36th Annual Conference of the Canadian Nuclear Society and 40th Annual CNS/CNA Student Conference
Toronto Marriott Downtown Eaton Centre Hotel, Toronto, ON, Canada, June 19-22, 2016

Investigation on pressure drop oscillation in natural circulation system Using CATHARE

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Abstract

In this paper the pressure drop oscillation in natural circulation system was investigated by CATHARE code. The calculation results show that the pressure drop oscillation was caused by the interaction between the natural circulation loop and the pressurizer in natural circulation system, which is the same as that in forced convection system. However the oscillation behavior is different. The effect of the system parameters on the pressure drop oscillation is studied. The oscillation amplitude decreases as the increase frictional resistance at the surge line increase. The volume of pressurizer has little influence upon the oscillation.

1. Introduction

Two-phase flow instability is of great importance in numerous design and operations of industrial applications, such as steam generators, heat exchangers, condensers and other two-phase flow systems. Nevertheless, it is well known that oscillations of flow rate and system pressure can cause mechanical vibrations, thermal fatigue, problems of system control, and in extreme circumstances disturb the heat transfer and promote thermal crisis occurrence. It is clear that the study of two-phase flow instability plays an important role in the design and safety analysis of two-phase flow systems. There are many types of two-phase flow instabilities including Ledinegg instability, boiling crisis, flow pattern transition instability, density-wave oscillations, pressure-drop oscillations, thermal oscillations, parallel channel instability, flushing induced instability and other instabilities[1],[2],[3].

Chiapero et al[4] reviewed the research which has been done on pressure drop oscillation. During the past decades, a large amount of experimental and theoretical results have been published about pressure drop oscillation. Substantial attention have been attracted to research the effect of these parameters, including mass flow rate, heat flux, inlet subcooling, compressible volume, flow inertia and thermal capacities of the pipes, on the amplitudes and periods of the oscillations.However most of these experiments were carried in an open loop, forced convection system with a pressurizer or expansion-tank.

The two-phase natural circulation has attracted a great amount of attention due to some advantages over forced circulation, such as elimination of the active device (pump) and reduced cost through simplification. The most different aspect of the natural circulation from the forced circulation is that the flow rate is determined by the distribution of temperature in the loop. The pressure drop oscillation in the natural circulation system may appear to be different from that in the forced circulation system. In order to research the pressure drop oscillation in the natural circulation system, an experimental loop is constructing now. The present paper reports the results of a investigation of pressure drop oscillation in a closed two-phase natural circulation system by means of thermal hydraulic code, CATHARE.

2. Description of the experimental loop

The schematic of the natural circulation experimental loop under construction is shown in Fig.1. The apparatus consists of test section, riser, heat exchanger, down-comer, surge line and pressurizer. Table 1 shows the main parameters of the experimental loop. The working fluid is deionized water. The fluid is heated in the test section, which is a tube with a cross section of φ25×2.5 mm and a length of 1000 mm. By using a 120 kW DC power supply, a large range of heat fluxes are applied to the test section. Thus the fluid temperature increases. The hot fluid then flows through the riser into the heat exchanger where it is cooled. Finally the cooled fluid returns to the test section. In addition the cylindrical pressurizer is used to maintain the system pressure through filling and let-downing with nitrogen gas.

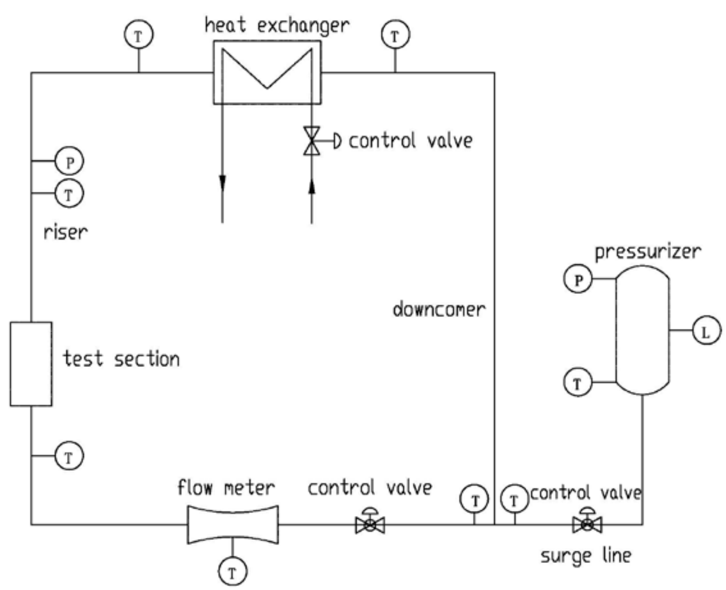


Figure 1 Schematic diagram of experimental loop.

Table 1 Main parameters of natural circulation loop

Parameters	Value	Unit
Total height of loop	4.75	m
Height between the center of test section and heat exchanger	2.5	m

Size of riser, down-comer and surge line	Φ25×2.5	mm
Length of riser	1.95	m
Length of down-comer	6.05	m
Length of surge line	0.9	m
Height of pressurizer	1.5	m
Power of test section	120	kW
Power of heat exchanger	120	kW

3. CATHARE description and model

3.1 Numerical codes for instability

A large number of thermal hydraulic codes and models, ranging from sophisticated system analysis codes that can simulate plant behavior, to simple models such as a single channel homogeneous equilibrium model to study basic physical phenomena, have been developed to deal with the flow instability issues. These codes and models are usually classified into Frequency domain codes and Time domain codes. Frequency domain codes are used to study the onset of instabilities and margins based on linearization and Laplace transformation of the partial differential equations. Time domain codes are based on the numerical solution of governing equations or the discretization of governing equations. These codes are capable of predicting the flow behavior in the two-phase region accurately. The general approaches in 1-D time domain codes are two-phase model, drift flux model, and homogeous equilibrium mixture model. The basic concept of the homogeous equilibrium mixture model and drift flux model are to consider the mixture as a whole, rather than two phases seperately. The two-phase model is based on 6-equations model where the two phases are treated as two separated fluids for which mass, momentum and energy balances are solved separately. This type of model allows considering thermal non-equilibrium and slip between two phases.

3.2 CATHARE code

The Code for Analysis of Thermal hydraulics during an Accident of Reactor and safety Evaluation (CATHARE) is a system code developed by CEA, EDF, FRAMATOME-ANP and IRSN for PWR safety analysis. The CATHARE code can be used to perform best-estimate analyses of LOCA, operational transients, and other accident scenarios in PWR. It can also model phenomena occurring in experimental facility designed to simulate transients in reactor systems.

The CATHARE code is based on a six-equation two-fluid model (mass, energy and momentum equations for each phase), with additional optional equations for non-condensable gases and radiochemical components. Relations for wall drag, interfacial drag, wall heat transfer, interfacial heat transfer, equation of state and static flow regime maps are used for the closure of the field equations. The interaction between the steam-liquid phases and the heat flow from solid structures is also considered.

Two phase flow instability of boiling channels always occurs when the fluid of outlet is in high equilibrium quality situation. The fluid in the channel is heated from single phase to two phase and the flow instability is influenced by this entire transient process. Therefore, the flow instability of boiling channels is a typical systematic transient phenomenon . The two-fluid formulation in the existent estimate simulation code is suitable for the study of two phase flow instability. Therefore, the CATHARE code is used for pressure drop oscillation instability analysis in this paper.

3.3 Nodalization of experimental loop

CATHARE has a flexible modular structure for the thermal hydraulic modeling in applications ranging from simple experimental test facilities to large and complex installations like Nuclear Power Plants (NPP). The main hydraulic components or elements are pipes (1-D), volumes (0-D), a 3D-vessel and boundary conditions, connected to each other by junctions. These models except 3-D vessel are based on the 6-equation model, including two mass balance equations, two momentum balance equations and two energy balance equations. The nodalization used to simulate the experimental loop is schematically represented in Fig. 2. The test section was modeled using an axial module with a Wall representing the heat generated by the DC power supply. Riser, down-comer and surge line as well as the primary side and secondary side flow channel of heat exchanger were represented using axial modules. In addition the heat losses of flow channel to the environment were modeled using a constant heat transfer coefficient (7 W/m2.C) and a constant outside temperature of 25 °C. The pressurizer was represented using a volume module. The inlet water temperature and the pressure at the outlet of the secondary side of heat exchanger were kept constant. The whole experimental loop was represented by 298 hydraulic nodes.

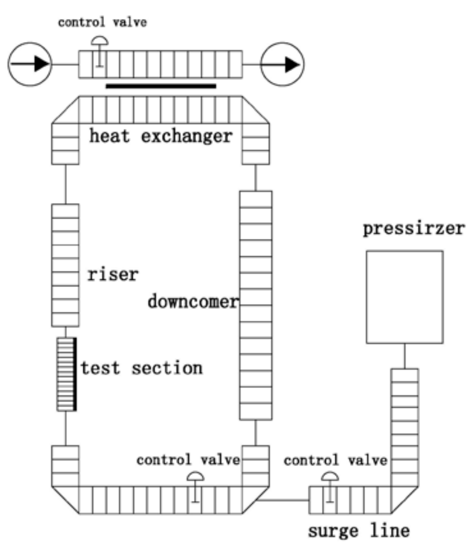
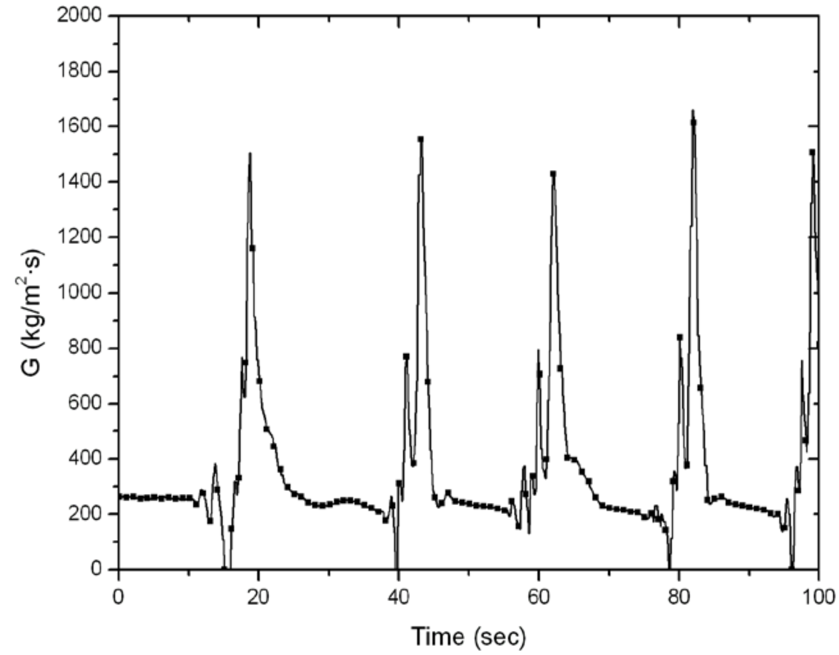


Figure 2   Nodalization of experimental loop

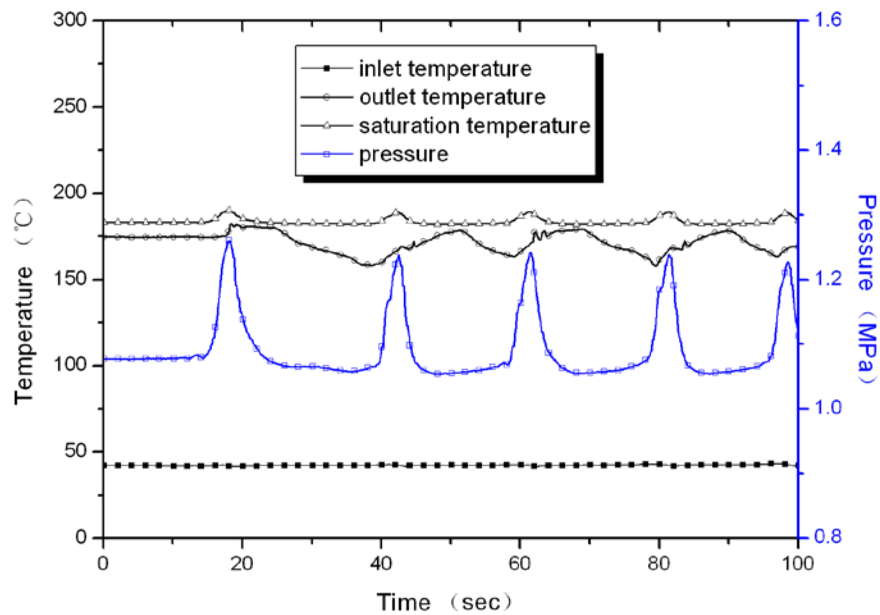
4. Result and discussion

4.1 Analysis of pressure drop oscillation

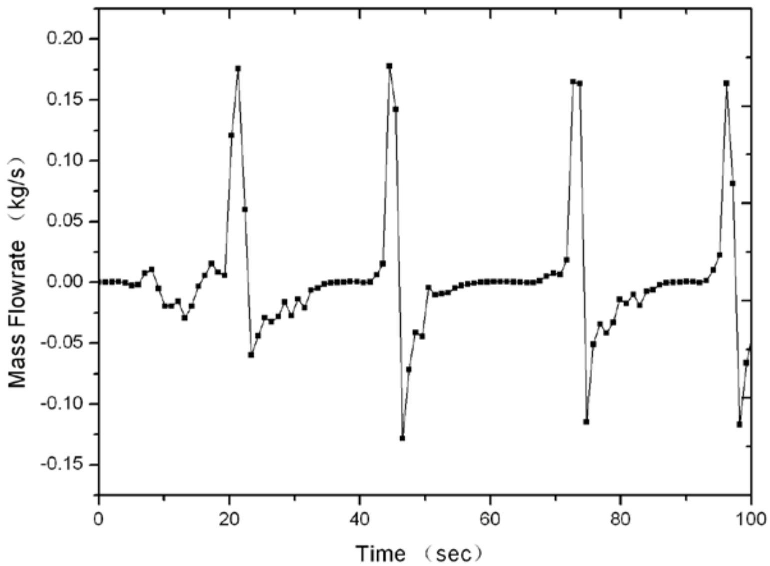
During the calculation the initial heat generation in the test section is zero, then the heated power increases step by step until the pressure drop oscillation appears. The main calculations of pressure drop oscillation in natural circulation system are documented in Fig.3. Before the occurrence of pressure drop oscillation, the fluid temperature, system pressure and and natural circulation flow-rate are stable. As the heat flux increases, the boiling occurs abruptly and the large void is formed within the test section. Then the pressure in the test section increases and a large amount of liquid in the natural circulation loop is pushed into the pressurizer. Accordingly, the test section inlet flow-rate decreases, which will bring on more void formation in the test section. The pressure in the pressurizer increases owing to the liquid inflow. After that, the liquid flows back into the natural circulation loop from the pressurizer. Then the test section inlet flow-rate begins to rise. The more bubble generated resulted in a substantial mount of the liquid flowing out to the pressurizer. The oscillation amplitude becomes large, and the reverse flow is even detected at the test section inlet. This reverse flow is followed by the sharp rise of the void formation and loop pressure, which begin to decrease until the large mount of fluid flows into the natural circulation loop from the pressurizer. After that, the stable natural circulation persists for a while. A new oscillation period begins when the boiling occurs abruptly and the large void is formed within the test section. Fig.3(c) shows the fluctuating flow rate in the surge line. It can be concluded that the occurrence of pressure drop oscillation in natural circulation system is due to the interaction between the natural circulation loop and the pressurizer, which is the same as that in forced convection system. However the variation of flow rate, pressure, and temperature are different from that in a forced convection and open loop system. Fig 3. shows the typical pressure drop oscillation experimental results performed in a closed forced convection loop with a surge tank by Guo et al[5]. The parameters in forced convection system presents approximate sinusoid. But in natural circulation system the flow curve is composed of a divergent sinusoid and a straight segments, in addition the pressure curve consists of a straight segment and peak value.



(a) Natural circulation flow rate (at the inlet of test section)



(b) Fluid temperature and pressure in the test section



(c) Fluctuating flow rate in the surge line

Figure 3 Pressure drop oscillation calculation results

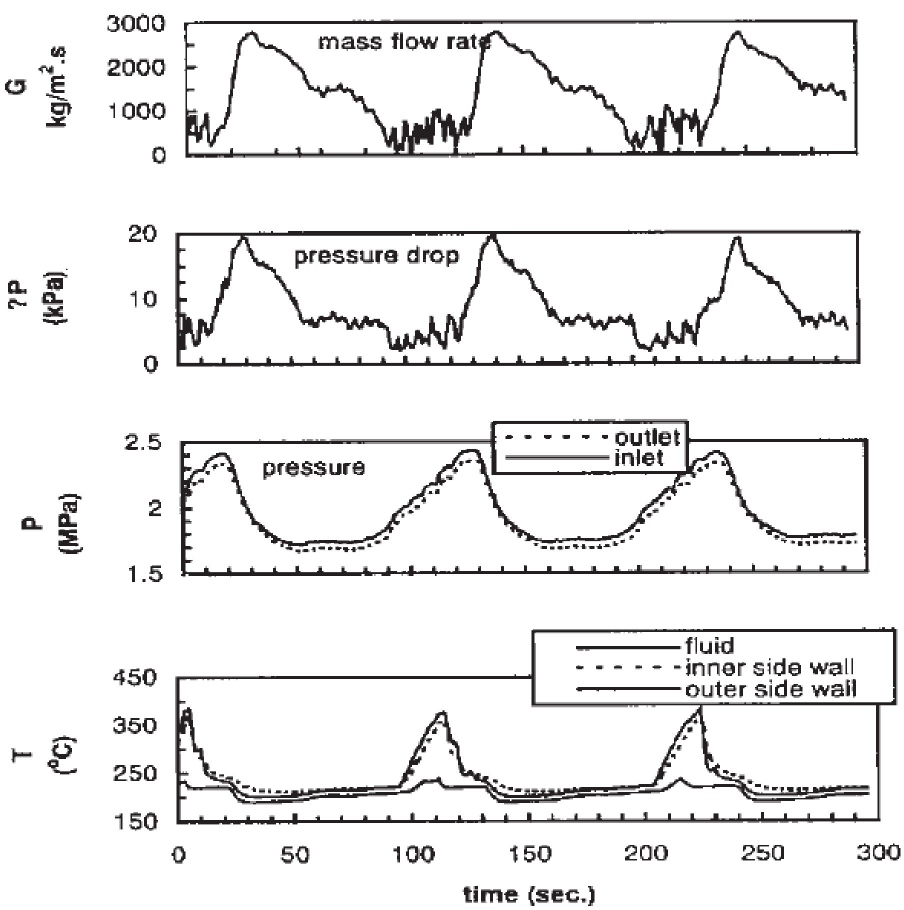


Figure 4 Typical Pressure drop oscillation curves

4.2 The effect of system parameters

4.2.1 Effect of pressurizer volume

The pressurizer volume brings about the influence on pressure drop oscillation, as shown in Fig. 5. It comes to the conclusion that the increase of pressurizer volume has non-significant effects on the pressure drop oscillation. Even the stability of pressure in the natural circulation system will increase with rising pressurizer volume, the small increase in pressure owing to the abrupt formation of bubbles in the test section is able to push the fluid from natural circulation loop to pressurizer and bring on the occurrence of pressure drop oscillation.

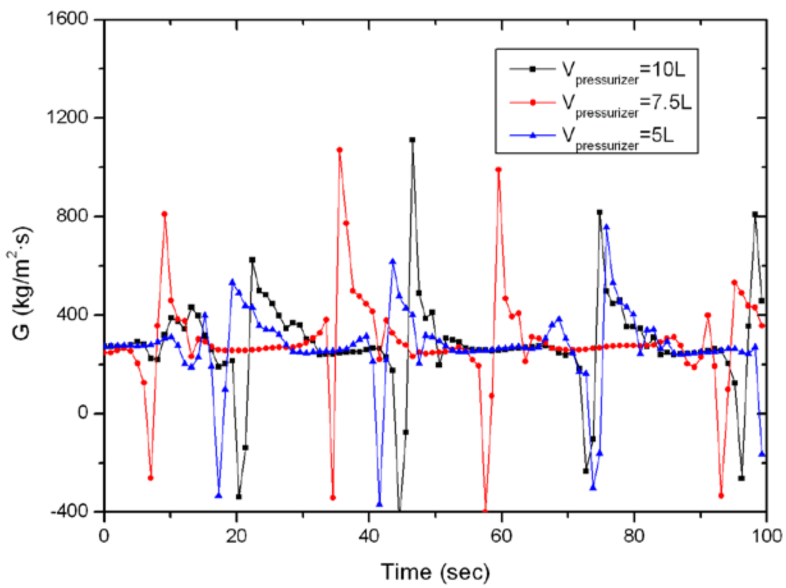


Figure 5 Effect of pressurizer volume on PDO

4.2.2 Effect of frictional resistance at the surge line

The frictional resistance at the surge line has great influence on the pressure drop oscillation, as shown in Fig. 6. It is observed that the higher the frictional resistance is , the smaller the oscillation amplitude is. The reason is that the increase of frictional resistance at the surge line tends to limit the fluctuating flow between the pressurizer and natural circulation loop. Even the frictional resistance at the surge line become very large, the pressure drop oscillation still exist in the natural circulation system.

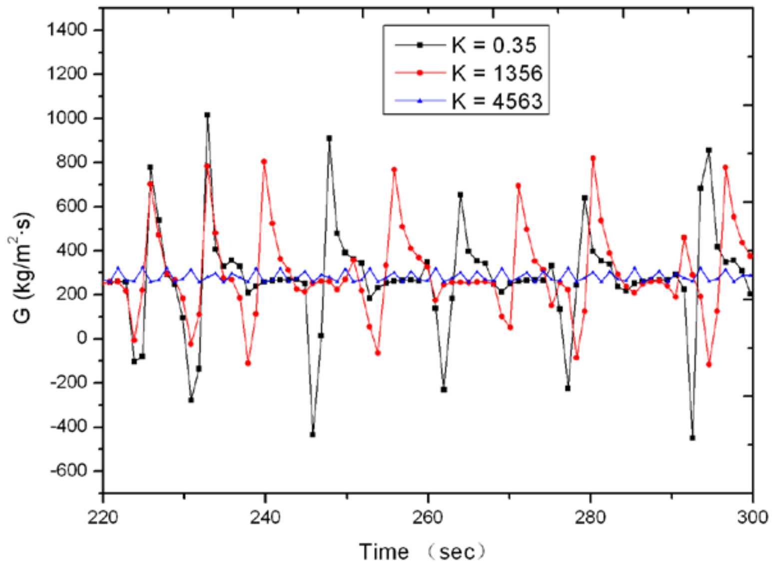


Figure 6 Effect of frictional resistance at the surge line on PDO

5. Conclusion

In this paper, we have conducted the research for the pressure drop oscillation in the natural circulation system. The occurrence of pressure drop oscillation in the natural circulation system is due to the interaction between the natural circulation loop and the pressurizer. The pressurizer volume has little influence on on pressure drop oscillation, while the increase frictional resistance at the surge line will help to limit the oscillation amplitude.

Although we have to be faced a fact that our research is lack of the verification by the experimental data, the analytical methodology and tool set applied in this work are credible enough to analyse the pressure drop oscillation in two-phase natural circulation system. Therefore the research results are reasonable to be accepted, and the experimental investigation on the pressure drop oscillation in two-phase natural circulation system will be carried out in the near future.

6. References

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