CHAPTER IV

EXPERIMENTAL APPARATUS AND PROCEDURE

This chapter describes the experimental equipment and procedures used in this research. Two rectangular natural circulation loops, namely the NCL#1 and the NCL#2, have been designed and constructed for simulation of a two-phase flow under two different configurations. The Fast Fourier Transform (FFT) method is employed to the temperature and the differential pressure oscillation observed.

4.1 Experimental apparatus for the NCL#1

Fig. 4.1 and Fig. 4.2 show respectively the schematic diagram and the actual setup of the NCL#1. The loop consists of the riser, the downcomer, the vertical heating, and the vertical cooling sections. The loop piping has the inner and the outer diameters of 22 and 25 mm respectively. An expansion tank with an atmospheric opening is installed on the top of the loop to allow volumetric expansion of the fluid. The entire loop is made of glass. The heating and the cooling sections are of the same length. The heating section is an annulus; the inner heating rod is made of stainless steel while the outer tube is made of glass. The outer glass tube has an inner diameter of 47 mm, an outer diameter of 50 mm, and a length of 500 mm. The inner U-shape heating rod is 8 mm in diameter and 400 mm in length. The cooler is a tube-in-tube type with the cooling water flowing in the annulus formed between the glass tubes. The hydraulic diameter of the annulus is 22 mm. The entire loop is in thermal contact with the atmosphere and is subjected to heat loss to the ambient.

The loop is equipped with the 1.6 mm diameter type K thermocouples to measure the temperature changes across the heater and across the primary and the secondary sides of the cooler. The thermocouples are positioned to measure the temperature at the tube center. The heating power is obtained from the electric current and voltage measured by analog AC ammeter and voltmeter, respectively. The uncertainty of the temperature measurement is within ± 1 °C. Data are acquired and stored in a computer via the RS-232 interface.

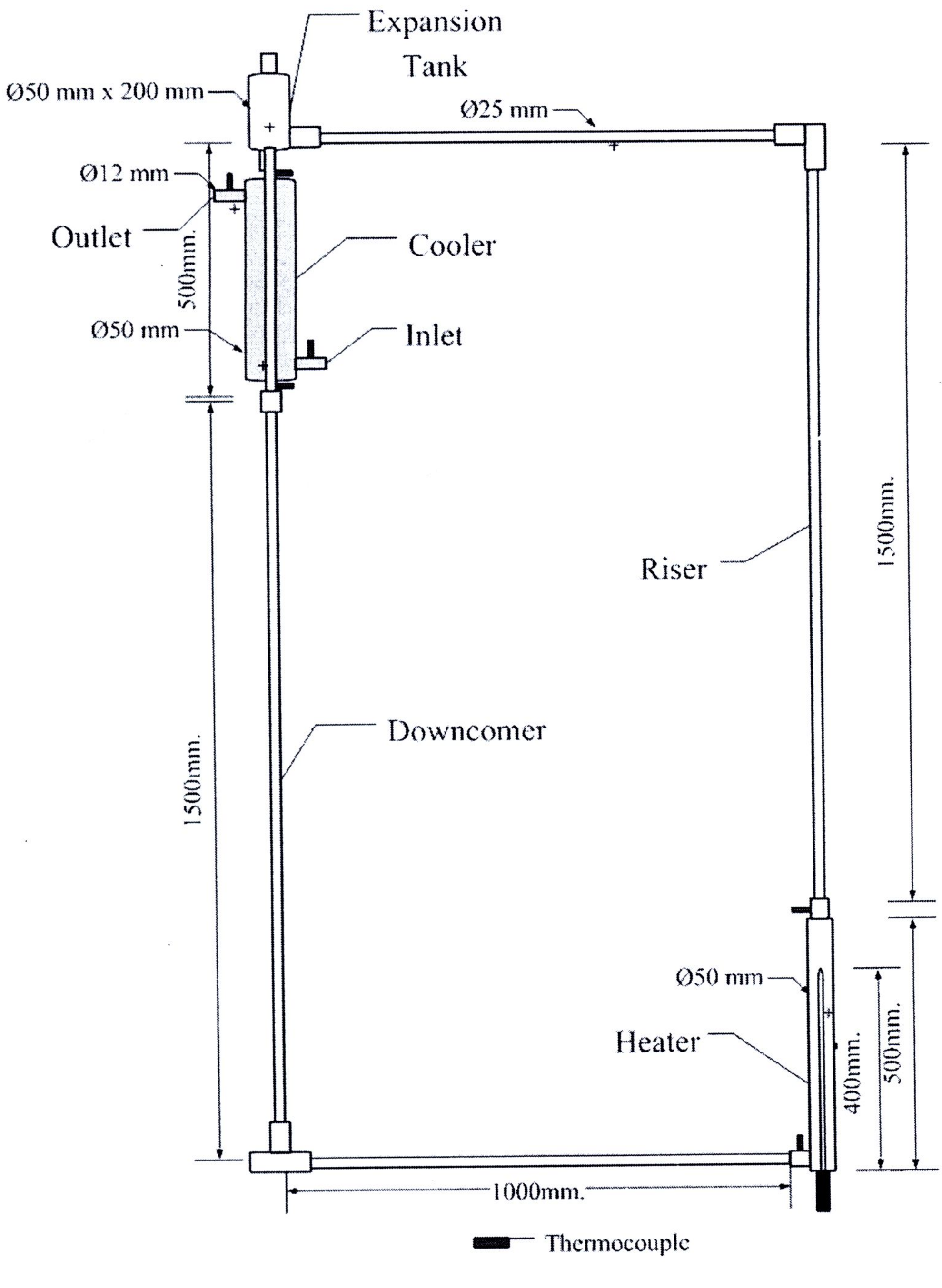

Fig. 4.1 Schematic diagram of the NCL#1

4.2 Experimental procedure for the NCL#1

The primary loop was filled with water. To remove the gases dissolved in the water, the loop was heated to reach the natural circulation condition with a high heating power to boil the water. The experiments were carried out in this loop at several heating power levels under the on/off condition for the cooling system. The heating power and the coolant water flow rate were maintained at the constant level during the entire duration of an experiment. The cooling water inlet temperature was 24 ± 1 °C. The following procedure was used for each test. At first, start the data acquisition and check of the uniformity of the system temperature and comparison with the ambient temperature. It should be noted that data acquisition from 7 type K thermocouples was performed every 2 s (time needed to record all the signals were 1 s). Next, start the cooling flow and the heating power. Finally, the test was concluded after 8000 s.

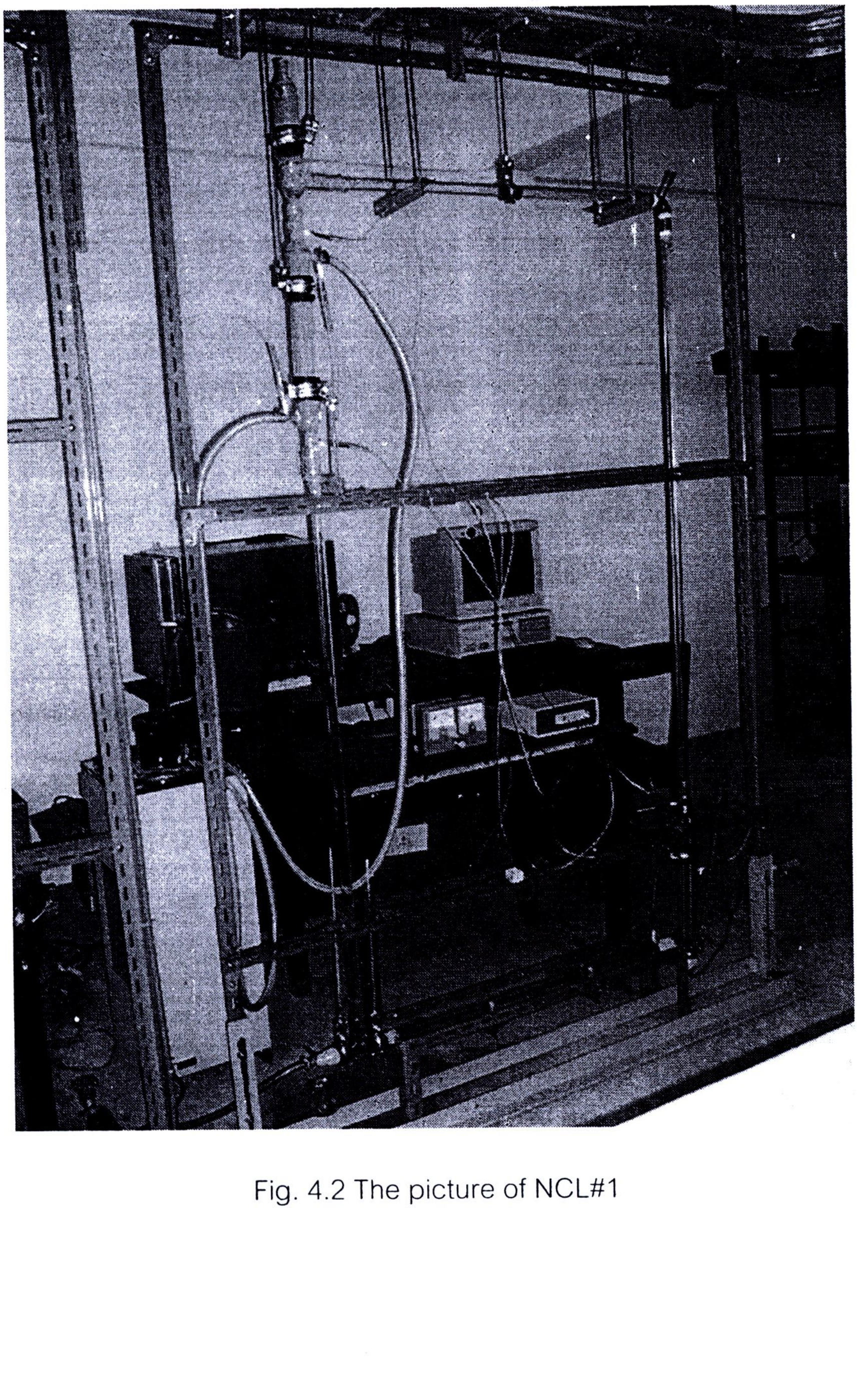

Fig. 4.2 The picture of NCL#1

4.3 Experimental apparatus - NCL#2

Fig. 4.3 and Fig. 4.4 show respectively the schematic diagram and the actual setup of the NCL#2. The loop consists of the vertical heating section, the riser, the condenser and the downcomer. The vertical heating section is an annulus; the inner heating rod is made of stainless steel while the outer tube is made of glass. The outer glass tube is measured 22 mm and 25 mm for the inner and the outer diameters respectively, with a length of 800 mm. The inner heating rod is 16 mm in diameter and 800 mm long. The gap width between the heating rod and the glass tube is 3 mm. The riser is a glass tube with the inner and the outer diameters of 22 and 25 mm, respectively. The riser is 1120 mm long. The condenser is a tube-in-tube type with the cooling water flowing in the annulus formed between the copper tube and the polyvinyl chloride (PVC) tube. The hydraulic diameter of the annulus is 21.5 mm. The condenser is 800 mm long. The downcomer is made of copper tube. The copper tube has dimensions of 26 mm for the inner and 28.5 mm for the outer diameters, with length equal to 1950 mm. An expansion tank with an atmosphere opening is installed on the top of the loop to allow volumetric expansion of the fluid. The glass tube is uninsulated to allow the visual observation of the flow. The entire loop is in thermal contact with the atmosphere, and is subjected to heat loss to the ambient.

Type K thermocouples are installed to measure the temperature changes across the condenser, the downcomer middle, across the heater, and the riser outlet. The bare wire butt welded thermocouples with the diameter of 0.5 mm are selected for fast response time. The response time is defined as the time required to reach 63.2% of an instantaneous temperature change. The pressure sensor is installed to measure differential pressure across the heater. Fig. 4.5 shows block diagram of the data recorder. The MAX6674 cold-junction-compensation thermocouple-to-digital converter performs cold-junction compensation and digitizes the signal from a type-K thermocouple. The microcontroller reads data from the MAX6674 via SPI interfacing and then converts to temperature value. The MPX5050DP is a piezoresistive transducer with on-chip signal conditioned, temperature compensated and calibrated. The output signal from MPX5050DP is read and converts by the microcontroller with a built-in 10-bit analog-to-digital converter (ADC). The resolutions for the measured temperature and differential pressure are 0.125 °C and 0.05 kPa, respectively. The uncertainty of the temperature measurement is within ± 1 °C. Data are acquired and stored in a computer via RS-232 interfacing.

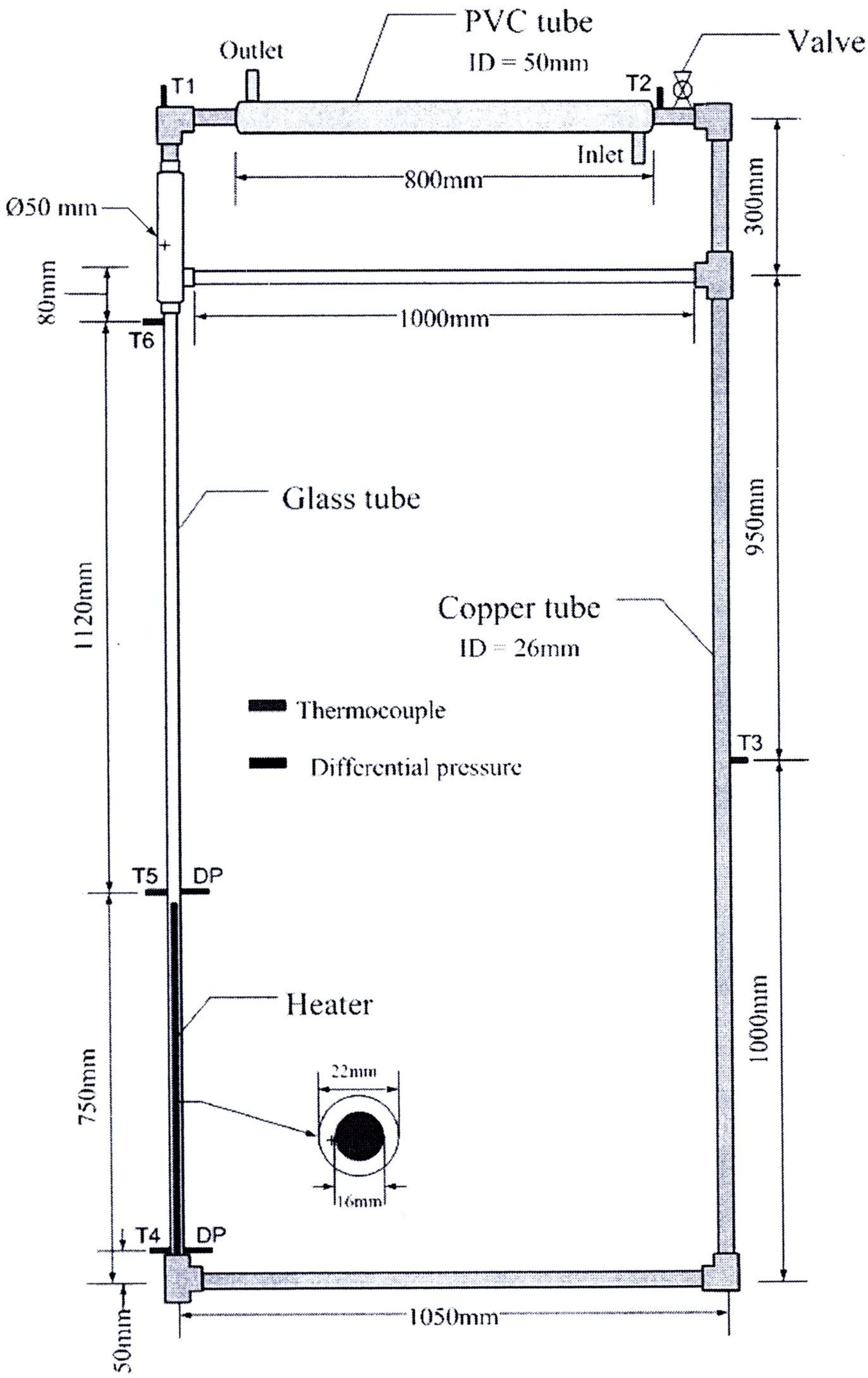

Fig. 4.3 Schematic diagram of the NCL#2

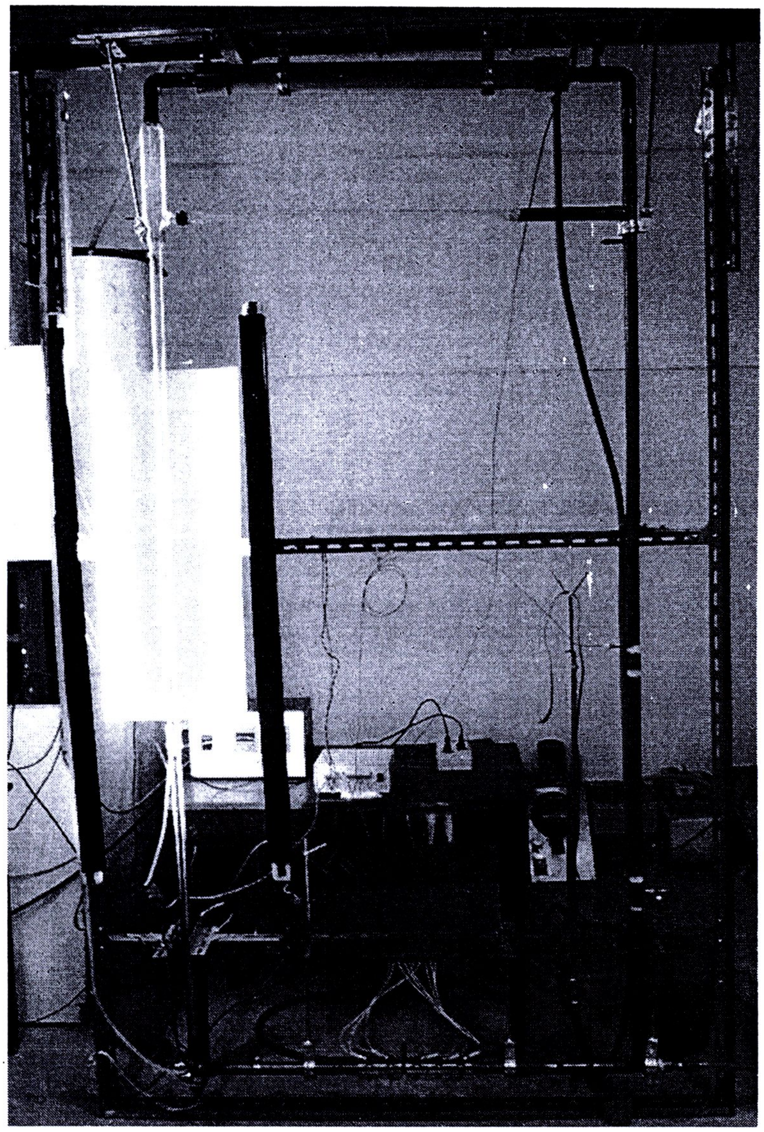

Fig. 4.4 The picture of NCL#2

Fig. 4.6 shows a block diagram of the power controller. The dimmer circuit and the power adjust knob are used to control the heating power. The current transformer, type TADK, is used for reducing the electric current from 15 A to 5 A. The heating power is obtained from the electric current and voltage as measured by digital AC ammeter and voltmeter (Carlo Gavazzi, type DI3-72 AV5), respectively.

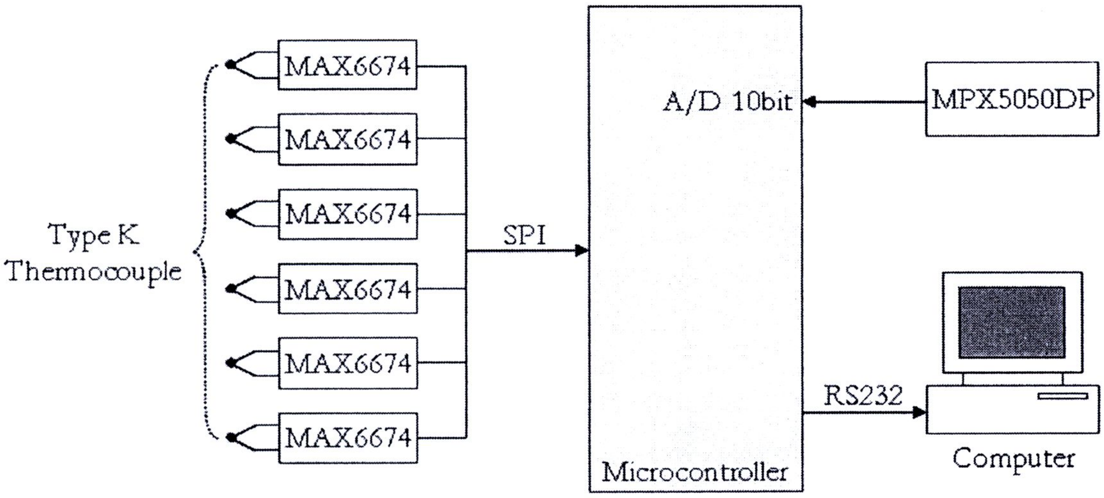

Fig. 4.5 Block diagram of the data recorder

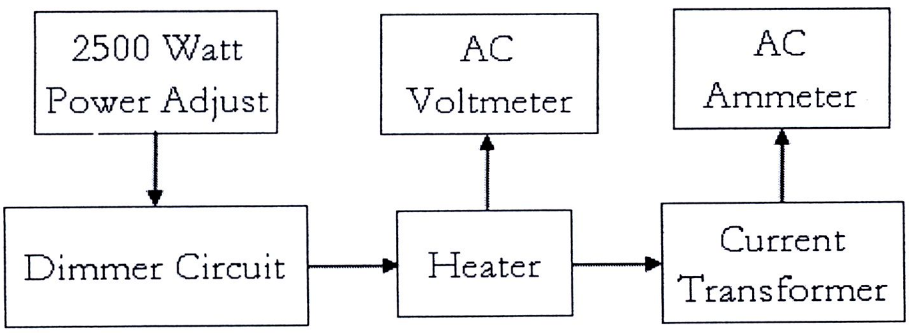

Fig. 4.6 Block diagram of the power controller.

Photographs of bubbles at the riser are taken by a single-lens reflex (SLR) camera (Olympus E510). The camera's shutter speed is 1/1000 second. Two 36 W fluorescent lamps are used as light source.

4.4 Experimental procedure for NCL#2

The loop was filled with water. To remove the gases dissolved in the water, the loop was heated to reach the natural circulation condition with a high heating power to boil the water. Two-phase natural circulation experiments were carried out in this loop at several heating power levels. The heating power was maintained at a constant level during the entire duration of an experiment. At the beginning of each experiment, before switching on the heating power the system temperature was checked for uniformity, and compared with the ambient temperature. Temperatures were recorded at 1-second interval. After switching on the heating power, temperature data is recorded until stable flow behavior is observed.

4.5 Fast Fourier Transform method

Fast Fourier Transform (FFT) of the temperature oscillation was computed with the Discrete Fourier Transform (DFT) function (Y = fft(X) in MATLAB program). The function Y = fft(X) implement the transform pair given for vectors of length N is defined by:

$$X(k) = \sum_{j=1}^{N} x(j)\omega_N^{(j-1)(k-1)}$$

Where $\omega_N = e^{(2\pi i)/N}$ is an N^{th} root of unity.

Appendix B.1 shows the MATLAB code for computing the FFT.