CHAPTER 1

INTRODUCTION

1.1 Fuel Coolant Interaction

The safe operation of the nuclear power plant is one of the most major concerns of all the important operation issues. The loss of coolant accident (LOCA) and the emergency core cooling system failure are two of the most common aware accidents. Both events can concurrently bring the reactor core into self-heating due to its fission product decay. Such heat can eventually melt the core and raise its temperature to the level of a few thousands of Kelvins. The molten core material then damages the supporting structure, drops down and comes into contact with the residual coolant at the lower plenum of the reactor pressure vessel (RPV). Or the molten core material bleeds out of RPV to the reactor cavity below and makes contact with the coolant. Such events may result in the process of vapor explosion. These events originate the phrase "Fuel-Coolant Interaction" or "FCI." The result of such process is the rapid pressurization in the vessel. This pressurization, also called transient pressurization or dynamic pressurization, can destroy the RPV structure and the containment by the shock wave interaction with the structure wall.

The study of vapor explosion is directly connected to the field of nuclear engineering. A fuel-coolant interaction or vapor explosion is a physical process in which a hot molten fuel rapidly fragments and transfers its internal energy to a colder and more volatile coolant. The coolant vaporizes and causes the local transient pressure at the time scale fast enough to produce the shock waves propagating at the velocity which may be greater than the characteristic speed of sound in the mixture ahead of the shock front [1].

Due to the destructive consequence, the vapor explosion has raised safety questions in a number of industries. The transport of the liquefied natural gas (LNG) as the real danger of the violent explosion exists when LNG is spilled on the water [2,3]. Although there apparently is no ignition of the natural gas, the pressure pulse is of sufficient magnitude to damage equipment.

In the paper industry, the accident can occur when the water is accidentally introduced into the furnaces above a pool of the molten smelt (mostly sodium carbonate) and cause a vapor explosion that is strong enough to destroy the pulp recovery boiler [4].

1.2 Experiments

Many vapor explosion test facilities have been constructed during the past few decades. Two notable large-scale test facilities are the FARO facility of JRC in Ispra, Italy and the ALPHA facility at the Severe Accident Research Laboratory of JAERI in Tokai, Japan.

In general, the equipment and installation of the large-scaled facilities such as the electric arc furnace, high temperature molten metal feed valve, high-speed camera, high shock pressure chamber, etc., are very expensive. Each test operation is costly, and so is the post-processing. All such expenses can not be affordable under the university laboratory condition and budget. However, even though the explosion can be affected by so many parameters (thermal properties, mechanical properties, chemical properties, nuclear properties, testing conditions, etc.), the major driving parameter of the process is the temperature difference between that of the molten fuel and coolant but not the absolute temperature itself. Therefore, it is postulated that the process can be simulated with the different materials whose the boiling and the solidifying temperatures are more manageable. Consequentially, the simulation of the process may be possible with the other materials under the condition which is less demanding and, thus, manageable at the university level.

The liquid cryogen-water interaction is the interaction that occurred at the low temperature. The possibility of cryogenic vapor explosions in fusion systems has been identified. For the liquid helium-water interactions, Duckworth et al [5] found that the pressure might climb as fast as 800 kpa/s. The researchers tried to develop a model, named MELCOR, while the experiments were conducted in parallel. The liquid nitrogen-water was also chosen as the liquid cryogen-water in a large free volume of the experimental facility. They found that, with the similar mass to the liquid helium tests, the pressurization was much less for the liquid nitrogen tests and no vapor explosion was observed.

1.3 Dissertation Objectives

The water and liquid nitrogen pair is chosen in this work. The water will be injected into the liquid nitrogen chamber with two important key processes, which are believed to cause such interaction, the fuel fragmentation and the heat transfer. Water injection pressure into a liquid nitrogen pool is presumed as a way to help mixing in a form of transient jet breakup or hydrodynamic fragmentation, while the volumetric ratio between water and liquid nitrogen will provide an initial internal energy for the heat transfer. The objectives will concern these two parameters that affect the process of the interaction and verify a degree at which they affect the process. The results are the pressurization of the system and the ice debris, which will be analyzed and simulated with an available computer code. Finally, the effect of volumetric ratio to the water-liquid nitrogen interaction under constant injection pressure will be explained, also the effect of injection pressures to the water-liquid nitrogen interaction under constant volumetric ratio.

1.4 Scope of Dissertation

1. Design and construct a system to conduct and observe the experiment.
2. Design and install the measuring system in order to detect and record the transient pressure during the process of low temperature vapor explosion.
3. Analyze the obtained results and schematically compare the process with those of the vapor explosion experiments at the high temperature.
4. Simulate the low temperature vapor explosion with the available computer codes designed for analyzing and simulating the process of vapor explosion based on the experimental parameters. Analyze the obtained results and compare them with the experimental data in order to verify the validity of the existing vapor explosion model for the process at the low temperature.

1.5 Dissertation Procedures

1. Conduct the literature review of the related topics.
2. Set up the parameters needed for the study.
3. Set up the LTV (low temperature vapor explosion) experiment with the instruments for detecting and recording the transient of the process.
4. Conduct the LTV experiments under the controlled conditions.
5. Analyze the transients obtained from the LTV experiments and schematically compare the process with that of the high temperature experiments.
6. Simulate the experiment with the available computer codes.
7. Analyzed the simulated data and compare the results from the vapor explosion experiment and from the simulations in order to verify the model for the vapor explosion at low temperature.
8. Summarize the research and complete the dissertation.

1.6 Expected Results and Benefits

Although the materials used and the interaction process occurred in FCI at the high temperature differ from those used in this work, the pressurization is one of the most interesting results. The author intends to observe the pressure spikes, which may occur in the experiments. The ice debris found after the experiments is also of interest since its shape or appearance can provide the information on the interaction. Finally, the expected result is to define the preliminary zone of interaction.

Four benefits are expected in this work. The first one is the interaction model at low temperature. The second is the installation and the procedure for conducting the research in depth at the cryogenics temperature. The third is the extensive scientific knowledge in the field of rapid heat transfer and multiphase flow under the condition of the low temperature. And the last is the capability for conducting a shock propagation experiment and studying a suitable structure to reduce the degree of the damage done by shock wave.