Nuclear Engineering and Design 342 (2019) 147–156

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Observation-based CHF model development: Dry spot – Dry patch models

Hee Cheon No[a,*], Moon Won Song[a], Sang-Jun Ha[b], In-Chul Ju[c], Jin Young Choi[d]

[a] Korea Advanced Institute of Science and Technology (KAIST), Department of Nuclear and Quantum Engineering, 291, Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea
[b] KHNP Central Research Institute, 1312-gil, Yuseong-daero, Yuseong-gu, Deajeon, Republic of Korea
[c] Korea Atomic Energy Research Institute, 989-111 Deadeok-daero, Yuseong-gu, Deajeon, Republic of Korea
[d] Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Deajoen 305-338, Republic of Korea

ARTICLE INFO

Keywords:
CHF
Transition boiling
Unquenchable dry patch
Dry spot model
Dry patch model

ABSTRACT

Recently advanced visualization techniques such as total reflection and IR methods have been applied to observe thermally and hydraulically the CHF mechanism at the surface as well as macroscopic bubble dynamics simultaneously. Based on observation Ha and No (1998a,b, 2000), and Choi et al. (2016) developed a Dry spot model and a Dry patch model, which is an extension version of the dry spot model. Experimental observations clearly showed that the production of unquenchable dry patches mainly contributes to the initiation of CHF.

Based on the above observatory conclusions and extensive literature survey, we discussed the physical basis of the Dry Spot/Dry Patch model. In the dry spot model, we assume that the dry spot can become unquenchable one when it is surrounded by 5 neighboring dry spots based on the geometrical consideration, which was confirmed by validation process. In the dry patch model, both criteria from the hydraulic and thermal considerations were proposed to estimate the critical size of unquenchable dry patch at CHF. The wall dry area fraction can be calculated by applying a probabilistic concept for the creation of the unquenchable dry patch. We showed that the Dry Spot/Dry Patch model can be extended into CHF predictions in both pool boiling and forced convective boiling. For transition boiling, we proposed models to represent two suppression mechanisms deactivating potential nucleation sites: nucleation site deactivation and non-availability mechanism. For the physical model of the nucleation site deactivation mechanism we introduced the spatial randomness concept. For the non-availability mechanism we proposed the multi-stage calculation method which considers the sequential bubble activation and their interaction. Then, we showed that the dry spot model modified with the current transition model well predicted the whole boiling curve including CHF, nucleate boiling, transition boiling, and film boiling.

1. Introduction

Since CHF has been known as a critical thermal-hydraulic phenomenon to determine the licensable power level, numerous analytical studies for development of CHF models have been performed for decades: hydrodynamic instability model, macroscopic dryout model, bubble crowded model, and so on.

A hydrodynamic instability model (Zuber, 1959) explained the CHF phenomenon considering two instabilities: Taylor instability for geometric parameters of cylindrical vapor columns and Helmholtz instability for critical vapor velocity. In this model, CHF mainly depends on the liquid properties as follows:

$$\frac{q''_{CHF}}{h_{fg}\rho_g^{0.5}[\sigma g(\rho_f-\rho_g)]^{0.25}}=\frac{\pi}{24} \tag{1}$$

A macrolayer dry out model (Haramura and Katto, 1983) described a big vapor mushroom connected to the heating surface by the vapor stem. When heat flux reaches near the CHF, the liquid film of the macrolayer is evaporated at the end of the hovering period and then there exists no more rewetting of the macrolayer. From this process, CHF is modeled with models related to the bubble dynamics, such as a hovering period and a macrolayer thickness, as follows:

$$q''_{CHF}=\frac{\rho_f h_{fg}\delta_c}{\tau_d}\left(1-\frac{A_v}{A_w}\right) \tag{2}$$

This model can qualitatively explain a CHF mechanism without any experimentally supporting observations.

Recently, advanced visualization techniques such as total reflection and IR methods have been applied to observe thermally and hydraulically the CHF mechanism at the surface as well as macroscopic

* Corresponding author.

https://doi.org/10.1016/j.nucengdes.2018.11.028
Received 30 July 2018; Received in revised form 16 November 2018; Accepted 26 November 2018
Available online 08 December 2018
0029-5493/