Preliminary Analysis of Steam Condensation Loads Due to Multi-Hole Spargers

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1. Introduction

KAERI has performed a series of blowdown tests to assess the performance of the prototype sparger that will be used in an APR1400 reactor [1]. This paper presents a preliminary analysis of the measured hydrodynamic loads due to steam condensation in a large water pool. The objectives of the steam condensation test are to study the characteristics of condensation phenomenon of a multi-hole sparger (unit cell sparger of the APR1400) and to provide test data for code development and verification.

2. Overview of Condensation Test Program

The condensation test program consists of steady state and transient steam condensation tests. Saturated steam was discharged into a pool through a steam sparger and dynamic pressures in the pool were intensively measured.

2.1 Test Facility

The condensation tests were conducted at the B&C test facility [2] in KAERI from an initial system pressure of 15.0 *MPa*, a steam temperature of 343 ℃ and pool temperature of 20 – 95 ℃. The B&C facility consists of a pressurizer, a quench tank, and piping and instruments. The volumes of the pressurizer and quench tank are 0.85 m^3 and 28 m^3, respectively, and the height of the quench tank is 4 m.

The main piping consists of 2" Scedule160 pipe. One of two spargers was installed in the quench tank and it was connected to the pressurizer via the main piping. A flow control valve was used to control steam flow rate during steady state tests. A venture flow meter and several instruments such as thermocouples, pressure gages, and 9 dynamic pressure sensors were installed.

A prototype unit cell sparger was used in the transient tests. For the steady state steam condensation tests, a reduced sparger has been used. The reduced steam sparger has the same dimension of the unit cell sparger but the number 10 mm hole was reduced from 144 to 64 and a bottom hole has not been simulated.

2.2 Test Matrix

Steady state steam condensation tests have been performed to investigate the condensation phenomenon of a multi-hole sparger. The range of steam mass fluxes for the steady state tests was selected to define the transition regime from the condensation oscillation to the stable condensation. The temperature of the water in the quench tank has been adjusted from 20 °C to 95 °C (Table 1) for a fixed mass flow rate condition.

Table 1. Test Matrix

Test	Steam Pressure (*MPa*)	Mass Flux (kg/m2/s)	Pool Temperature (*°C*)
Steady State Test	15.0	100 - 500	20 – 95
Transient Test	15.0 – 15.8	100 - 750	20 - 95

Transient steam condensation tests have been performed to determine the influence of higher steam mass fluxes not covered in the steady state tests. Saturated steam of 15.0 MPa in the pressurizer has been discharged to the quench tank through a unit cell sparger, which will be used in the APR1400. The temperature of the water in the quench tank has been adjusted from 20 °C to 95 °C.

3. Test Results and Discussion

3.1 Condensation Loads

Two locations were selected to compare condensation loads in the quench tank. The one is at wall of the quench tank where the level is about the same as that of the discharging holes of the unit cell sparger, and the other is at the center of bottom of the quench tank.

The dynamic load at the quench tank increases as the pool temperature increases up to 80 °C and then it decreases rapidly at higher temperature. The load at the bottom of the quench tank is always much greater than that at the circumferential location (Figure 1). The biggest pressure loads during the tests are ± 95 kPa and were measured at the bottom of the quench tank for 80 °C pool temperature condition.

For a given pool temperature condition, the load generally increases up to a specific mass flux, and then it decreases very rapidly as the steam mass flow rate increases. After it reaches minimum value, the load maintains constant or decreases very slowly. However, for the 90 °C pool temperature condition, the loads continuously increase as the steam mass flux increases. Further tests with increases mass flow rate are required.

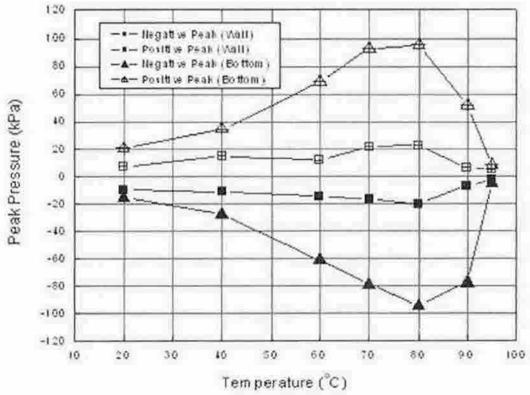

Figure 1. Maximum Pressure vs. Water Temperature.

3.2 Frequency in the Steady State Test

The Fast Fourier Transform (FFT) analysis for dynamic pressure induced by steam condensation in the quench tank has been performed to investigate the frequency pattern in condensation phenomenon. The result of FFT analysis shows that several major amplitude peaks (Figure 2) are generated during the steam condensation process.

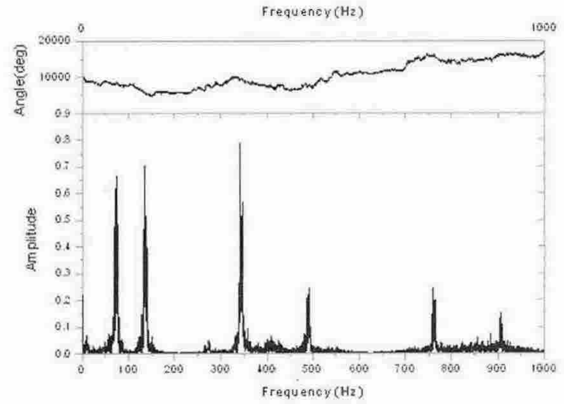

Figure 2. Result of FFT for 40 °C-300 kg/m$_2$-s Test

For specific water temperature in the quench tank, the FFT results show that the frequency distributions are the same for certain range of steam mass flow rate. Further increase of the steam mass flow rate results in the disturbance of previous frequency distribution. The amplitude of the frequency peaks are decreased or disappeared completely as the mass flow rate was increased.

The amplitude of the first amplitude peak is the largest of all peaks and the frequency of the first amplitude peak generally decreases as the steam mass flux increases in oscillation condensation regime. The frequency of the first amplitude peak increases as the pool temperature increases up to 60 °C (90 Hz), and it rapidly decreases to 6 Hz as the temperature increases to 95 °C.

3.3 Applicability of Test Data

The load measured during the steady state tests in this test program was compared to the transient test results of this program and ABB ATOM test data [3]. The major difference between steady state test and the tests described above is the existence of bottom hole in the sparger and number of discharging holes. The overall tendency of load variation is similar between tests. However, there is big difference in the magnitude of loads measured at the bottom. In general, the load at the tank bottom in the steady state test is much bigger than those in the transient test and ABB Atom data. However, the loads between two transient tests are of same order.

The difference between steady-state test and transient test data may come from the existence of bottom hole. Or the fast transient test may not simulate the real situation where quasi-steady-state blowdown is expected in the plants. Further experimental study is required

4. Conclusion

A series of steam condensation tests have been performed. The test results show that:

1. The dynamic load at the quench tank increases as the pool temperature increases up to 80 °C and then it decreases rapidly at higher temperature. The maximum magnitude of the pressure wave reaches ± 95 kPa.
2. The frequency of the first amplitude peak increases up to 60 °C (90 Hz) and then it decreases very rapidly.
3. The magnitude of pressure wave increases very rapidly after it reaches minimum value for 90 °C temperature condition. Further study is required.

REFERENCES

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