CHAPTER I

INTRODUCTION

Steam quality is an important parameter that needs to be measured in order to understand the fundamentals of two-phase steam-water flow phenomena. Since when steam quality is known, not only many properties of steam-water mixtures such as density and enthalpy can be calculated but also other useful parameters for plant design and control like pressure drops and heat transfer coefficients are evaluated. This, in turn, determines the efficiency of the equipment or system. Moreover, it also helps prevent many severe failures related to wet steam erosion-corrosion especially in the steam piping systems of both nuclear and fossil power plants as well as petrochemical plants that are also sensitive to these problems.

For oil field technology, it is also important to determine the steam quality since it directly affects oil or petroleum production by steam flooding, which is one of the practical thermal methods for secondary recovery operations from a subterranean petroleum well. Such a process requires the steam, which supplies both a fluid and heat, to be injected through an elaborate network of conduits or pipes into a reservoir for stimulating the satisfactory flow of crude oil in a formation downhole. Therefore, it would be particularly useful in balancing the amount of energy reaching the underground formation and achieving the uniform characteristics of the steam in order to determine the efficiency of the process.

In general, the way to investigate steam quality is to measure void fraction of the mixture. Steam quality is based on the mass fraction while void fraction is depended on the volume fraction of the vapor in the mixture. A variety of techniques has been proposed and used for steam quality measurement; for example, impedence devices, quick-closing valves and the liquid expulsion method. Most of them are discussed in many recent reviews (Hewitt, 1982). However, it is inconvenient to apply these conventional methods to the high-pressure pipes of boiling water system since the thick walls need to be penetrated in order to measure steam quality. This also disturbs the flow pattern, which is one of the main disadvantages. Therefore, radiation techniques become more attractive due to their nonintrusive nature. Many types of nuclear radiation such as beta particles, gamma rays, x-rays and neutrons are employed to investigate the steam quality.

The technique based on the attenuation of beta particles has the disadvantage of being too sensitive to detect void fraction in systems that contain water due to the large absorption cross section of water. This leads to a limitation of the test section size and of the wall thickness of the metallic pipe (Sha and Bonilla, 1965). More popular methods are gamma-ray and x-ray attenuation techniques, with the same principles but different photon energies and sources. Both methods are based on the interaction between photons and the electrons of the hydrogeneous flowing material inside the pipe. This indicates the electron density of that material, which is then used for calculating the void fraction. The example application of this technique is a low-energy, multi-beam, gamma-ray densitometry (Åbro and Johansen, 1999), which employed ^{241}Am as source and cadmium zinc telluride (CZT) detectors to determine the oil and gas fraction in pipelines. This device can eliminate many problems such as the pressure drop over the instrument, the detector corrosion and the flow interruption since it has clamp-on capability and is easy to be installed and removed without shutting down the process. Nevertheless, photon attenuation techniques do not give results good enough in a high-pressure system, which is generally composed of thick-wall metallic pipe, and are also of limited use in systems that contain large amounts of high atomic number solid materials such as rod bundles (Banerjee *et al*, 1978). This is because the electron density of the metallic pipes or the solid materials is much higher than that of the hydrogeneous flow material, which is usually of low atomic number. The metals shield the interaction of the hydrogeneous flow material with the electromagnetic fields (Hussein, 1995). A high source strength then becomes necessary to compensate for the photon attenuation caused by the thick-wall metallic pipe (Hussein, 1988).

Such problems are overcome by using neutron techniques, because neutrons are strongly influenced by the presence of the fluid instead of by the effect of the metallic pipe. Therefore, the techniques based on neutrons are the most suitable for steam quality measurement in high-pressure systems. Among various neutron energy groups, the scattering and transmission of fast neutrons is the most promising method, as recommended by the early workers (Banerjee *et al.*, 1978) for two main reasons. First, the results obtained by using thermal neutron beams were not successful, especially for transient flow boiling systems due to the poor statistics from the strong absorption by the hydrogeneous flow material (Banerjee *et al.*, 1978) and the enclosing container (Moss and Kelly, 1970 and Harms *et al.*, 1971). This limited sizes and shapes of pipes to be small and thin, which was impractical in high-pressure systems. Second, fast neutrons are readily produced from inexpensive and compact sources such as a radioisotope, which is also appropriate for making a portable device.

The fast-neutron scattering techniques are based on the fact that the liquid phase in the gas-liquid flow is the more effective neutron slowing-down material in the mixture due to the higher concentration of hydrogen atoms. However, they are different in the position of the detector. The axis of the collimated detector has to be located perpendicular to both the neutron beam and the test section axis in order to measure the total number of neutrons that collide with the hydrogen atoms of the liquid. Then, a scattered thermal neutron flux, which is proportional to the amount of hydrogeneous material and relatively independent of phase distribution, is obtained from fast neutron thermalization. The fast neutrons that are emitted from an isotropic neutron source pass through the test section and collide with the hydrogen atoms of liquid. After several collisions, a fast neutron loses a significant amount of energy and becomes a the thermal neutron, which will be scattered out of the test section and measured by the detector. The technique and device based on the measurement of the scattered thermal flux from a fast neutron beam are called “scatterometry” and “scatterometer”, respectively.

For the fast-neutron transmission techniques, on the other hand, the collimated detector has to be co-axial with the neutron beam. The fast neutrons that pass through the test section without collision are counted and the transmitted flux, which determines the amount of hydrogen atoms only in the collimated zone, can be estimated. Most research using transmitted thermal flux has several collimated detectors, or one collimated detector moving along the test section, to estimate the two-phase flow regime distribution. This is because the flow pattern has a remarkable effect on neutron transmission and, consequently, on the detector response. Transmission techniques can also be applied for void fraction measurement over the entire cross-section of test section if the detector has a diameter close to that of the test section. In previous works (Hussein, 1984), it is suggested that the neutron transmission techniques should be use for steam-water pipes of no more than 25 mm in diameter. This is because in larger pipes the contribution of collided neutrons becomes excessive and the contribution of uncollided neutrons sharply drops.

An example of an application that combines both fast-neutron scattering and transmission is the online and non-intrusive method for determining the volume fractions of the three-phases in an oil-water-gas mixture flowing in a pipe (Hussein and Han, 1995). Fast-neutron transmission indicates the gas fraction while neutron scattering (utilizing the natural salinity of oilfield water) discriminates between the fractions of oil and water. However, further studies are needed for this method such as the optimization of the neutron source energy, the determination of the effect of non-homogeneity of the distribution of the phases in the pipe and the improvement of the calibration curves for the detectors.

Fast-neutron scattering techniques was the focus of this work because the primary concern was to develop a technique for determining the steam quality or void fraction of a steam-water mixture accurately under high-pressure and temperature conditions (some experiments on fast neutron transmission were done in a dynamic air-water experiment to see if there is any possibility for the technique to be developed for the steam quality measurement). In the previous study (Boonyanuwat, 2001), a scatterometer was successfully applied at pressures up to 5 MPa: changes in the density of water were linearly correlated with the neutron count rate, which is compatible with the theory as determined with a Monte Carlo simulation.

In this present work, the performance of Boonyanuwat's preliminary scatterometer was simulated with MCNP4C (Monte Carlo N-Particle version 4C), applying to it to three new system geometries in order to confirm the theoretical adequacy of this technique. The results of the static air-Lucite experiment on the density of water were also confirmed. Nitrogen-water experiments were performed under actual flow condition at atmospheric pressure using both scattering and transmission techniques in order to study not only the difference of the neutron count rate response between these two techniques but also the possibility of the transmission techniques for steam quality measurement. Flowing steam-water experiments under high pressure and temperature conditions in an autoclave were performed and the resulting quality measurements were compared to those obtained from thermodynamic calculations. In addition, the effects of temperature on the scatterometer response were investigated.