Nuclear Engineering and Design 339 (2018) 244–252

Contents lists available at ScienceDirect

Nuclear Engineering and Design

journal homepage: www.elsevier.com/locate/nucengdes

Frequency analysis of chugging condensation in pressure suppression pool system with pattern recognition

Elina Hujala*, Vesa Tanskanen, Juhani Hyvärinen

LUT School of Energy Systems, Nuclear Engineering, Lappeenranta University of Technology (LUT), P.O. Box 20, FIN-53851 Lappeenranta, Finland

ARTICLE INFO

Keywords:
Two-phase flow
Suppression pool
Chugging
Pattern recognition
FFT

ABSTRACT

Direct contact condensation (DCC) phenomena in boiling water reactor (BWR) pressure suppression pool systems need to be understood to properly assess the performance of the pool as a heat sink and as a safety critical structure. Condensation oscillations in the form of chugging are challenging to predict by computational fluid dynamics (CFD) methods but safety relevant because of associated high dynamic loads on in-pool structures and the pool itself. Recently, new measurement methods for CFD validation purposes have become available. One of these techniques is visual observation using the high-speed cameras and suitable data processing method. Pattern recognition is a well suited technique for the determination of large oscillating bubble dynamics in a pressure suppression pool.

In this work, the formation and collapse of the steam bubbles in chugging condensation mode are evaluated by using the pattern recognition algorithm. The pattern recognition algorithm is based on video material recorded during the direct contact condensation experiment DCC-05 of the PPOOLEX test facility. The formation speed, the shape and size of the steam bubbles and the acceleration of collapsing bubbles are estimated with the algorithm. Fast Fourier transform (FFT) is used for frequency analysis of the pattern recognized data. The frequencies found are compared to the frequency data of the pressure transducers collected during the experiment and to the previous results of the NEPTUNE_CFD simulations of the same experiment.

The frequency analysis shows that the chugging frequencies of the steam bubbles range from 1 to 3 Hz, as predicted. Also the natural frequencies of the bubbles are visible around 53 Hz. Another frequency spike was observed close to the 125 Hz. This frequency is close to the mechanical resonance frequencies of the suppression pool and the blowdown pipe. Because of neither the pressure suppression pool nor the blowdown pipe are visible to the pattern recognition, the spike of the higher frequencies is most likely from the interfacial area of the bubble which resonates with the suppression pool system, affecting rapid condensation at a certain point.

1. Introduction

The small size of the BWR containment bring on the possibility that a large amount of steam should be rapidly condensed into the suppression pool during the loss of coolant accident (LOCA). Injected steam causes structural loads to the suppression pool and demands a lot of its strength. One main cause of these structural loads are the pressure oscillations and chugging of condensed steam, which have been studied through the decades. Test facilities small (Aya et al., 1980; Aya and Kobayashi, 1983; Aya and Nariai, 1987; Simpson and Chan, 1982; Gregu et al., 2017) and large size (Utamura, Moriya, and Uozumi, 1984; Kukita et al., 1984; Kukita et al., 1987; Pellegrini et al., 2016) have been used to study these condensation modes. DCC is present in all of the modes, which emphasizes the need to validate and develop condensation models being able to capture interfacial condensation rate correctly with the CFD software. Already, even in the old experiments, movie cameras were used for visual observation, but the observation results were hardly published. At first, the data analysis concentrated for pressure data analysis, but the arrival of the CFD made possible to model the physical behavior of the condensation more accurately than with simplified analytical models (Lahey and Moody, 1993; Lahey, 2005). Different condensation modes have been modeled by using CFD (Patel et al., 2017; Mimouni et al., 2011). As the modeling of two-phase flows using CFD has challenges (Bestion, 2014), a new measurement methods for CFD model validation purposes has been put into operation. Lately, the high-speed cameras have been started to use to record the experiments in more thorough manner (Issa et al., 2014; Tanskanen, 2012) to make data analysis more feasible. The measured data is used

* Corresponding author.
E-mail address: Elina.Hujala@lut.fi (E. Hujala).

https://doi.org/10.1016/j.nucengdes.2018.09.018
Received 29 June 2018; Accepted 18 September 2018
Available online 26 September 2018
0029-5493/

Nomenclature

Variables

A	surface area
d	diameter
f	frequency
f_0	natural frequency of oscillating bubble
P_0	steady state pressure
p_1, p_5	pressure transducers p_1 and p_5
r	radius
R_0	steady state radius of the bubble
t	time
V	volume
$\|Y(f)\|$	dimensionless absolute value of amplitude
γ	ratio of the specific heat of the water
ρ_w	density of the water

Abbreviations

BWR	boiling water reactor
CFD	computational fluid dynamics
DCC	direct contact condensation
FFT	Fast Fourier Transform
LOCA	Loss of coolant accident
LUT	Lappeenranta University of Technology
PACTEL	parallel channel test loop
(P)POOLEX	condensation pool experiments

to evaluate different features diameter, velocity, position of the condensing bubbles (Issa et al., 2014). At Lappeenranta University of Technology (LUT) a preliminary pattern recognition algorithm was created for the use of former condensation pool test facility POOLEX (Tanskanen et al., 2014b). Later on, the pattern recognition and data analysis algorithm has been upgraded to evaluation of diameter, surface area, volume, velocity, acceleration and frequencies of the condensing steam bubbles (Hujala, 2013; Hujala et al., 2013; Hujala et al., 2018).

This paper presents the frequency analysis of the recorded video data of direct contact condensation experiment DCC-05-4 of the PPOOLEX test facility using FFT on the volume data evaluated by using the upgraded pattern recognition and data analysis algorithm. The results are briefly compared to the NEPTUNE_CFD code simulations and the pressure transducer data. The source of some frequency spikes have also been tracked by applying hammer tests to the PPOOLEX facility.

2. Experiments and methods of analysis

2.1. PPOOLEX test facility and DCC-05 experiment

The PPOOLEX test facility is a scaled down test facility of Nordic type BWR containment. The schematic view of the PPOOLEX test facility is shown in Fig. 1.

The 31 m^3 stainless steel pressurized vessel has the total height of 7.45 m and diameter of 2.4 m. It consists of two main parts, the dry well compartment and the wet well compartment separated by an intermediate floor, an inlet plenum and air/steam piping. A route for air/steam flow from the dry well to the wet well is created by a vertical blowdown pipe attached non-axisymmetrically underneath the floor. The different lengths and widths of the blowdown pipe can be used depending on the needs of the ongoing experiment. Steam needed in the experiments is produced by near PACTEL test facility, which has the core power of 1 MW. The more detailed description of the PPOOLEX test facility is presented in (Puustinen et al., 2013).

DCC-05 experiment was one part of the direct contact condensation

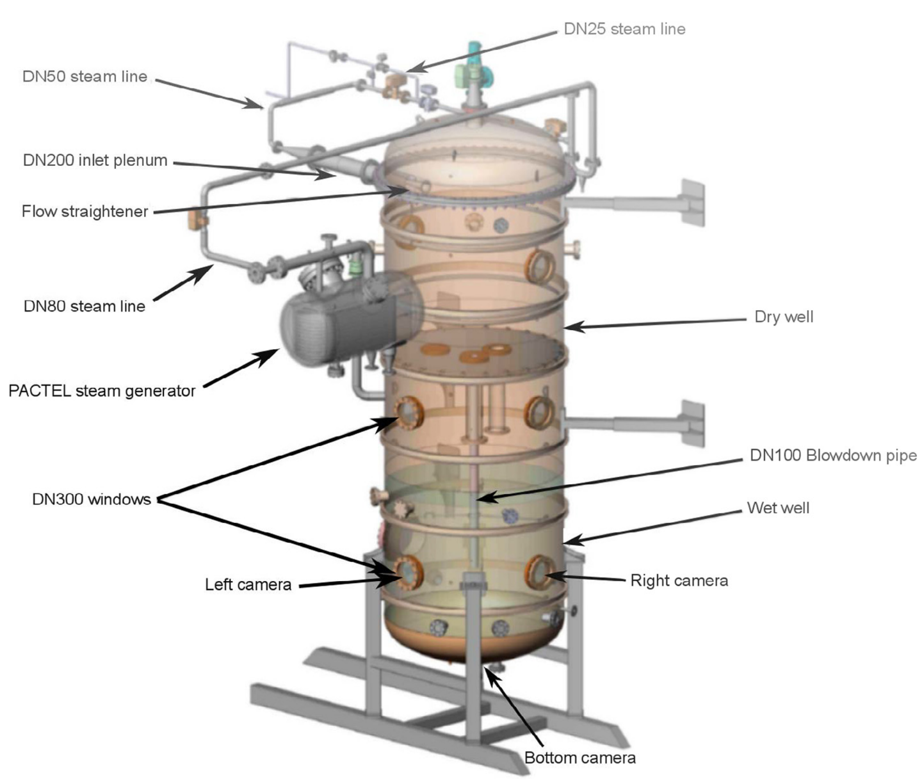

Fig. 1. Schematic view of the PPOOLEX test facility.