Development of Wall-to-Fluid Heat Transfer Package for the SPACE Code

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1. Introduction

A SPACE code which has a multi-dimensional analysis capability by incorporating a dispersed liquid phase into the thermo-hydraulic field equations is under development for a safety analysis of PWRs. Several research and industrial organizations are participating in the collaboration for the development program, including KAERI, KOPEC, KNF, and KEPRI. The main task of KAERI is to develop physical models and correlation packages for constitutive equations; a wall heat transfer package, a wall and interfacial friction package, an interfacial heat and mass transfer package and a flow regime selection package. This paper describes the development program for a wall-to-fluid heat transfer package for the SPACE code.

2. Wall-to-Fluid Heat Transfer Package

2.1 Development of a heat transfer mode transition map

The wall-to-fluid heat transfer mode consists of a single phase convection, single phase natural convection, nucleate boiling, critical heat flux, transition boiling, film boiling and a condensation heat transfer. A total of 11 heat transfer modes have been determined according to a non-condensable gas quality, a void fraction, a degree of subcooling, and a wall temperature as shown in Table 1.

Table 1: Classification of wall-to-fluid heat transfer modes

Mode	Application
Mode 0	Convection at supercritical pressure
Mode 1	Convection to non-condensable steam-water mixture
Mode 2	Convection to single phase liquid
Mode 3	Convection to single phase vapor
Mode 4	Subcooled nucleate boiling
Mode 5	Saturated nucleate boiling
Mode 6	Subcooled transition boiling
Mode 7	Saturated transition boiling
Mode 8	Subcooled fillm boiling
Mode 9	Saturated film boiling
Mode 10	Condensation

A heat transfer mode transition map was developed to make sure a smooth transition between adjacent two heat transfer modes and to minimize numerical instability. The developed heat transfer mode transition map is shown in Fig.1.

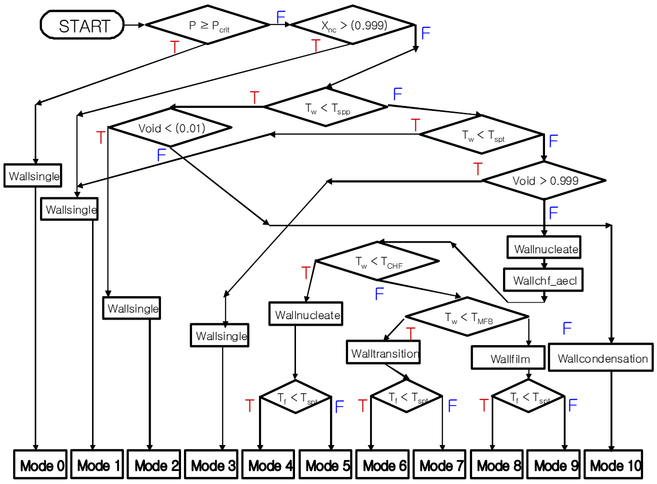

Fig. 1. Heat transfer mode transition map

2.2 Review of the existing models

In order to select wall-to-fluid heat transfer model for the SPACE code, different models currently used in major best-estimate nuclear reactor system analysis codes, which are RELAP5, TRAC-M, COBRA-TF and CATHARE, have been reviewed. Furthermore, a vast scope of literature survey was conducted in order to develop the best wall-to-fluid heat transfer package for the SPACE code.

2.3 Heat transfer package for the SPACE code

Through an in-depth literature review process, the best model for each heat transfer mode was selected and implemented into the SPACE code. In the heat transfer regime in which a model's uncertainty is expected to high, an alternative model is additionally programmed as a user option. The selected heat transfer models consisting of the wall-to-fluid heat transfer package of the SPACE code are summarized in Table 2. A detailed description of the model selected can be found in a report [1].

3. Code Implementation and Verification Tests

3.1 Code implementation

The program language for the SPACE code has been decided as C++. Several C-functions were implemented depending on a heat transfer mode defined in Table 1. The heat transfer regime selection algorithm was coded in the function "wallheatmode". The major heat transfer models were programmed in the functions of "wallsingle", "wallnucleate", "wallchf", "walltranstion", "wallfilm", and "wallcondensation". A CHF and film boiling look-up table was coded in a separate source file in order to easy maintenance of the SPACE code. [2]

Table 2: Heat transfer models of the existing codes

Regimes	Models
Natural convection	1) McAdams for laminar 2) Warner & Arpaci for turbulent
Forced convection	Dittus-Boelter
Nucleate Boiling	Chen
CHF	2006 AECL-UO look-up table
Transition Boiling	1) Leung, 2) Bjornard, 3) Chen
Film Boiling	2004 AECL-UP look-up table
Condensation	1) max(Nusselt, Chato, Shah) 2) Non-iterative model (No-Park)

3.2 Verification results

Two different code verification works were conducted: one is for boiling and the other is for condensation. Wall temperature of a heat structure was arbitrarily increased so that heat transfer mode was changed from single phase convection to the film boiling, resulting in a typical boiling curve. The SPACE result was compared with that of MARS code as shown in Fig.2. In the MARS code calculation, the same boundary conditions were used for direct assessment of the SPACE code developed. It can be found that the agreement between two boiling curves is excellent except for the post-dryout region.

Condensation model was assessed by comparing the SPACE results and several models in the literature for different wall temperatures as shown in Fig. 3. The implemented models could simulate the heat fluxes in the horizontal, vertical and turbulent conditions quite reasonably for the pure steam condensation. However, the two-phase flow properties should be given properly to give more reasonable results for the condensation with the noncondensable gas present, Especially, No-Park's model should be improved for the low temperature conditions and an iteration scheme should be revised to finalize the Colburn-Hougen's model.

4. Conclusion

Wall-to-fluid heat transfer package for the SPACE code was developed and its calculation results were verified with a counterpart calculation with the MARS code for boiling phenomena. Both calculations resulted in almost the same results, but a difference in the post-dryout region was observed. The implemented condensation models could simulate the heat fluxes reasonably for the pure steam condition but a few revisions are necessary for the condensation with the noncondensable gas present.

At the moment, a full assessment for the heat transfer package is not possible due to an incompleteness of the hydraulic solver. As the SPACE code structure is improved, much more rigorous verification will be performed in the near future.

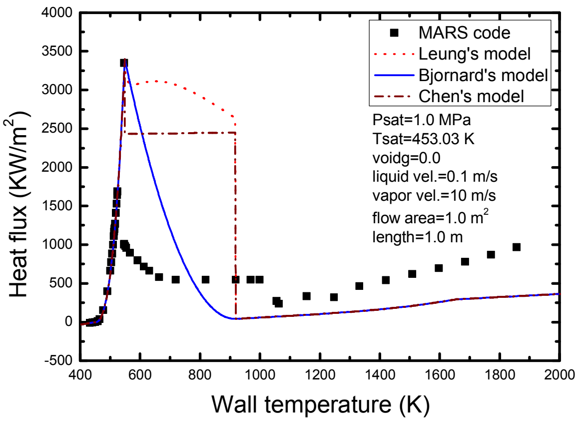

Fig. 2. Comparison of a boiling curve between the SPACE and the MARS code

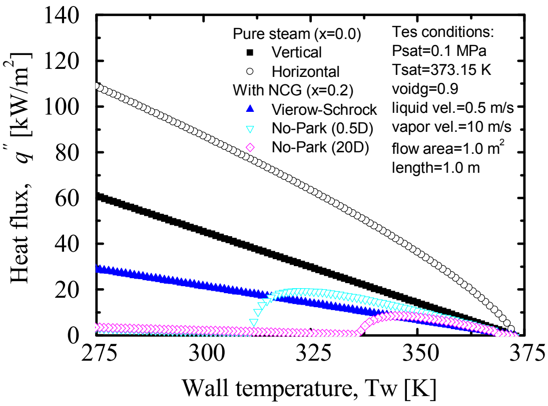

Fig. 3. Heat fluxes calculated from the wall condensation models implemented in the SPACE code

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REFERENCES

[1] Kim, H. D. et al., "Investigation and Selection of Wall-to-Fluid Heat Transfer Correlations for the Development of Constitutive Relation," SPACE's Software Design Description, S06NX08-A-1-RD-03, Rev.00. (2008)

[2] Kim, H. D. et al., "Coding of Wall-to-Fluid Heat Transfer Correlations for the Development of Program Module," SPACE's Software Design Description, S06NX08-A-1-RD-11, Rev.00. (2008)