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Literature Survey on Flow Instability Analysis Cases using System Code

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I. Introduction

Natural circulation systems including the boiling channels can undergo different types of two-phase flow instabilities depending on the geometric parameters and operating conditions. Flow instabilities can threaten the structural integrity of the component and increase the uncertainty of the system performance. System analysis codes such as RELAP5 and MARS-KS have been used to investigate followings: 1) the characteristics of flow instability in the target system or component, 2) determine the stable and unstable operation range of the system, and 3) the improvement of the system design.

Recently, various passive safety systems are adopted to develop the advanced nuclear power plants. Many passive safety systems operate in natural circulation mode. Flow instabilities are considered in the optimum design of the passive safety system. To figure out how to model the passive safety system (nodalization scheme) to simulate flow instability, in this study, we performed the literature survey on flow instability analysis cases using system code, focusing on how the system were modeled in previous researches [1-14].

II. Literature Survey Results

2.1 System Code Nodalization

Many researches [1,2,4,5,6,8,9] focused on the investigation of the Density Wave Oscillation (DWO) in single channel and two parallel channels. They modeled the heating channel with PIPE components and the flow and pressure boundary with TMDPVOL and TMDP-JUN as shown in Fig. 1(a).

Prasad et al. [3] investigated the characteristics of DWOs by RELAP5 simulations for a simple double-channel natural circulation system. They modeled the system with TMDPVOL as steam outlet and water inlet as shown in Fig. 1(b). Kozmenkov et al. [7] and Zhao et al. [11] performed RELAP5 simulation to investigate the flashing-induced flow instability in natural circulation system. They modeled the system by introducing the heat structures for condenser, cooler, and preheater as shown in Fig. 1(b).

There were also researches [10,12,13,14] on the flow instabilities in the Passive Containment Cooling System (PCCS). They modeled the PCCS as open loop or closed loop as shown in Fig. 1(c). Hou et al. [10] investigated the applicability of RELAP5 to simulate the thermal-hydraulic behaviors of PCCS. They modeled the PCCS heating tube by the heat structure where the boundary condition is set as the constant heating rate. They did not model the containment atmosphere. They performed the sensitivity analyses for the nodalization. Three different kinds of nodalizations were tested according to the total node numbers; 120, 240, and 320 nodes. Simulation results showed that 120-node case is inaccurate compared with other nodalization; while 240 and 320-node cases showed similar results. So, they chose the 240-nodes as the appropriate nodalization by simultaneously considering the accuracy and rapidity of the RELAP5 simulation.

Kim et al. [12] modeled the PCCS heat exchangers as the constant heat flux boundary conditions. They analyzed the natural circulation behaviors of PCCS according to various operating conditions and design parameters by MARS-KS to observe the flow instability and deduced the flow stability map of PCCS design.

Lim et al. [13] developed the stability maps for flashing-induced instability in a PCCS. They modeled the PCCS heat exchanger with a heat-flux boundary condition. The PCCS inlet flow rate and the inlet temperature were controlled by TMDPVOL and TMDPJUN connected to the top of the PCCT model. For the better prediction, they performed the sensitivity analyses for 1) the nodalization scheme, 2) time step size, and 3) alternative models and correlations.

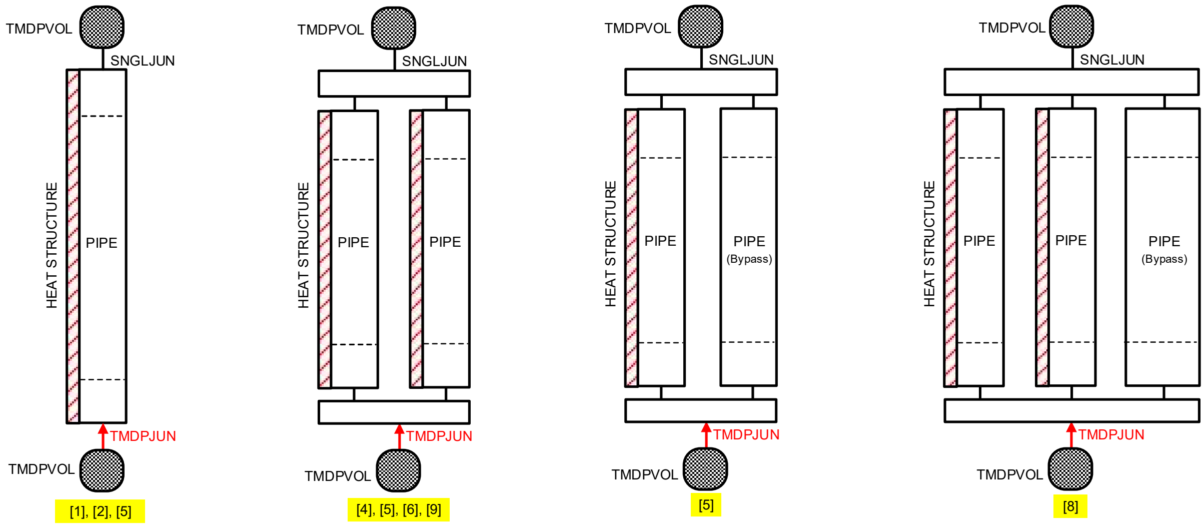
As a result of the literature survey, the following common points were confirmed in the modeling: 1) Boiling section is included. 2) Flow instability characteristics in the system were investigated while controlling the flow rate and heat flux.

2.2 Code Simulation Considerations

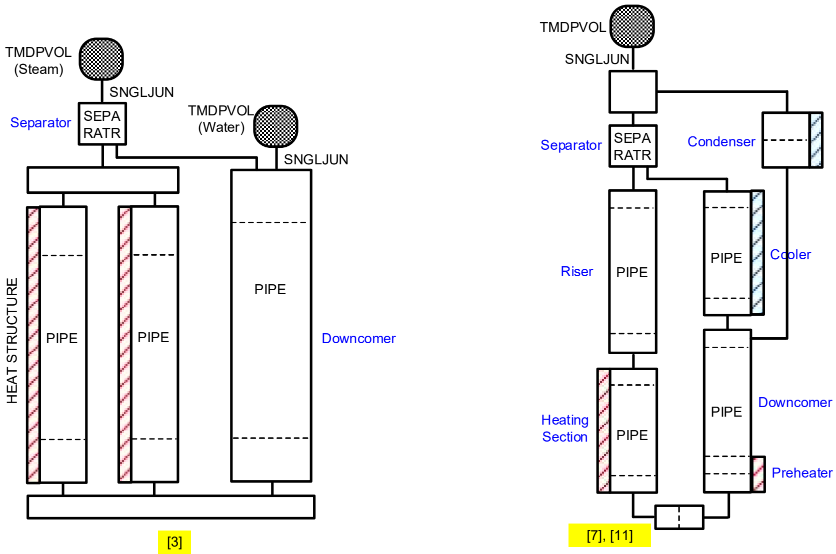
As a result of the literature survey, it was confirmed that the following items should be considered when analyzing flow instability using system codes.

1) System code prediction results are very sensitive to the nodalization (e.g. number of nodes). It is essential to select the appropriate number of nodes through node number sensitivity analysis.

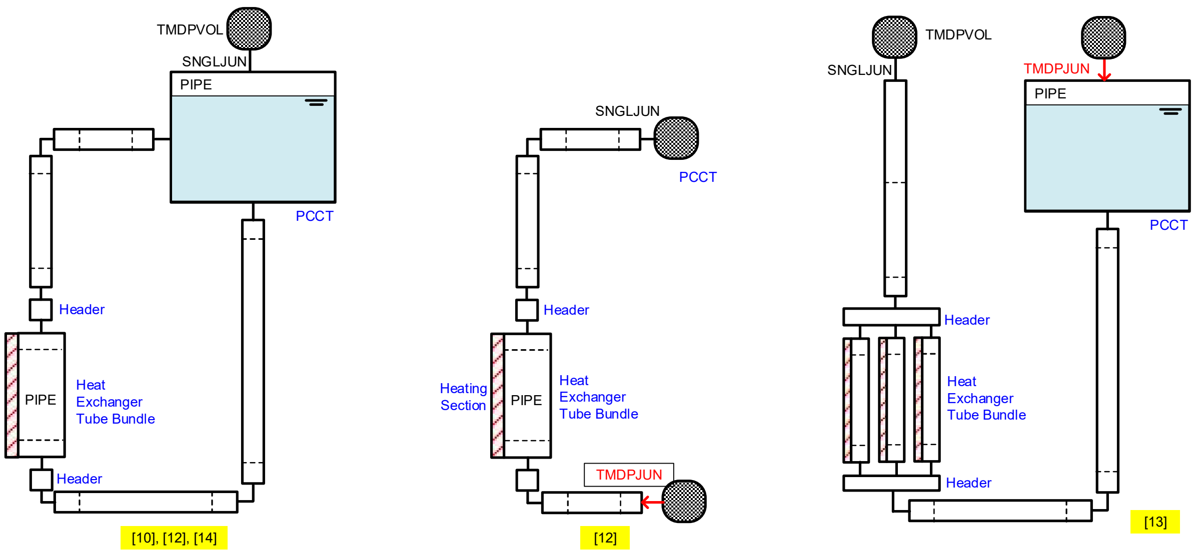
2) It is necessary to keep the calculated time step constant to capture the cycle of possible flow instability as well as possible. In addition, it is recommended that code calculation proceeds at a time step sufficiently smaller than the minimum Courant number. Therefore, the appropriate time step size selection is very important by simultaneously considering the accuracy and rapidity of the code simulation.



(a) Single channel and parallel channels



(b) Natural circulation system



(c) PCCS

Fig. 1. System code nodalization of flow instability analysis

3) There is no clear criterion (or threshold) for determining whether flow instability occurs. In Ref. [5] the system was considered unstable when mass flow rate oscillation amplitude reached 100% of the steady-state value. In Ref. [6], it is considered to be an unstable state if the mass flow rate oscillation magnitude grows to a certain value (more than 10%). In this regard, it is necessary to carefully judge whether the flow instability occurs by comparing the simulation results with experimental data that can be referenced.

4) System code calculation results becomes different according to the relevant model (e.g. boiling, void fraction, condensation, pressure drop, and etc.). It is important to use the best-estimate model and correlations based on various sensitivity analyses.

III. Conclusions

The literature survey on flow instability analysis cases using system code were conducted. It is believed that major cases of instability studies using system analysis codes have been presented. Reviewed papers and modeling approaches will be helpful to model the passive safety system and investigate flow instabilities.

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