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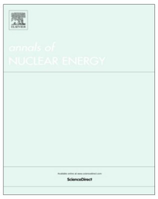

Mathematical spacer grid models for two phase flow

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ABSTRACT

The fuel rods of nuclear power plants covering Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR) cores are supported by spacer grids. Even though spacer grids add to the pressure loss in the reactor core, spacer grids have several benefits in LWRs. Some of these benefits are: (i) increasing the turbulence at the bottom of the reactor core for better heat transfer in single phase region of the LWRs, (ii) improving the departure nucleate boiling ratio results for PWRs, and (iii) improving critical power ratio (CPR) values by increasing the thickness of film in annular flow regime in the top section of the reactor core of BWRs. Several mathematical models have been developed for pressure loss across the grid spacer. Almost all of them significantly depend on Reynolds Number. Spacer designs have evolved (incorporating mixing vanes, springs, dimples, etc), resulting in the complexity of the analysis across the grid, all the models have been compared not only theoretically but also quantitatively. For the quantitative comparisons, this work compares the results of mathematical spacer models with experimental data of BWR Full Size Fine Mesh Bundle Tests (BFBT). The experimental data of BFBT provides very detailed experimental results for pressure drop by using several different boundary condition and detailed pressure drop measurements. Since one CT-scanner was used at the bundle exit and three X-ray densitometers were used for the chordal average void distribution at different elevations to generate the BFBT results, detailed two phase parameters have been measured in BFBT database. Detailed experimental data of BFBT was used for analyzing two phase flow mathematical models of spacer grid for various boundary conditions of BWR in this paper. It was observed and discussed that pressure drop values due to spacer models can be significantly different.

1. Introduction

In the first part of the series of papers, “Spacer Grid Models for Single Phase Flow,” the effects of spacer grids on liquid phase pressure loss, measured in a full size simulator using an actual fuel bundle, were compared to available spacer pressure loss mathematical models. The second part of this series involves two phase flow through the same fuel bundle simulator used for the study of one phase flows, continuing the focus on the effects of the spacer grid on pressure loss. As stated before, the mixing and turbulence caused by the spacer grid provides benefits such as heat distribution, and enhanced critical power ratios by increasing the thickness of the liquid layer in BWRs. However, there are more complex two phase flow patterns and characteristics which are sensitive to pressure changes.

The main difference between single and two phase flows is the increased complexity of the flow, which involves more than the phase properties. The flow is characterized to determine important ratios between the phases, particularly the void fraction, velocity ratio, and the pattern of the flow within the different sections of the fuel bundle. Even though these factors are complex and full analysis and accuracy of the two phase pressure losses requires 3 dimensional computer flow dynamics (CFD) modelling, several 1 dimensional historical models for two phase spacer pressure loss are commonly used in system and sub-channel computer codes in nuclear industry. Some of these models, developed especially for single phase flow, are modified with two-phase flow applications. As with the single phase spacer grid pressure loss, the accuracy and precision of these models are evaluated to determine their validity when applied to different conditions by using the Nuclear Power Engineering Corporation (NUPEC) BFBT experimental database.

2. Experimental facility and experimental equipment

The test facility, the fuel bundle and the spacer grid are the same equipment described in the BFBT specifications (Neykov et al., 2006). The pressure measurement is also taken across dpT1, recorded as “section 301” in the test results, of the fuel sim-

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Nomenclature

ΔP_{in-out}	pressure change between two points (Pascal kg/m-s^2)
$\Delta P_{acceleration}$	pressure change from compressibility of the vapor phase
$\Delta P_{accel\ 301}$	pressure change from vapor change across section 301
ΔP_{form}	pressure change from channel modification
$\Delta P_{gravity}$	pressure change from elevation change
$\Delta P_{gravity,\ 301\ ave}$	pressure change from elevation change across section 301
$\Delta P_{friction}$	pressure change from channel friction
ΔP^{2P}_{fric}	two phase frictional pressure loss
ΔP^{liq}_{fric}	frictional pressure loss only from the liquid phase
$\Delta P^{2P}_{Friedel,301}$	two phase Friedel frictional pressure loss (across section 301)
ΔP^{2P}_{sp}	the two phase pressure change at the spacer
ΔP_{EXP}	the pressure change through an expansion
Δz	the difference in elevation
$Ø_{liq}$	2 phase multiplier based on the liquid phase
$Ø_{liq,Friedel}$	2 phase multiplier based on the liquid phase for the Friedel correlation
$Ø_{liq,sp}$	general 2 phase spacer pressure multiplier based on the liquid phase
$Ø^{Lottes}_{liq,sp}$	Lottes 2 phase spacer pressure multiplier
$Ø^{Lottes\ exp}_{liq,sp}$	Lottes 2 phase spacer pressure multiplier, expanded version for different void fractions
$Ø^{Romie\ exp}_{liq,sp}$	Romie 2 phase spacer pressure multiplier, expanded version
$Ø^{Romie}_{liq,sp}$	Romie 2 phase spacer pressure multiplier
$Ø^{2P\ Richardson}_{liq\ o\ sp}$	Richardson 2 phase spacer pressure multiplier
$Ø^{Mendler}_{liq,sp}$	Mendler 2 phase spacer pressure multiplier
$Ø^{Mendler\ corr}_{liq,sp}$	Mendler 2 phase spacer pressure multiplier, corrected version
$Ø^{Beattie}_{liq,sp}$	Beattie 2 phase spacer pressure multiplier
$Ø^{Chisholm}_{liq,sp}$	Chisholm 2 phase spacer pressure multiplier
α	void fraction (m^2/m^2)
α_{sp}	void fraction at the spacer
$\alpha_{301\ in}$	void fraction at the spacer
β	volumetric flow fraction ((m^3/s)/(m^3/s))
$\beta_{301\ in}$	volumetric flow fraction at the inlet of section 301
β_{sp}	volumetric flow fraction at the spacer
ρ	general density (kg/m^3)
ρ_m	two phase density
ρ_v	vapor phase density
ρ_{liq}	liquid phase density
$\rho_{v,301\ in}$	vapor phase density at the inlet of section 301
$\rho_{liq,301\ in}$	liquid phase density at the inlet of section 301
$\rho_{m,301\ ave}$	average two phase density (across section 301)
$\rho_{v,sp}$	vapor phase density at the midpoint of the spacer
$\rho_{liq,sp}$	liquid phase density at the spacer midpoint
μ	dynamic viscosity (kg/m-s)
μ_{liq}	liquid phase dynamic viscosity
μ_v	vapor phase dynamic viscosity
$\mu_{liq,301\ in}$	dynamic viscosity of the liquid phase at the inlet of section 301
$\mu_{liq,301\ ave}$	dynamic viscosity of the liquid phase across section 301
$\mu_{v,301\ ave}$	dynamic viscosity of the vapor phase across section 301
$\mu_{liq,sp}$	liquid phase dynamic viscosity at the spacer
$\mu_{v,sp}$	vapor phase dynamic viscosity at the spacer
$\mu_{m,sp}$	two phase dynamic viscosity at the spacer
v	specific volume (m^3/kg)
v_v	specific volume vapor phase
v_{liq}	specific volume liquid phase
γ	surface tension – (Newton/m)
γ_{ave}	average surface tension
$\gamma_{301\ in}$	surface tension at the inlet of section 301
σ	contraction ratio
σ	standard deviation
ϵ	blockage ratio
A	cross sectional area (m^2)
A_B	flow through area of the channel (Bundle) (m^2)
B	Chisholm two phase spacer pressure multiplier coefficient
BWR	boiling water reactor
D_H	hydraulic diameter of the bundle (m)
$E_{1\ Prem}$	specific parameter of the Premoli Correlation
$E_{1\ Prem,301\ in}$	specific parameter of the Premoli Correlation at the inlet of section 301
$E_{2\ Prem}$	specific parameter of the Premoli Correlation
$E_{2\ Prem,\ 301\ in}$	specific parameter of the Premoli Correlation at the inlet of section 301
$E_{Fried,301}$	specific parameter of the Friedel Correlation (across section 301)
$F_{Fried,301}$	specific parameter of the Friedel Correlation (across section 301)
$Fr_{\ Fried,301}$	specific Froude number of the Friedel Correlation (across section 301)
$f_{liq,Fried\ 301}$	the Friedel liquid phase friction factor (across section 301)
$f_{v,Fried\ 301}$	the Friedel vapor phase friction factor (across section 301)
g	gravity (9.81 m/s^2)
$G_{liq,sp}$	mass flux of the liquid phase at the spacer
$G_{v,sp}$	mass flux of the vapor phase at the spacer
G_m	2 phase mass flux through the fuel bundle
$H_{Fried,301}$	specific parameter of the Friedel Correlation (across section 301)
$j_{liq,sp}$	superficial velocity of the liquid phase (m/s)
$j_{v,sp}$	superficial velocity of the vapor phase (m/s)
K_{sp}	the single phase spacer pressure loss coefficient
K_U	the single phase velocity transition coefficient
K_{EXP}	the single phase pressure loss coefficient through an expansion
L	length (m)
$\dot{m}$	mass flowrate (kg/s)
$\dot{m}_{liq}$	mass flowrate of the liquid phase
$\dot{m}_v$	mass flowrate of the vapor phase
$\dot{m}_{liq\ bundle\ in}$	mass flowrate of the liquid phase going into the bundle
P	general pressure (Pa-Newtons/m^2-kg/m-s^2)
PWR	pressurized water reactor
$Re_{Prem,301\ in}$	the Reynolds number of the fuel bundle at the inlet of the 301 section
$Re_{liq,ave\ 301}$	the average Reynolds number of the liquid phase between points (across section 301)
$Re_{v,ave\ 301}$	the average Reynolds number of the vapor phase between points (across section 301)
$Re_{2P\ sp}$	the two phase Reynolds number of the fuel bundle at the spacer
S	slip (velocity) ratio ((m/s)/(m/s))
$S_{301\ in}$	slip ratio at the inlet of the 301 section
U	general velocity (m/s)
$We_{Prem,\ 301\ in}$	the Weber number of the fuel bundle at the inlet of the 301 section