reduce TBR and increase structure damage.

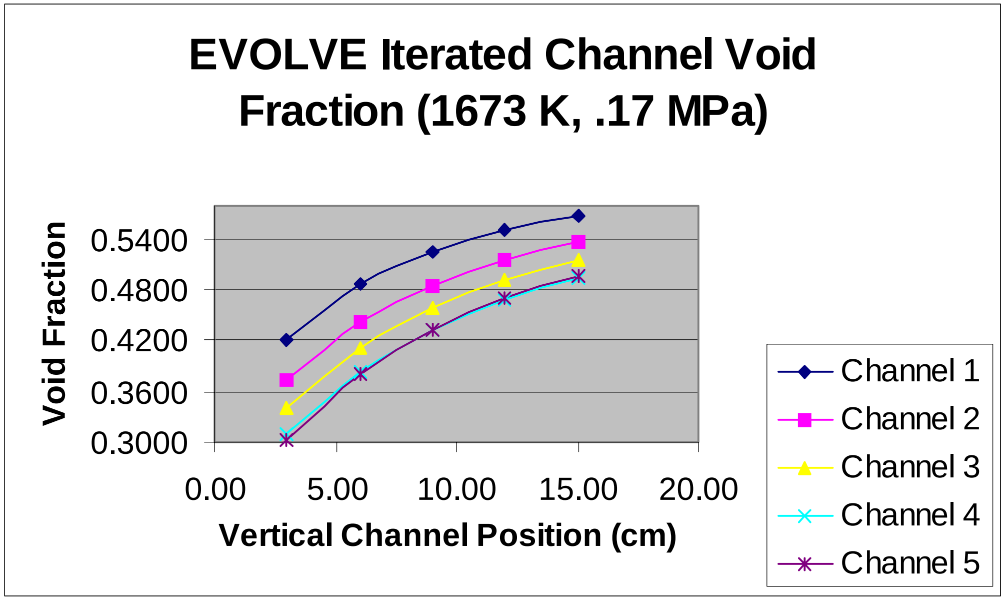
- Once the void fraction distribution is finalized, nuclear performance parameters will be updated

- Iterated void fraction values, starting with 17% void, are shown on the following pages (1373 K to 1673K)


EVOLVE Iterated Channel Void Fraction (1373 K, .015 MPa)
Void Fraction
0.6800
0.6550
0.6300
0.6050
0.5800
0.00
5.00
10.00
15.00
20.00
Vertical Channel Position (cm)
Channel 1
Channel 2
Channel 3
Channel 4
Channel 5


EVOLVE Iterated Channel Void Fraction (1473 K, .037 MPa)
Void Fraction
0.6500
0.6100
0.5700
0.5300
0.4900
0.00
5.00
10.00
15.00
20.00
Vertical Channel Position (cm)
Channel 1
Channel 2
Channel 3
Channel 4
Channel 5


EVOLVE Iterated Channel Void Fraction (1573 K, .084 MPa)


EVOLVE Iterated Channel Void Fraction (1673 K, .17 MPa)

Conclusions

- Voids appear to be significant (mainly because of low operating pressure)
  - Drift-flux model
    - Magnitude of nuclear heating 2nd order, when Jg large (>5)
    - Low pressure ensures large void fractions
    - Currently using ideal gas formulation for vapor density
      - When compared with tabular values, ideal gas looks fine
      - When better properties received they will be integrated, should not make much difference
    - Void fraction approaches $1/C_o$ as volumetric vapor flux (jg) increases

- MHD effects
  - Just beginning to review
  - With "vigorous" boiling, MHD appears to be 2nd order
  - Lykoudis paper
    - Magnetic effect may cause "channeling", voids up to 10%

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