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Preliminary Analysis of Rapid Condensation Experiment with MARS-KS Code

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1. Introduction

The importance of passive safety in nuclear facility is continuously increasing to achieve an enhanced reactor shutdown, core heat removal, and radioactivity confinement. To implement the passive safety in real design, several new concepts of shutdown system, decay heat removal system, containment cooling system, and other systems are being developed worldwide. Among these systems, many enhanced cooling systems are utilizing rapid condensation function. Rapid condensation mechanism is effective to reduce the pressure of a certain part of system by injecting a cold flow into steam or by condensing steam on a cold surface.

In the present study, the rapid condensation experiment performed in MANOTEA facility [1] is analyzed with the MARS-KS code [2]. It is known that there exists some limitation with a system code to predict this kind of a very active condensation due to direct mixing of cold injection flow and steam. Through the analysis we investigated the applicability of MARS-KS code for the design of various passive safety systems in the future.

2. Analysis

The configuration of the experimental facility MANOTEA, which has been constructed at the University of Maryland - United States Naval Academy, is described and the modeling approach using the MARS-KS code is also provided. The main purpose of the experiment was to obtain data to validate multi-dimensional multi-phase flow phenomena during condensation-driven transients. The major results obtained from the code analysis are compared with the experimental data.

2.1 Modeling of Experiment

The experimental facility consist of a boiler pipe and condenser pipe connected by a counter-current double-pipe heat exchanger. The boiler pipe of 7.62 cm ID and 8.26 cm OD was made of carbon steel pipes insulated with 5.08 cm-thick fiberglass insulation. The temperature distribution in the boiler section was measured at 3 elevations. The material geometry and composition of condenser pipe were identical to the boiler pipe except that the temperatures was measured at 11 different elevations. At the central part of the double-pipe heat exchanger (DPHE) a copper tubing of 0.635 cm ID was located and the outer wall of the DPHE was constructed with 2.54 cm-diameter schedule 80 PVC pipe.

Before the main experiment, the boiler pipe and condenser pipes were evenly half-filled with water, then 3.79 L of water was added to the water inventory to prevent the uncover of heaters during the experiment. After that, each heater was turned on to heat up the water inventory with the venting of non-condensables in the pipes. Then, the heater in boiler section was turned off and the vent valve from condenser section was closed to cause the buildup of condenser pressure and also the movement of water to the boiler side.

When the boiler pipe is fully filled with water, the boiler heater was turned on again and the condenser heater off and the boiler pipe was isolated from the condenser pipe by closing the valves in the connection pipe at the bottom side. Further, the primary side of the DPHE become connected to boiler section by opening the valve between the boiler pipe and the DPHE, and secondary water supplied to the DPHE. At this states, the heat loss from the condenser section made the pressure in the condenser decreased to 101kPa while the pressure in the boiler increased up to 121 kPa. If this condition was achieved, the boiler heater turned off.

Finally, the transient was initiated by opening the valve between the primary side of DPHE and the condenser pipe. The condensation in condenser section induces condensation of steam and it causes the continuous fluid motion from the boiler section.

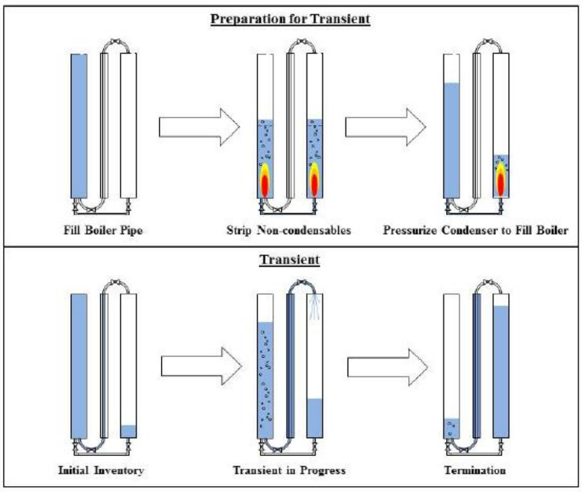


Fig. 1. The procedures of rapid-condensation experiment [3].

Figure 2 shows the nodalization of experimental facility for MARS-KS simulation. The condenser pipe is divided into 11 sub-volumes to match the 11 thermocouples locations. The boiler pipe is also modeled with 11 axial nodes. The heat structures are used to model the wall of each pipe and the heat transfer from the tap water to the primary water flow through the copper tube in the DPHE. In MARS-KS modeling, the thermal tracking model, water packing model, and vertical stratification model are applied.

The magnitude of condensing during the transient is quite affected by the nozzle type at the top of the condenser pipe, which causes modeling limitation in the simulation because the exact shape is not available. In the present study, the jet nozzle identified as EZNF0800 is adopted.

The content of non-condensable gas in the condensing section is one of the dominant factors affecting the condensation rate. In the experiment, the air remained in the primary side of the colder DPHE becomes the source of non-condensable gas. Referring to the evaluation on the experimental results [3], it is assumed that about 1% of non-condensable gas is included in the vapor space of the condenser at the initial state of the transient.

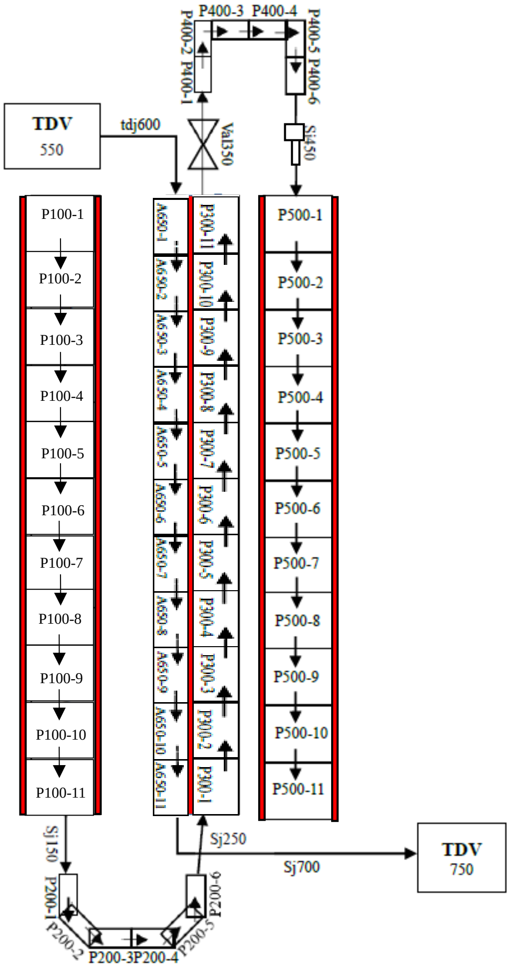
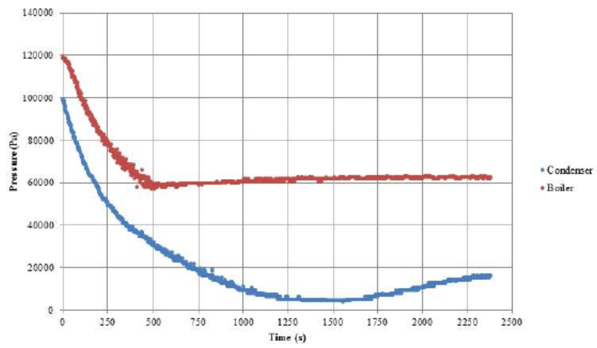


Fig. 2. MARS-KS nodalization of MANOTEA facility

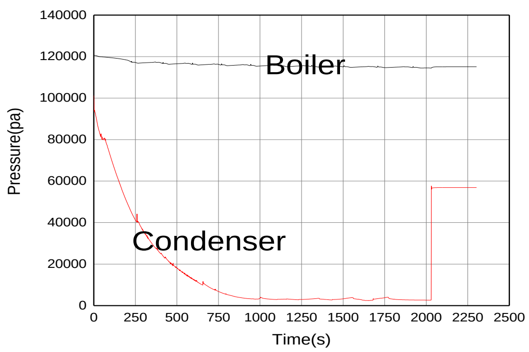
2.2 MARS-KS Analysis

Figure 3 compares the measured pressure and the predicted pressure for boiler pipe and condenser pipe. It is found that the pressure drop in boiler at early stage is not predicted correctly. This trend was already predicted in the study with TRACE code [4]. It is presumed that the initial superheating of the water in boiler pipe is not modeled in the simulation. The pressure change in the condenser pipe is quite correctly predicted in the MARS-KS simulation. However, a stepwise pressure increase at the later part of the simulation seems unrealistic mainly due to the overestimation of the water flow from the boiler section.

The predicted temperature distribution and the measured one in the condenser section are given in Fig. 4. It is found that the general temperature behaviors are well reproduced in the simulation. When the predicted temperature changes are compared with those predicted with TRACE code [4], the MARS-KS is evaluated to simulate the transient correctly. However, the MARS-KS prediction shows abrupt temperature increase at some points. The change of flow regime or heat transfer pattern need to be checked to identify the reason of this results.

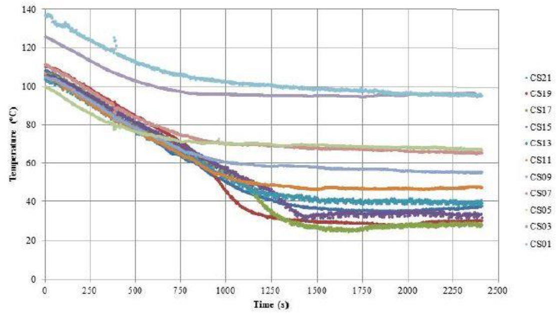


(a) Experimental data [1]



(b) MARS-KS prediction

Fig. 3. Comparison of boiler and condenser pressures for the EZNF0800 nozzle.



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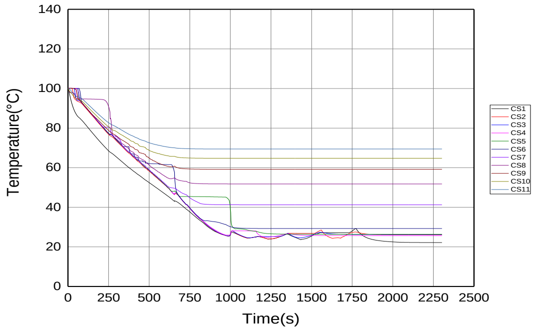

(b) MARS-KS prediction

Fig. 4. Comparison of the measured and the predicted temperature distributions for the EZNF0800 nozzle.

3. Conclusions

A rapid condensation experiment performed in the MANOTEA facility is simulated with the MARS-KS code to validate the applicability of the code to various passive safety systems utilizing active condensation. The preliminary result shows that the MARS-KS predicts the general trend of pressure and temperature in the condensing part correctly. However, it is also found that there exist some limitations in the simulation such as an unexpected pressure peak or a sudden temperature change. The reason of these limited predictions will be identified and an advanced simulation will be pursued in further studies.

REFERENCES

[1] A. Pollman and M. di Marzo, Simplified, integral, rapid-condensation transient experiment, Nucl. Eng. Des., Vol. 249, p. 357, 2012.
[2] KAERI, MARS code manual, KAERI/TR-3042/2005, 2006.
[3] A. Pollman, Experimental validation of TRAC-RELAP Advanced Computational Engine (TRACE) for simplified, integral, rapid-condensation-driven transient, University of Maryland, Ph.D. Dissertation, 2011
[4] A. Pollman, K. Vierow, and M. di Marzo, Analysis of rapid-condensation transient using TRACE, Nucl. Eng. Des., Vol. 250, p. 512, 2012.