Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

Natural Circulation Flow in the Adiabatic Model of Design of Core Cather Cooling System

K.W. Song[a], S.F. Huang[a], S. T. Revankar[*a,b], B.W Rhee[c], R.J. Park[c], K.S. Ha[c], J.H. Song[c]
[a]*Division of Advanced Nuclear Engr. POSTECH Pohang, Gyungbuk Korea*
[b]*School of Nuclear Engineering, Purdue University, West Lafayette, IN 47906, USA*
[c]*Korean Atomic Energy Research Institute, Daejeon, Korea*
[*]*Corresponding author: shripad@postech.ac.kr*

1. Introduction

Recently Song et al., (2011) have developed a core catcher concept, which can be adapted for both existing reactors and the advanced light water reactors. This core catcher is a passively actuating device, which can arrest, stabilize and cool the molten core material inside the reactor cavity and thus reduce its impact on containment pressurization. Primary goal of the proposed ex-vessel core catcher is to reliably accommodate and rapidly stabilize the corium, including the entire core inventory and reactor internals that is injected into the cavity following a postulate severe accident. The cooling channel is made of a single channel between the core catcher body and inside wall of the reactor cavity. The cooling channel also has an inclination angle of ~10 degree and a vertical section to facilitate the steam venting in to top tank. A down-comer is provided to result in a two-phase natural circulation. The present work addresses the effort towards an experimental testing program of the core catcher cooling system, specifically to understand the natural circulation driven cooling, two-phase flow and possible CHF issues due to high void fraction in inclined section of the core catcher cooling channel.

The model test facility objective is to study the flow patterns, natural circulation flow rates and twophhase parameters in the core catcher cooling system. Instead of steam-water system, an adiabatic air-water flow is considered. In the design of the test facility a scaling analysis for the two phase natural circulation in the core catcher cooling loop has been carried out. The scaling analysis was primarily based on local phenomena scaling such as CHF, local drift velocity and global phenomena scaling such as natural circulation, and two phase flow.

2. Core Catcher Cooling System Scaling

To keep the consistency of the prototype and the modeling system, scaling analysis is necessary covering the difference in geometry and fluids' properties. Most important parameters in scaling are related to heat flux, mass flow rate, quality and void fraction and system pressure drop. For a two-phase natural circulation system, similarity groups have been developed based on mass, momentum and energy equations integrated along the loop. The non-dimensionalization of these response functions yields the key integral scaling such as phase change number, sub-cooling cumber, Froud number, drift-flux number, time ratio number, thermal inertia ratio, friction number, and orifice number. The scaling parameters include heat flux, exit void fraction, mass flux, friction coefficient, and pressure drop.

The flow is driven by buoyancy force depending on the void fraction in the flow. The flow rate is determined by the total pressure drop. In order to have a given flow in a two phase natural circulation, the pressure gain due to buoyancy force should equal pressure drop due to flow losses. A drift flux model, is applied to calculate slip ratio in the present study, where the distribution coefficient and the drift velocity correlations are used (Sonnenburg 1989). The basic flow sheet of the calculation of natural circulation flow is shown in Fig. 1.

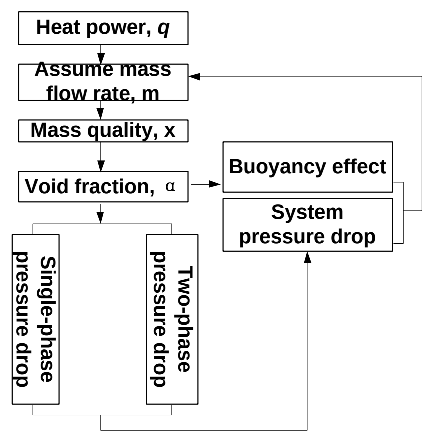

Fig. 1 Flow sheet of scaling analysis.

Since the channel of the test section is complicated, it can be treated separately in different parts when calculating the slip ratios:(1) Horizontal part: L(length)=300mm, L/D<<1, therefore slip ratio is assumed to be unity; (2) Inclined part: L=2740mm, D=200mm, L/D=13.7, inclination angle =10°. We can obtain slip ratio by linear interpolation based on horizontal and vertical model [0°, 90°]; (3) Vertical part: L/D=5, not fully developed. L/D=20 can be regarded as fully developed condition. The interpolations can be depicted in Fig. 2 for inclined and vertical parts respectively.

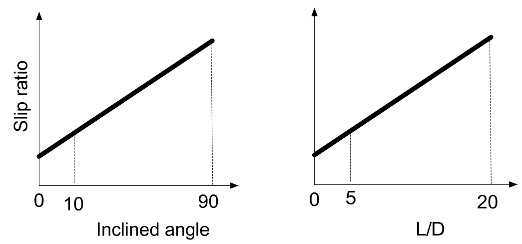

Fig. 2. The interpolations in terms of the inclined angle and length

3. Scaled model prediction

Figs. 3 and 4 give the calculation results of scaling study for the prototype system. The natural circulation flow rate increases non-uniformly with heating power. The slip ratio in the inclined and vertical test sections is less than 2.5, due to the developing flow.

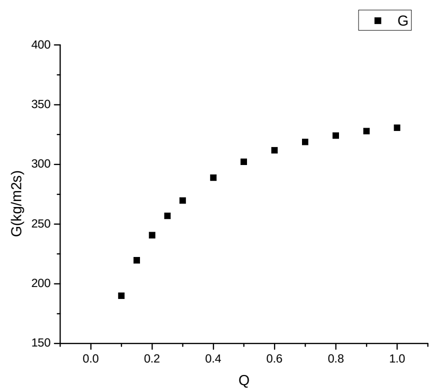

Fig. 3 Mass flux against heating power percentage.

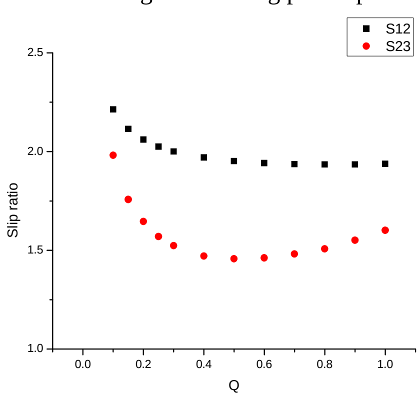

Fig. 4 Slip ratios of inclined and vertical parts against heating power percentage.

4. Experimental Facility

The model core catcher is presented in Fig. 5. Instead of steam, air is supplied from the top of the channel to simulate two phase flow with five air injection ports. Air compressor supplies certain amount of air obtained by the calculation of core decay heat power.

There are some changes we have made in terms of actual test section geometry. Between 10° inclined channel and vertical channel, we added one more inclined channel forming 40° with both channel for ease of construction. Whole test section, including horizontal, inclined and vertical, is made of transparent polycarbonate to visualize the flow.

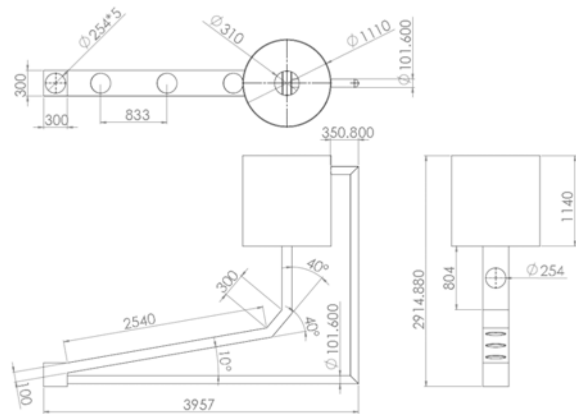

Fig. 5. model core catcher drawing

With double sensor conductivity probe, the void fraction, air-water mass flow rate, bubble chord length, and bubble velocity are measured. We also can observe the flow regime and bubble shape. And film thickness probe will measure the liquid film thickness.

This data are important with understanding the natural circulation driven cooling, two-phase flow and possible CHF issues due to high void fraction in inclined section of the core catcher cooling channel.

5. Conclusions

A detailed scaling analysis of the core catcher cooling system was carried out based on which the design of the adiabatic test facility was carried out. The natural circulation flow rates and other flow characteristics were obtained which will enable the comparison of the measured data from model facility with prototype system.

ACKNOWLEDGMENTS

This work was supported in part by World Class University (WCU) program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (R31 - 30005).

REFERENCES

[1] J. H. Song et al. 2011, A core catcher design for advanced light water reactors, Proceedings of ICAPP 2011, Nice, France, May 2-5, 2011, Paper 11216.
[2] Sonnenburg, H.G.,1989, Full-range drift-flux model base on the combination of drift-flux theory with envelope theory, NURETH-4 2, 1003–1009, 1989.