A Simulation of the Flow Distribution Change in the Conceptual Heat Exchanging System due to the Line Pressure Drop Variation

D.J.Euh [a*], T.S.Kwon [a], J.W.Choi [a]

[a]*Korea Atomic Energy Research Institute, Daedeok-daero 1045, Yuseong, Daejeon, 34057, Korea*
[*]*Corresponding author: djeuh@kaeri.,re.kr*

1. Introduction

The equilibrium flow characteristics in a heat exchanging system is controlled by the line pressure drop and heat exchanging rate. The thermodynamic status such as pressure, temperature, and void fraction or quality are affected by the momentum and energy balance at the boundary in the closed loop. The current study is motivated by a hydrogen system having boiling and condensation phenomena in a circulation loop. During the manufacturing process of the loop system, the actual flow path dimension or configuration was changed due to some mechanical problem in the detailed design and construction phase. The current issue comes from the weld bead inception into the flow path, which contracts the flow area at the junction point and induces an additional hydraulic resistance. Generally the increasing line pressure loss induces smaller flow rate than the nominal value if the hydraulic head does not change drastically. The enthalpy change in the heat exchanger sections in the boiling system should be larger under the reduced flow rate. For such a circumstance change, the equilibrium condition can be selected with the various options according to the desirable system specific control philosophy.

In the current study, a performance simulation with a simply assumed conceptual system has been performed to have an insight for the thermal hydraulic condition and seek an adequate system control strategies. Since we don't have adequate simulation code for the system that hydrogen is used as the working fluid, a conventional water and steam system was adopted for the simulation of the conceptual system. Although the working fluid is different from that of the interested system, the overall trend is expected quite similar and the strategy for the transient loop condition mitigation can be setup from the insight from the current simulation.

2. Methods and Results

The conceptual system consists of the boiler, riser, heat exchanger and downcomer, of which the primary side forms a close system and there is no inventory loss or addition. The primary system pressure is controlled only by the heat exchange amount and secondary temperature. Fig. 1 shows a nodalization diagram for the simulation. MARS_KS version 1.5 has been utilized for the thermal hydraulic calculation. The four "pipe" components were adopted for the boiler, riser, heat exchanger and downcomer, respectively.

The generated two phase mixture due to boiling in the boiler flows directly into the riser and condensing in the heat exchanger. The pressure of the heat exchanger primary side is set at 0.2MPa, which is the similar condition of the target system.

The additional line pressure drop in the manufacturing process due to the weld bead insertion into the flow path was modeled by pressure drop coefficient referred to the handbook of hydraulic resistance [2]. Three weld points were assumed at the downcomer line, of which the effect was collected at the junction between downcomer and boiler. The base case, case 0, assumes the two volumes of the downcomer and boiler be connected smoothly according to the ideal design. The case 1 has been defined the line resistance due to the additional flow resistance such as due to flow area contraction. The loss coefficient, K is assumed to 10.5 with some conservatism referred to the handbook of the hydraulic resistance.

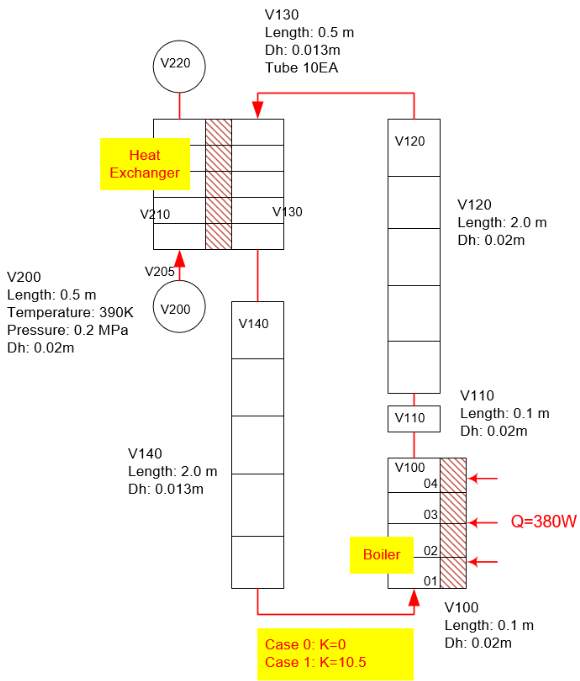

Fig. 1. MARS model for conceptual heat exchanging system

The pressure drop of the circulation system strongly depends on the fluid velocity, which depends on the hydraulic head in the natural convection system. Although the working fluid is different at the target system, the current problem sets around 0.2 m/s as the nominal velocity, which is similar with the target system.

Table I. Case Definition

Case	Boiler Inlet Junction K (between V140 and V100)
Case 0 (Base)	0.
Case 1	10.5

Table II. Major boundary conditions

Design Parameter	Value
Heating Power, W	380
Pressure at HX, MPa	~0.2
Boiler Power, W	380
Boiler Tube I.D., m	0.02
Boiler Height, m	0.5
Riser I.D., m	0.02
Riser Height, m	2.0
HX 2danary Inlet Temp, K	390
HX Tube I.D., m	0.013
HX Tube number	10
HX Height, m	0.5
Downcomer I.D., m	0.013
Downcomer Height, m	2.0
Downcomer I.D., m	0.013
Equilibrium velocity, m/s	~0.2

3. Results

Table III shows the results for the important parameters. Since the flow in the riser also has water, the hydraulic head inducing the flow driving force is less than 2m which is the height of the downcomer. The simulation shows 2% reduction of the equilibrium flow due to the line drop increase.

Table III. Case Definition

Case	Case 0 (Base)	Case 1 (Line Pressure Loss Case)
Equilibrium flow, g/s	25.8	25.3
Velocity in the downcomer, m/s	0.2211	0.2168
HX Primary Pressure, MPa	0.2203	0.2205

The flow reduction leads to the enthalpy rise in the boiler. In the current simulation, the HX exit condition after the steam is condensed, is set as the temperature of the secondary temperature. In other words, the boiler inlet temperature is controlled almost same between the two cases. Therefore, the enthalpy of the boiler exit is increased in the case 1, which is the system having additional line pressure drop. The enthalpy increase is expressed by void fraction increase in the riser. Since the steam volume is increased in the case 1, the system pressure is also increased. However, the increasing degree is calculated to be very small. Such amount of the pressure variation can be sufficiently controlled by adjusting the heat transfer rate by varying the heat exchanger secondary temperature or flow rate. Fig. 2 and 3 shows the pressure increase in the heat exchanger and void fraction increase in the riser in the case 1.

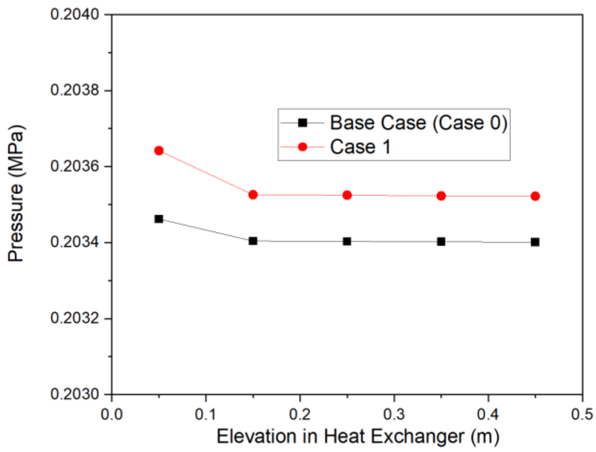

Fig. 2.Pressure distribution in the heat exchanger

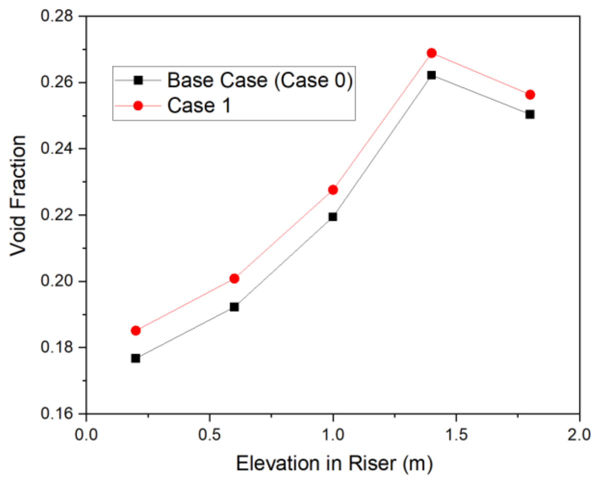

Fig. 3.Void fraction distribution in the riser

3. Conclusions

A simple conceptual heat exchange system is simulated to have an insight for the new equilibrium thermal hydraulic condition and to seek an adequate system control strategies by using the working fluid as water since we don't have an adequate simulation tool for the hydrogen boiling and condensing system. The simulation has been performed by setting the system pressure, fluid velocity and heat power to be similar to the interested system. As the results, a reduced flow rate and increased system pressure and void fraction degree was calculated. The hydraulic head loss due to the line pressure loss increase induces 2% reduction of flow, which supports the pre-expected flow variation trend. The primary system pressure is maintained a similar level though small increase. Although the working fluid is different from that of the interested system, the overall trend is expected quite similar and the strategy for the undesired loop condition can be setup from the insight from the current simulation.

ACKNOWLEDGEMENTS

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