Determining Hydraulic Resistance Parameters for BWR and PWR Fuel Assemblies for HI-STORM System Thermal Modeling

By

Holtec International

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PRESENTATION OBJECTIVE

- In a September 17th 2004 letter, the NRC provided an evaluation of Holtec thermal analyses supporting increased HI-STORM System decay heat load limits, which identified three areas where the NRC Staff was "unable to confirm or verify Holtec's calculated results."
- One of these areas was the calculation of hydraulic resistance parameters for fuel assemblies stored in the MPC fuel baskets.
- This presentation provides an overview of a topical report (HI-2043285) prepared by Holtec International to address this technical issue.

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FEATURES OF FUEL ASSEMBLIES THAT NEED TO BE CONSIDERED

- **Flow of helium through fuel assembly rod arrays is laminar, which is dominated by viscous forces.**
- **Support grids and top and bottom nozzles create inertial losses.**
- **BWR fuel assemblies can have channels, yielding two parallel flows (one within the channel and one between the channel and the storage cell).**

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DIFFICULTY IN CALCULATING VISCOUS LOSS IN LAMINAR FLOW

- For laminar flow in circular tubes, the friction factor is typically calculated as $f = 64 / Re$.
- For laminar flow in non-circular passages, the friction factor may not be accurately predicted by calculating an equivalent hydraulic diameter and using $f = 64 / Re$.
- Various references give other friction factor relationships for laminar flow, but all are based on empirical procedures.

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USE OF CFD TO AVOID DIFFICULTY IN CALCULATING VISCOUS LOSS

- **Laminar flow is governed by the Navier-Stokes equations.**
- **CFD yields direct, numerical solutions of the Navier-Stokes equations without reliance on empirical friction factor formulas.**
- **Viscous friction is determined internally by the CFD code based on shear forces between fluid and solid elements.**

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DIFFICULTY IN CALCULATING FLOW DISTRIBUTION IN BWR FUEL ASSEMBLIES

- Flow is split between in-channel and outside channel (ex-channel) flows.
- The distribution of flow between these two parallel flow paths cannot be known before a detailed analysis is performed.
- Averaging the in-channel and ex-channel flow resistances may not correctly capture the flow distribution between these parallel paths.
- In-channel flow paths between rods are not all of uniform size due to water rods.

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USE OF CFD TO AVOID DIFFICULTY IN CALCULATING FLOW DISTRIBUTION

- **In-channel and ex-channel flows can be explicitly modeled with geometric accuracy.**
- **In-channel flow passages can be explicitly modeled with geometric accuracy.**
- **A flow distribution between parallel flow paths does not need to be assumed to perform a solution.**

HOLTEC MODELING OF BWR FUEL ASSEMBLY

- **Constructed separate models for in-channel and ex-channel flows for GE-12/14 10x10.**
- **Modeled all fuel rods, all grids, and top and bottom nozzles explicitly.**
- **Modeled water rods with porous regions at top and bottom.**
- **Used geometrically accurate submodels to calculate water rod porous region resistance parameters.**

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HOLTEC MODELING OF PWR FUEL ASSEMBLY

- Constructed model for Westinghouse 17x17 Optimized Fuel Assembly (OFA) / Vantage.
- Modeled all fuel rods and guide tubes, all grids, and top and bottom nozzles explicitly.
- Modeled guide tubes as being completely closed (i.e., no flow through guide tubes).
- Modeled perforated sections of top and bottom nozzles as porous regions with flow resistance calculated per a well-recognized source.

CFD MODEL EVALUATIONS

- **Evaluated all models for a range of pressure drops, calculating resultant flow rates.**

- **Flow versus pressure drop results of water rod top and bottom region submodels are used as inputs to in-channel BWR model evaluations.**

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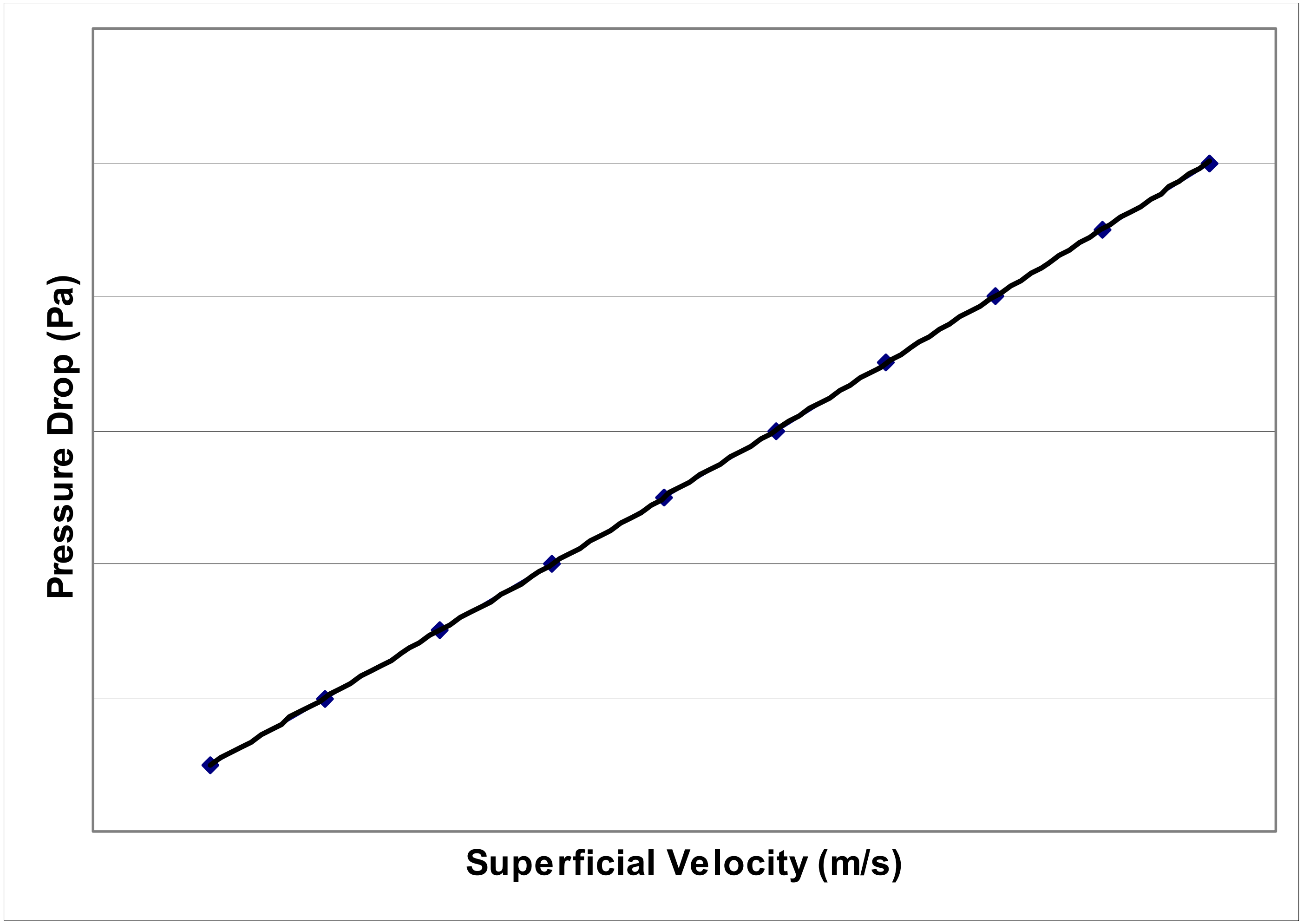
POST-PROCESSING OF CFD RESULTS

- Obtained superficial velocity versus pressure drop data sets for BWR (both in-channel and whole cell) and PWR fuel assembly models.
- Calculated BWR whole cell superficial velocity by summing in-channel and ex-channel flow rates and dividing by storage cell area.
- Fit curves to data sets to obtain equations for pressure drop as a function of velocity.
- Included both viscous and inertial terms in pressure drop versus velocity equations.

EXAMPLE OF RESULTS



CONCLUSION

- **CFD approach to fuel assembly hydraulic resistance modeling avoids the pitfalls of laminar flow friction factor calculations and, for BWR fuel assemblies, assumptions of in-channel and ex-channel flow distribution.**
- **CFD approach to fuel assembly hydraulic resistance modeling yields robust equations that can be used in subsequent 2-D or 3-D cask thermal modeling.**