Modeling of Boiling Water Reactors

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Presented at

Nuclear Regulatory Commission
TRACE/SNAP User Workshop
Columbia, Maryland
March 26 – March 29, 2018

Organization

BWR Modeling and Model Assessment Session Agenda

1. Model Overview
2. Determining Key Analysis Parameters
3. Important BWR Phenomena
4. BWR Specific Components
5. Steady State Model
6. LBLOCA Simulation

Important BWR Phenomena

Not all of the phenomena important to BWR accident analysis are covered in this session. Rather, the focus will be on a couple of phenomena that are important for BWR LOCA analysis and how to set up a TRACE model to capture them. These phenomena include the following:

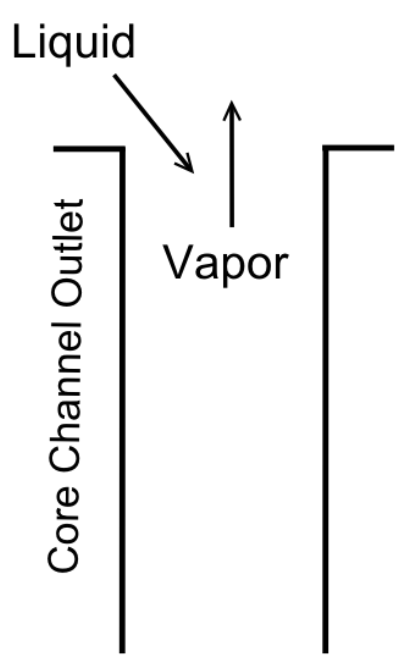
- Countercurrent Flow Limitation (CCFL)
- Choked Flow (in Jet Pumps)
- Rod Bundle Radiation Heat Transfer

Counter Current Flow Limitation (CCFL)

CCFL in BWRs occurs at flow restrictions where vapor flow at the restriction is sufficiently high to limit liquid influx.

- CCFL correlations predict the limit on liquid influx in relation to vapor out-flux.
- CCFL is geometry dependent.
- CCFL flags can be set at edges where CCFL is relevant in TRACE.

CCFL is considered to be particularly important for predicting core spray flow from the upper plenum into the core channels at the upper tie plate.



CCFL can also be important in predicting flow into the side entry orifice at the bottom of the channels.

“Typically, without .. CCFL .. TRACE will .. overpredict the amount of liquid downflow in the region of countercurrent flow” - *TRACE Theory Manual*

Counter Current Flow Limitation (CCFL)

How does CCFL influence PCT?

“It has been found that in BWR fuel rod bundles, which are enclosed by individual channels, a global counter current flow limiting (CCFL) condition normally determines the critical power.” – *Thermal Hydraulics of a Boiling Water Nuclear Reactor* by R. T. Lahey and F. J. Moody pg. 83 (Section 4.2.0).

Critical power is the power necessary to cause departure from nucleate boiling (DNB). In other words, the timing of DNB is often determined by CCFL phenomenon, and the timing of DNB is critical to determine the PCT that will be reached. CCFL at the channel exit is ranked high in the PIRT analysis during the reflood stage.

Counter Current Flow Limitation (CCFL)

The CCFL model in TRACE is based on the Bankoff correlation, which combines the Wallis and Kutateladze correlations. All three correlations have the form:

$$H_g^{1/2} + M \cdot H_l^{1/2} = C$$

H_g and H_l are dimensionless mass fluxes for gas and liquid respectively, and coefficients M and C are determined experimentally and are user inputs in TRACE.

Counter Current Flow Limitation (CCFL)

The Wallis and Kutateladze correlations differ in how the mass fluxes are scaled. Wallis nodimensionalizes mass flux using a length scaling based on the hydraulic diameter, whereas Kutateladze uses a length scale derived from surface tension. Bankoff defined a constant E that is used to interpolate between the two length scales. When E is 0, Wallis scaling is used. When E is 1, Kutateladze scaling is used.

CCFL Correlation

$$H_g^{1/2} + M \cdot H_l^{1/2} = C$$

Dimensionless Mass Flux

$$H_k = j_k \left(\frac{\rho_k}{g w (\rho_l - \rho_g)} \right)^{1/2}$$

Kutatetladze Length Scale

$$L = \left(\frac{\sigma}{g(\rho_l - \rho_g)} \right)^{1/2}$$

Bankoff Interpolation

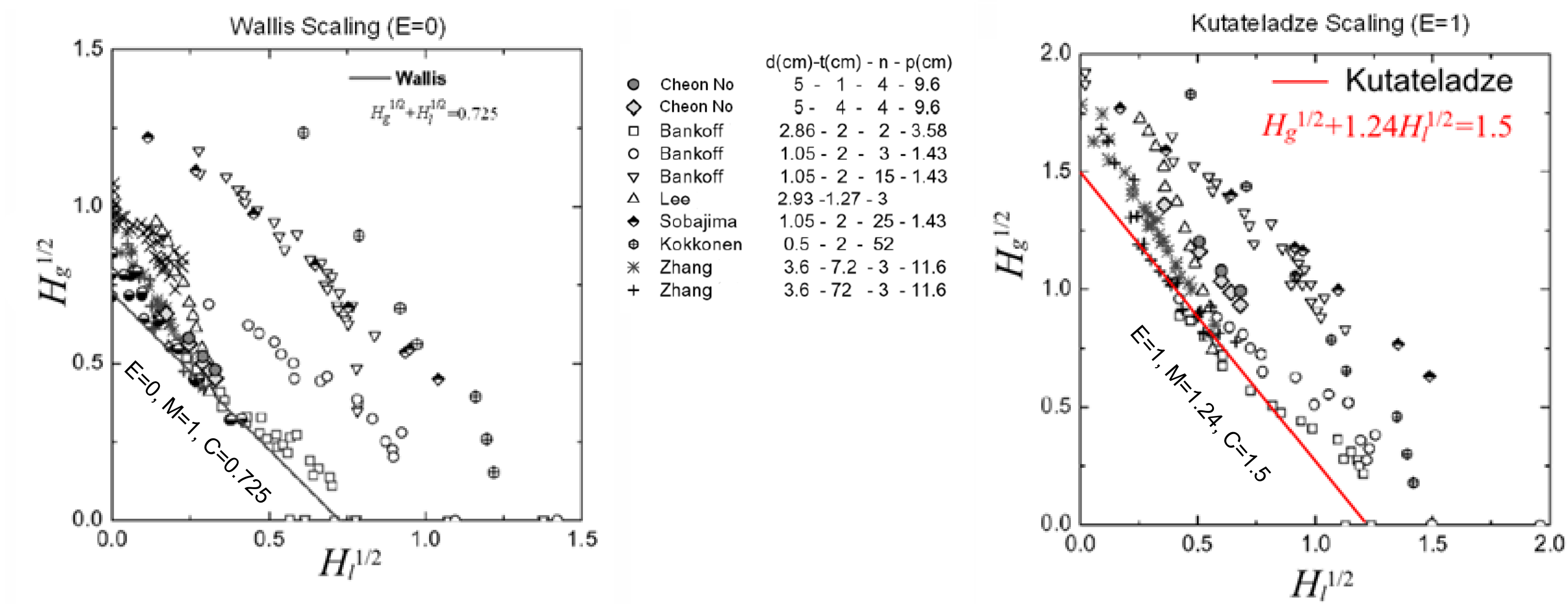
$$w = D^{1-E} L^{E}$$

k indicates phase (g or l), j is phase velocity, D is hydraulic diameter,

g is gravitational constant, σ is surface tension, ρ is density

Counter Current Flow Limitation (CCFL)

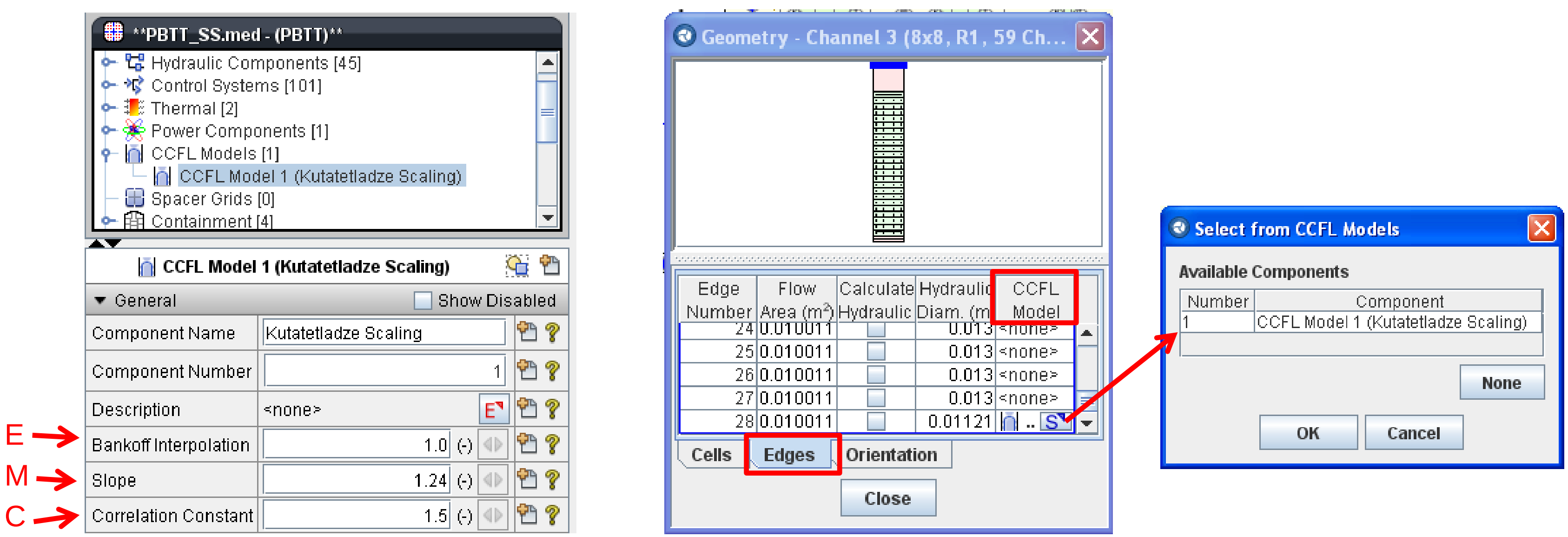
Example Wallis and Kutateladze correlations are shown below plotted against experimental data. Note that both plots show the **same data** scaled using Wallis vs. Kutateladze scaling.



Figures come from “An experimental study on air-water countercurrent flow limitation in the upper plenum with a multi-hole plate”, Hee Cheon No, Kyung-Won Lee, and Chul-hwa Song, Nuclear Engineering and Technology, Vol. 37 No. 6 December 2005

Counter Current Flow Limitation (CCFL)

CCFL correlations are defined in SNAP by specifying *M*, *C*, and *E*. In SNAP, *E*=‘Bankoff Interpolation’, *M*=‘Slope’, and *C*=‘Correlation Constant’ respectively. CCFL is enabled at specific edges in the model.



Choked Flow

Choked flow can have a significant impact on flow rates particularly at locations where flow restrictions occur.

- Choked flow at the break is important.
- Choked flow at the jet pump nozzle is also important for LOCA simulation (PIRT analysis).

- **Caution:** TRACE guidance recommends setting the choking flag at only those locations where choking is expected. Numerical and unrealistic results can be realized if choking is set in adjacent cell edges.

Radial Power Profile

Radial Power Profile in a BWR core region is important with respect to predicting the PCT during the reflood stage of a LOCA (PIRT study).

A BWR model usually includes multiple CHAN components. A radial power profile is defined in the model by proportioning power to the CHANs **and** by proportioning power to the rods within the CHAN.

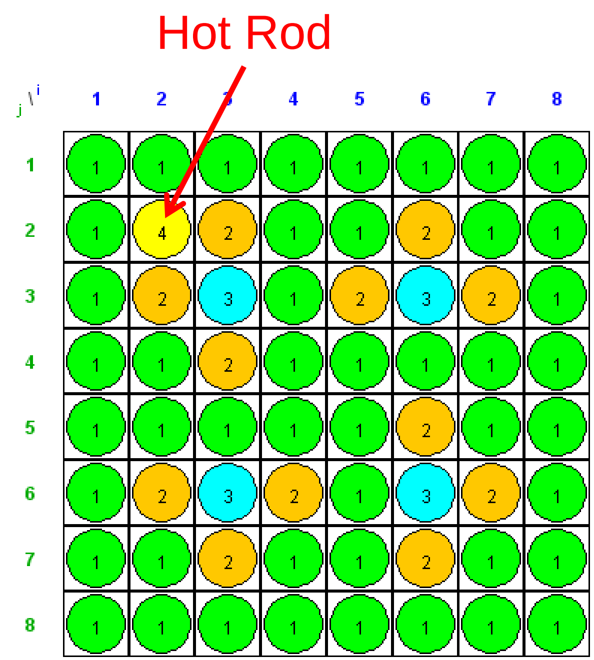
Often a **hot bundle** (with an elevated power) is added to the model. Departure from Nucleate Boiling (DNB) usually occurs in the hot bundle first. Often a **hot rod** is configured within the hot bundle. The hot rod is typically where PCT occurs.

Rod Bundle Radiation Heat Transfer

Rod bundle radiation heat transfer can be an important phenomenon in a BWR LOCA.

TRACE has the capability to model radiation between rods and from rods to the channel wall.

For calculating radiation transfer in the bundle, you can define rod groups and indicate the average power of each rod group. (Four rod groups are defined in the example to the right.)



A group can also be defined for the hot rod.

Rod Bundle Radiation Heat Transfer

When does radiation heat transfer become important?

How does radiation heat transfer affect the temperature profile across the CHAN?

How does radiation heat transfer influence PCT?

Exercise

Do the '**Adding Choking, CCFL, Power Distribution, and Radiation Models**' exercise (BWR-3-Exercise.pdf)