CHAPTER III

EXPERIMENTAL

3.1 MCNP Simulation

3.1.1 <u>System Geometry</u>

A schematic diagram of the neutron scattering device for a 0.5-inch outside diameter stainless steel 316 pipe with 0.049-inch thickness is shown in Figure 3.1 along with the y and z coordinates of the Cartesian system used. The dimensions of pipe for an input data were the inside radius of 0.501 cm and the out side radius of 0.625 cm.

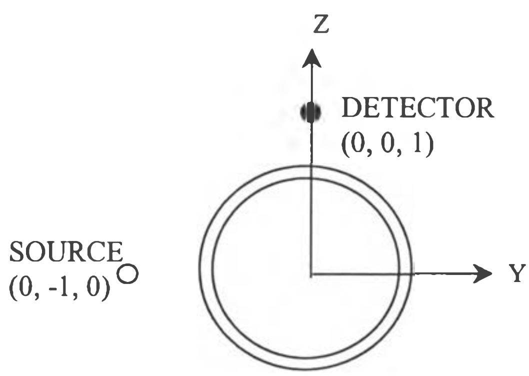

Figure 3.1 Geometry of the neutron scatterometer.

The MCNP analysis begins by simulating this simple geometry. A scatterometer consists of a fast neutron source incident on a test object with the neutron detector typically located perpendicular to both the incident beam and the test section as shown in Figure 3.1. Cf-252, which is a neutron emitter by spontaneous fission, is the source. The temperature of the steam water mixture inside this pipe is 260 °C and the pressure is the saturated value. The density of the mixture can be varied from 0 to 1 of void fraction as expressed by the following equation.

$$\rho = \rho_l - \alpha(\rho_l - \rho_g) \qquad (3.1)$$

where ρ, ρ_l and ρ_g are the density of mixture, liquid phase and vapor phase respectively and α is the void fraction. The detector, located close to the pipe, is employed to estimate the scattered neutron flux. The detector designated as a point is used for simplification but it can be expected (at least for comparative purpose) to provide results similar to those of a volume detector. To confirm the adequacy of this proposed geometry before proceeding to experimental work, the MCNP simulation program is employed.

3.1.2 MCNP Simulation

MCNP stands for Monte Carlo N-Particle, which is a computer program based on the Monte Carlo method for calculating radiation transport. The Monte Carlo group in the applied theoretical physics division at the Los Alamos Laboratories developed MCNP from 1973 until 2000. It can be used in several transport modes: neutron only, photon only, electron only, combined neutron/photon transport where the photons are produced by neutron interactions, neutron/photon/electron, photon/electron, or electron/photon. For neutron transport, the energy regime is from 10 -11 MeV to 20 MeV. Neutron cross section (probability of interaction) information is in the point form derived from well-established libraries.

The MCNP requires users to create an input file, which defines the geometry, detectors and source in a right-handed Cartesian coordinate system. The geometric cells are defined by the intersections, unions, and complements of the regions bounded by surfaces. The surfaces are defined by supplying coefficients to the analytic surface equations. MCNP gives users the flexibility of defining geometrical regions and then combining them with Boolean operators. A cell card is the list of the cell number, material number and material density followed by a list of the surfaces that bound the cell, which are used to specify the geometric cells.

The source is defined in MCNP by the listing of the position, energy, direction, particle weight and other parameters such as starting cells or surfaces. The source can be either isotropic or biased and can emanate from a point, a surface or a volume. For this design, the source is specified as the spontaneous fission spectrum.

The detector is specified in MCNP through a tally card. There are six basic neutron tally options. For this experimental simulation, the tally option of detecting flux at a point detector is employed. MCNP will terminate when a tracked source particle reaches a specified cutoff parameter, unless it has terminated earlier for some other reasons (for instance, the particle escapes from the system). In addition, the number of source particles simulated are sufficient to generate detector tallies with less than 5% relative error. The example of input file can be found in Appendix D.

3.2 Static Experiment

A static experiment is defined as an experiment with a solid material to simulate the water fraction. To check consistency of the scatterometer before connecting to the two-phase flow water mixture pipe, the static experiment has to be achieved. The technique and configuration of static experiment are described in following sections.

3.2.1 Experiment Arrangement

The static experiment was arranged as shown in Figure 3.2. The experiment consisted of a neutron source, detector and test section. The detector and test section were enclosed in cadmium sleeve. Cadmium can prevent any thermal neutrons produced outside the system and allow fast neutrons to enter the system (cadmium cut-off energy ~0.5eV).

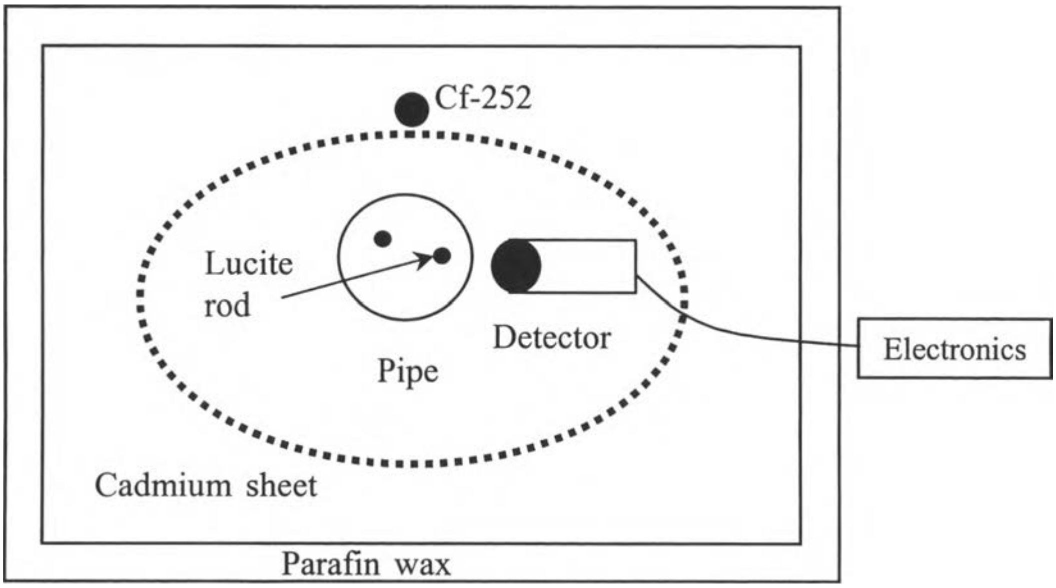

Figure 3.2 The static experiment arrangement.

3.2.2 Test Section

Lucite ($C_5H_8O_2$) was selected to simulate the water fraction in the static case. It was physically suitable to be a water substitute due to a high hydrogen content and a density of 1.18 g/cm^3. The stainless steel pipe was 0.5 inch outside diameter with thickness 0.049 inch. The test section was rested on a paraffin base. There are two sizes of a lucite rod, which were arranged randomly to vary different lucite fractions. A 3-mm diameter lucite rod represents 0.1 volume lucite fraction. A 9-mm diameter lucite rod is equivalent to a full test section. Therefore, the range of the simulated water fraction from 0-1 lucite fraction was investigated.

3.2.3 Neutron Source

The neutron source was 2 μg of Cf-252. This source underwent spontaneous fission of 3% of the total decays to release a neutron with a half-life of 85.5 years. The source produced 2.3×10^{-6} n/s/μg. The gamma dose rate was about 1.6×10^{2} mR/hr/mg at 1 meter from source.

3.2.4 Neutron Detector

The Helium-3 detector was employed. The detector had the physical dimension of 2-inch diameter and 6.5-inch length with a gas filling pressure of 4 atmospheres.

Detector works on the principle that neutrons can be captured into certain elements, which are changed to make charged particles. The sum of the accumulated charge is proportional to the number of incident neutrons. It undergoes (n, p) reaction as shown below:

$$He^3 + n \longrightarrow H^3 + p + 765\ keV \qquad (3.2)$$

3.2.5 Electronics

The electronic instrumentation, which is shown in Figure 3.3, consisted of a preamplifier, an amplifier a multi-channel pulse height analyzer and a high voltage supply. An oscilloscope was used to set the counting system. It can check the quality of a signal as well as the level and the type of the electronic noise.

The output signals from the detector were transmitted through the preamplifier. A preamplifier provided a low impedance output that was capable of driving the signal through a long cable with small loss of amplitude. After that the amplifier increased the signals. Then, the multi-channel pulse height analyzer recorded the signals. At the end of the counting period, the total number of pulse recorded was displayed.

For the setting of the counting system, suitable Coarse and Fine gain on the amplifier are important parameters. The high Coarse gain and low Fine gain are recommended to produce the same overall gain. The high voltage was set at 1600V. For this experiment, there was no single channel analyzer to reduce the electronic noise. However, the multi-channel pulse height analyzer was employed. As a result, the electronic noise was eliminated.

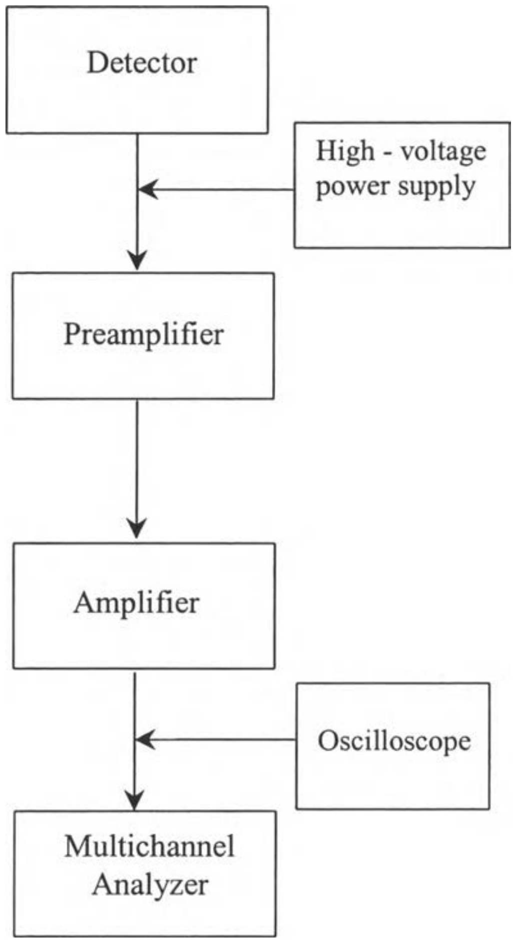

Figure 3.3 The electronic system for the static experiment.

3.2.6 Calibration Method

As in the simulation results, the linearity of scatterometer response can be expected. To simplify the calibration process of the device, two calibration points that are zero and one lucite fraction were used. The estimated lucite fraction was calculated from the relation ship below:

$$\hat{\rho} = \frac{N(\rho)-N(0)}{N(1)-N(0)} \tag{2.2}$$

However, this calibration process is valid for the atmospheric condition. As temperature and pressure can affect the probability of neutron interactions or the macroscopic cross-section. The adequacy of this calibration process will be demonstrated in the dynamic experiment.

3.2.7 Static Experimental Procedure

1. Electronic instruments were warmed up for 45 minutes before starting the experiment.

2. The amplification levels for this experiment were set to be:

- Coarse gain at 200
- Fine gain at zero.

3. The empty test section was measured to check the stability of the electronics for ten times. The proper counting period should produce at least 1000 counts.

4. To check the stability of the electronics, the standard error was calculated by following equation (A.4). The acceptable standard error should less than one percent. If not, there might due to the unstable equipment, external signal and insufficient time for warn-up the equipment.

5. The full test section by using the 9-mm lucite rod was measured. And different lucite fraction was obtained by inserting the 3-mm lucite rod randomly. Each point was repeated ten times.

3.3 Dynamic Experiment

A dynamic experiment involves in an actual two-phase steam- water flow. The test section was connected to the autoclave in the experimental loop. The objective of this part is to determine the effect of pressure on the scattering device response.

3.3.1 Experimental Loop

The experimental loop depicted in the Figure 3.4, which consisted of a 60-liter reservoir, pump, pulsation dampener, heat exchanger, pre-heater, autoclave and cooler. Water from the reservoir was pumped through the heat exchanger into an electric pre-heater before entering the autoclave. Then the heated water was passed through the heat exchanger before going through the cooler and after that back to the reservoir. When the valve connected on the test pipe was opened, the heated water passed through the test section. A pulsation dampener was employed to reduce the pressure pulse produced by the diaphragm pump. A safety feature valve and an autoclave by-pass line were also included in the system.

The test pipe was an half-inch stainless steel 316 pipe with the thickness of 0.049 inch that is exactly the same as in static experiment. The source, the detector and cadmium shielding were arranged the same way as in the static experiment.

3.3.2 Dynamic Experimental Procedure

1. Electronic instruments were warmed up for 45 minutes before starting the experiment.

2. The amplification levels for this experiment were set to be:

- Coarse gain at 500
- Fine gain at zero.

3. The empty test section was measured to check the stability of the electronics for ten times.

4. To check the stability of the electronics, the standard error was calculated by equation (A.4). The acceptable standard error should less than one percent. If not, there might be due to the unstable equipment, external signal and insufficient time for warn-up the equipment.

5. The multi-channel pulse height analyzer was selected from channel 194 to channel 1179 to eliminate the electronic noise and external noise, which came from the observation by subtracting the signal between the empty and full test section.

6. The density of compressed water was changed by varying temperature 50, 100, 150 and 200°C at constant pressure 5 MPa. Each point was repeated ten times.

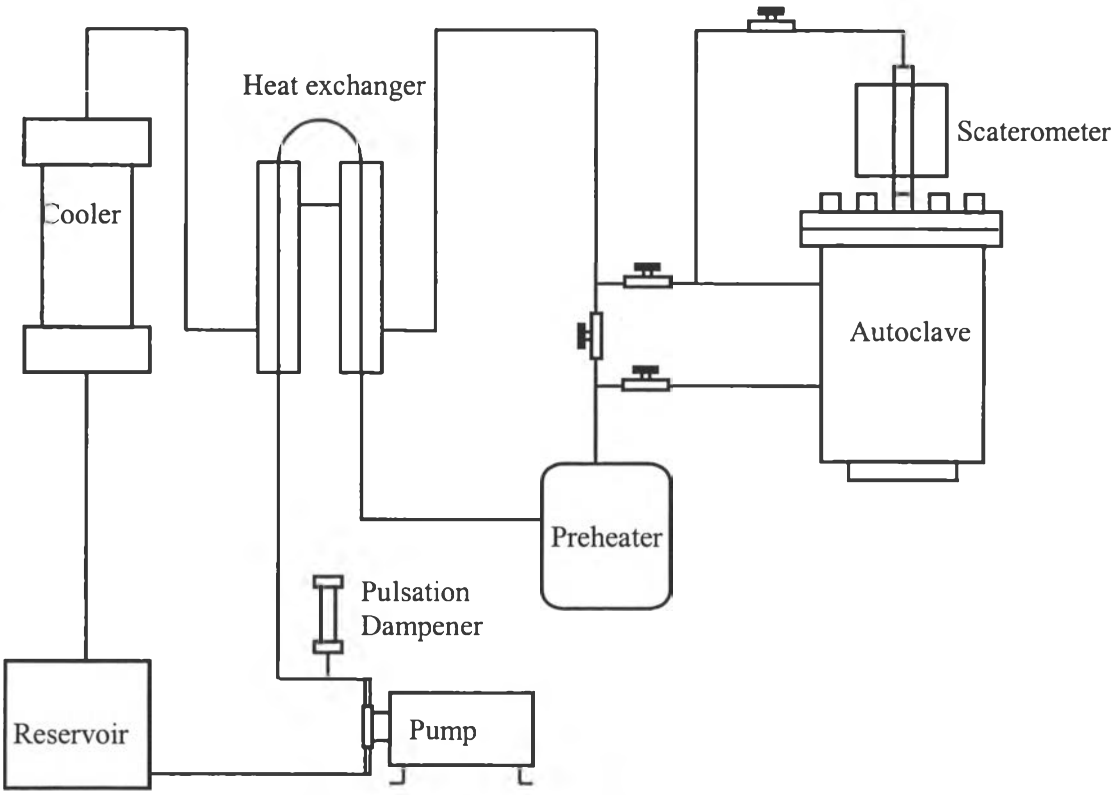

Figure 3.4 The flow chart of experimental loop.