CHAPTER I

INTRODUCTION

1.1 Background on problems of interest

Two-phase natural circulation systems have found their places in many of the modern nuclear reactor designs and industrial processes because they commonly possess three important features: passive, economical, and simple. The systems' passive nature allows less usage of valves and pumps for flow regulation. The production cost can therefore be reduced, and maintenances are generally simpler in comparison to the conventional active systems. In addition, the risk of failures associated with the usages of valves and pumps also decrease. There is a caveat, however. Various types of instabilities can occur in the flow, preventing the two-phase natural circulation systems from being effectively implemented. The sources of the instabilities can vary depending upon the systems' geometries and their operating conditions. Nevertheless, they can cause problem to the system operation and control, and may reduce the thermal margin [1].

Oscillations of flow rate and system pressure are undesirable, as they can cause mechanical vibrations, problems of system control and in extreme circumstances, disturb the heat transfer characteristics so that the heat transfer surface may burn-out. In a recirculating plant, where burn-out must be avoided, flow oscillations could lead to transient burn-out. Under certain circumstances, large flow oscillations can lead to tube failures due to increased wall temperature. Another cause of failure would be due to thermal fatigue resulting from continual cycling of the wall temperature; the thermal stresses set up in the wall and the cladding material in nuclear reactor fuel elements can cause mechanical breakdown, leading to more serious accidents, such as release of radioactive materials. It is clear from these examples that the flow instabilities must be avoided, and every effort needs to be made to ensure that any two-phase system has an adequate margin against them [2].

There are several reviews of flow instabilities in boiling system [2,3,4,5,6,7]. These reviews indicate that different models of two-phase flow have been employed for modeling thermal hydraulics. In most of the studies of two-phase flow instabilities, the homogenous equilibrium model is widely used. This model treats the two-phase flow as the flow of single phase compressible fluid. The velocity of both phases is assumed to be equal, and the temperature is taken to be the saturated temperature. These assumptions are valid for rapid interfacial rates of heat and momentum transfer. Therefore, the model can be expected to be most applicable for those two-phase regimes where the phases are well-mixed, such as bubbly, churn, or drop flow regimes. The drift-flux model, which has gained much acclaim in the last decade, takes the relative velocity between the phases into account, while assuming thermodynamic equilibrium. It is presumably most valid for cases in which the drift velocity is significant compared with the volumetric flux. This limits its usefulness to the bubbly, slug and churn flow patterns. In the most general formulation of the two-phase flow problem, the conservation equations are written separately for each of the phases which is called two-fluid model. Although this model is the most satisfactory in theory, it is complicated to use in problems of practical importance because of the seven constitutive laws that are required, viz. four at the wall (friction and heat transfer for the two phases) and three at the interface of the phases (mass, momentum and energy transfer). However, it is the only model available for accurate modeling of the two-phase phenomena where the two phases are weakly coupled. Examples of these are sudden mixing of two phases, transient flooding and flow reversal, transient countercurrent flow and two-phase flow with sudden acceleration. Therefore two-fluid modeling is open for future research.

Natural circulation systems may undergo thermal hydraulic instabilities under low pressure condition, which occur during start-up. At low pressure, a natural circulation loop typically has three operating ranges: single-phase stable region, two-phase unstable region and two-phase stable region. Numerous investigations, both theoretical and experimental have been conducted to understand the stability at low pressure startup in two-phase natural circulation loop. Aritomi et al. [8] and Chiang et al. [9] pointed out three types of the instabilities, namely geysering, natural circulation oscillations and density wave oscillations, which could occur in the boiling natural circulation loop. Kuran et al. [10] and Furuya et al. [11] conducted several experiments to investigate instabilities that may occur at low-pressure and low-flow conditions during the startup of boiling natural circulation loop. The experimental results showed the signature of condensation-induced oscillations during the single-phase to two-phase natural circulation transition. A large number of thermal hydraulic codes and models exist, which have been developed to deal with the stability issues, 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.

In 1999, Paniagua et al. [12] developed a thermal hydraulics computer code for simulate the geysering instability in a natural circulation system starting from subcooled conditions and to assess the impact of the system pressure and channel inlet subcooling on the inception of instability. The formulation of thermal hydraulics is inherently general and accounts for both single-phase liquid flow and nonhomogeneous, nonequilibrium two-phase flow. The computer code is based on momentum integral method where the current practice of basing fluid properties on the system averaged pressure has been relaxed and the local properties are based on local pressures estimated using the shape of steady-state pressure distribution, thereby, improving the predictions while preserving the computation speed, one of the important strength of the integral methods. This is an important modeling feature since the local vapor generation rate depends on local saturation temperature. The methodology has been validated with the experiments conducted to investigate the instabilities in a low pressure natural circulation loop at low powers and high inlet subcoolings. The numerical simulations predicted periodic channel flow reversal, which is one of the feature of condensation-induced geysering. Basing local properties on local pressures instead of system average pressure led to decrease in the discrepancy in the prediction of the positive side amplitude from 40% to 6% and in the frequency from -15% to 5%. In addition, it was observed that the start-up instability can be avoided by increasing system pressure or by decreasing channel inlet subcooling. This study showed that the integral method coupled with local pressure variation for the vapor generation model is suitable to predict startup or geysering transients.

In 2002, Chaiwat Muncharoen [13] studied effect of heat flux, pressure and subcooling on instabilities of two-phase natural circulation in parallel channels system. The heat flux was increased from 50 to 550 kW/m^2. The system pressure was varied from 0.1-0.7 MPaA and the inlet subcooling was fixed to 5, 10 and 15 K. The numerical code was developed by using two-fluid model for predict stability in two-phase natural circulation. The semi-implicit scheme was utilized for finite difference equations. Newton block gauss seidel method was employed to solve the system equations for unknown variable. The experimental results indicate that the increase in system pressure and subcooling stabilize the system. In addition, the two-fluid model can give the good results and are in good agreement with experimental results.

In 2006, Nayak et al. [14] presented a numerical study of boiling flow instability of a reactor thermosyphon system. The numerical model solves the conservation equations of mass, momentum and energy applicable to a two-fluid and three-field steam-water system using a finite difference technique. The main conclusions of this study are 1) conventional homogeneous two-phase flow models with empirical relations for void fraction and two-phase friction factor multiplier overestimate the natural circulation flow of the reactor, 2) the two-fluid model predicts the natural circulation flow closest to the measured value of the reactor and 3) an increase in power or a decrease in subcooling has a destabilizing effect on the natural circulation.

Several scale test facilities [10,11] have been built to investigate flow instabilities. The results obtained from these facilities were more accurate and could be used in predicting flow behavior of typical natural circulation system implemented in boiling water reactor (BWR). However, the construction cost was expensive due to its complexity and large size. Alternately, rectangular natural circulation loop [9,12,15,16,17] can also be used for the study. It has advantage over scale test facilities because of its simplicity, low cost, and adaptability for various configurations of heating and cooling sections.

One of the main interests in flow instability is the temperature oscillation. Such oscillation in the worst scenario can seriously damage the heater and the flow loop. In a normal circumstance, such oscillation can interrupt the heat transfer process, and thus reduces the process efficiency. A number of observations in the oscillation of temperature under the flow instability have been reported and the data are analyzed. For example, Khodabandeh [18] used fluctuation value, defined as the maximum deviation from the average value, to analyze the wall temperature oscillation. Of particular interest was the usage of Fast Fourier Transform (FFT) method to analyze the oscillation curve of mass flow in the twin-channel system instability under ocean conditions by Yun [19]. Kosar [20] also reported that FFT method can also be used to analyze the oscillation of pressure signals during the unstable boiling condition.

1.2 Thesis objective

1. To modify and apply a computer program for simulating the two-phase flow to simulate the transient in a natural circulation loop.

2. To develop the two-phase natural circulation loop for measuring mass flow rate, pressure drop, inlet subcooling and heating power in order to benchmark the modified computer program.

3. To simulate and analyze the startup transient for the two-phase natural circulation loop under different configurations.

1.3 Scope of work

1. Design and construct a two-phase rectangular natural circulation loop.

2. The effect of initial conditions such as water temperature and heating power on the two-phase rectangular natural circulation loop will be investigated.

3. Modify and apply an existed one-dimensional two-fluid numerical code, TEXAS (Thermal EXplosion Analysis Simulation), to simulate the transient.

4. The results from computer program will be compared with the experimental data and analyzed.

5. Simulate and analyze the startup transient for the two-phase natural circulation loop under different configurations.