Two-Phase Flow Instability in Water-side Tube of SG under Axially Uniform Heat Flux Conditions

Eui Kwang Kim*, Dehee Kim, Yoon Jung, Tae-Ho Lee
Korea Atomic Energy Research Institute, SFR NSSS System Design Division, 1045 Daedeok-daero,Yuseong-gu, Daejeon 305-353, KOREA
**Corresponding author: ekkim1@kaeri.re.kr*

1. Introduction

The SG of PGSFR is of once through integrated type, and is a vertical counter flow shell and tube heat exchanger with sodium on shell side and water-steam in tubes. The phenomenon of two-phase flow instability has been observed in many industrial domains like boiling systems, steam generators. Since the oscillations induced by two phase flow instability can cause many problems like a degradation of the heat transfer performance, thermal fatigue of the tube, and enhancing water-side corrosion, it is required to develop a tool to predict the thresholds of flow instability. In this paper the numerical methods were studied, and a computer code was developed for two-phase flow instability in steam generator, and representative results of the model calculations are presented.

2. Methods and Results

In this section some of the methods used to develop the code to model the dynamics of boiling systems are described. Flow stability has been studied by solving the time dependent mass, momentum and energy conservation equations representing the system. These equations are generally solved either in frequency-domain or time-domain to determine stability boundaries in appropriate parameter spaces. In the time-domain approach, the conservation equations are solved numerically using, for example, finite-difference techniques. The approach requires some techniques to approximate the partial derivatives, which makes the resulting algebraic equations numerically unstable and limited by time-step constraint. Moreover, this approach is very time consuming when used for stability analyses, since the allowable time step size may be very small, and large numbers of cases must be run. A novel method of solution of the finite difference equations is developed by Chatoorgoon [1] to study system stability.

2.1 Governing equations

For homogenous two-phase, constant area, one-dimensional channel flow, the mass, momentum and energy conservation equations, and the equation of state can be written as follows:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}=0$$

$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho u^2)}{\partial x}+\frac{\partial p}{\partial x}+C_k\rho u^2+\rho g=0$$

$$\frac{\partial}{\partial t}\left[\rho\left(h+\frac{u^2}{2}\right)\right]+\frac{\partial}{\partial x}\left[\rho u\left(h+\frac{u^2}{2}\right)\right]+\rho u g=\frac{\partial p}{\partial t}+q_w$$

$$\rho=f(p,h)$$

2.2 Numerical approach

The equations are discretized in space by integration from point i to i + 1, and forward-difference scheme in time are employed to derive the difference equations for the mass, momentum and energy conservation. The one-dimensional flow channel is divided into axial computational cells or control volumes, with a non-staggered grid, i.e. the grid points are located at the cell edges as shown in Fig. 1.

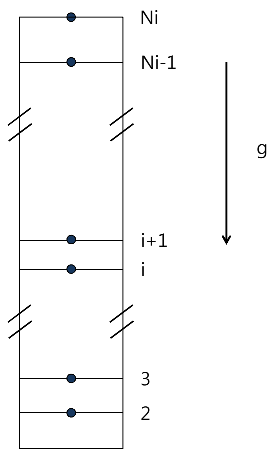

Fig. 1. Spatial grid and control volume in the flow channel.

The kinetic energy terms and pressure term in the Energy equation for two-phase systems can be ignored, as they are generally very small.

The algorithm employed to solve the coupled, non-linear, time-dependent discretized equations is given in Fig. 2 [1]:

There are four unknown variables (ρ, u, p and h) to be solved at each time step for each grid point I from 2 to last grid Ni. Inlet conditions (ρ, p and h) of the flow are maintained constant at the grid point 1. Before starting the transient simulations, the steady-state solution for the unknown variables was slightly perturbed. In the present analysis, velocities at the steady-state was increased by 1%, as an initial condition at every grid point.

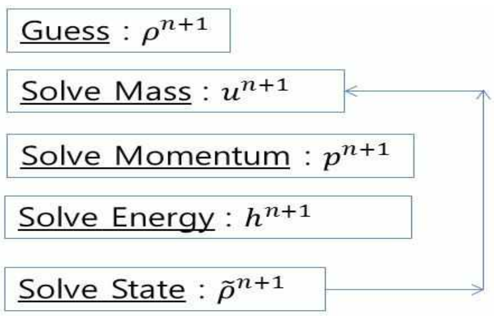

Fig. 2. Sequence of solving.

2.3 Boundary Conditions

For the present investigation, constant pressure drop boundary condition along with constant inlet conditions are applied to the flow channel, i.e. inlet temperature, inlet pressure and outlet pressure are assumed to be prescribed. The program will iterate on the inlet flow velocity to match the outlet pressure boundary condition. To get improved guess for inlet flow velocity, u, “Shooting Method” was employed.

2.4 Stability Analysis

Steady-state and time domain analyses are carried out for a single tube of PGSFR SG. The detailed information of the problem is given in Table 1. Fig. 3 and Fig. 4 show the transient solutions for two inlet pressures, and an increase in system pressure is found to have a stabilizing effect. In Fig. 4, inlet pressure of 96% of the rated inlet pressure was selected as part of parameter study to find threshold pressure.

Table 1. Problem Description

Number of nodes	51
Time step	1 sec
Number of tubes	703
Inner dia. of tube	0.0127 m
Length of tube	23.28 m
Thermal power per SG	196 MW
Rated inlet pressure	16.87 MPa
Rated outlet pressure	16.7 MPa
Inlet temperature	240 C
Rated inlet flow rate	86.85 kg/s

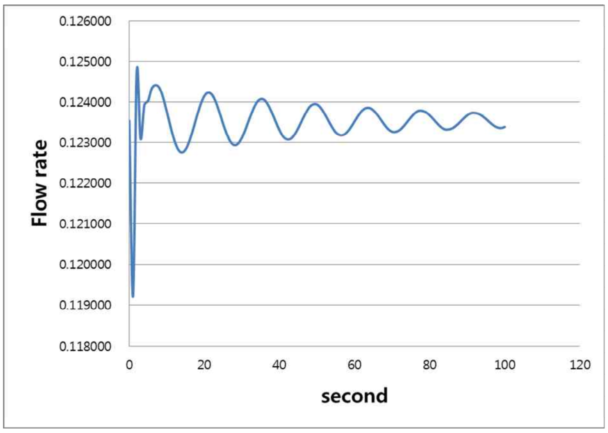

Fig. 3. Inlet flow velocity at inlet pressure of 16.87 MPa.

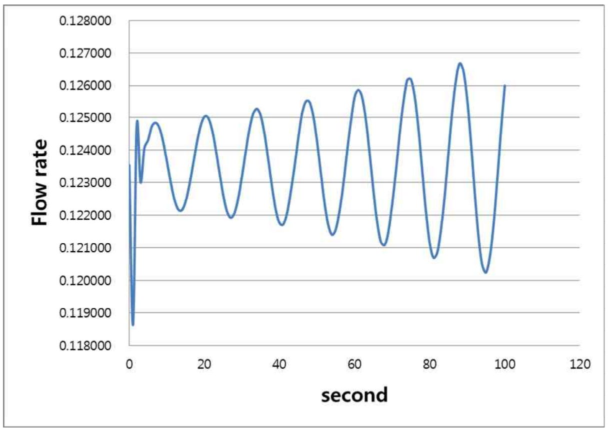

Fig. 4. Inlet flow velocity at inlet pressure of 16.2 MPa.

3. Conclusions

A computer code is developed for investigating two-phase flow stability under constant heat flux conditions. Solution algorithm for the sodium flow field and tube conduction will be developed for the application to sodium-heated SG.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIP). (No. 2012M2A8A2025624)

REFERENCES

[1] V. Chatoorgoon, SPORTS – A Simple Non-Linear Thermalhydraulic Stability Code, Nuclear Engineering and Design, Vol.93, p. 51-67, 1986.