Nuclear Engineering and Design 299 (2016) 37–45

Contents lists available at ScienceDirect

Nuclear Engineering and Design

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

Simulation benchmark based on THAI-experiment on dissolution of a steam stratification by natural convection

M. Freitag*, E. Schmidt, S. Gupta, G. Poss

Becker Technologies GmbH, Koelner Str. 6, 65760 Eschborn, Germany

HIGHLIGHTS

- We studied the generation and dissolution of steam stratification in natural convection.
- We performed a computer code benchmark including blind and open phases.
- The dissolution of stratification predicted only qualitatively by LP and CFD models during the blind simulation phase.

ARTICLE INFO

Article history:
Received 25 June 2015
Accepted 3 July 2015
Available online 28 August 2015

ABSTRACT

Locally enriched hydrogen as in stratification may contribute to early containment failure in the course of severe nuclear reactor accidents. During accident sequences steam might accumulate as well to stratifications which can directly influence the distribution and ignitability of hydrogen mixtures in containments. An international code benchmark including Computational Fluid Dynamics (CFD) and Lumped Parameter (LP) codes was conducted in the frame of the German THAI program. Basis for the benchmark was experiment TH24.3 which investigates the dissolution of a steam layer subject to natural convection in the steam-air atmosphere of the THAI vessel. The test provides validation data for the development of CFD and LP models to simulate the atmosphere in the containment of a nuclear reactor installation. In test TH24.3 saturated steam is injected into the upper third of the vessel forming a stratification layer which is then mixed by a superposed thermal convection. In this paper the simulation benchmark will be evaluated in addition to the general discussion about the experimental transient of test TH24.3. Concerning the steam stratification build-up and dilution of the stratification, the numerical programs showed very different results during the blind evaluation phase, but improved noticeable during open simulation phase.

1. Introduction

The aim of the test series TH24 was to provide validation data for the development of CFD and LP models to simulate the atmosphere in the containment of nuclear reactor containment. The benchmark is part of a comprehensive concept for generating a code validation data base of continuously increasing complexity and simultaneous performing simulation benchmarks. TH24 (Gupta et al., 2012), the last experiments of a systematic experimental series shall also contribute to resolving remaining open questions from ISP-47 (Allelein et al., 2007). During ISP-47 it was identified that significant model improvements were required especially for CFD codes, in order to predict gas stratification build-up and erosion quantitatively.

In test series TH21 (Fischer et al., 2009), by means of differentially heating the vessel walls, a flow pattern in the vessel atmosphere was established which was characterized by thermal buoyancy and natural convection. Fast injection of light gas into the upper plenum of the vessel formed a stable stratification in TH22 (Gupta et al., 2010; Fischer and Gupta, 2011) which was dissolved by the natural convection, driven by differential heating of the vessel walls. A similar benchmark was recently performed, utilizing measurement data from the small scale MiniPanda facility (Kelm and Ritterath, 2013). The light gas injection of TH22 is replaced by a steam injection in the TH24 test series, which partially condenses due to the low temperature at the cooled vessel walls.

* Corresponding author. Tel.: +0049 6196 936117.
E-mail address: freitag@becker-technologies.com (M. Freitag).

http://dx.doi.org/10.1016/j.nucengdes.2015.07.001
0029-5493/

It was pointed out in the OECD State-Of-the-Art Report on Containment Thermal-hydraulics (1999) that experiments should not lack three-dimensional measurement data in order to validate CFD codes. The TH24 benchmark addresses the phenomena of steam stratification and steam condensation under flow conditions which have been studied in previous blind and open benchmarks (TH21 and TH22) successfully. In the frame of the TH21 and TH22 tests explicit 3-dimensional flow measurements using particle image velocimetry (PIV) were performed and data are available for code validation purpose (Fischer and Gupta, 2011).

2. THAI test TH24.3

2.1. Experimental set-up

The tests of the series TH24 investigates the dissolution of steam stratification under the presence of natural convection in the atmosphere of the THAI test vessel. The 60 m^3 THAI test vessel is made of 22 mm stainless steel, its height being 9.2 m and its diameter 3.2 m. The thermally insulated vessel is equipped with three heating/cooling jackets over the height for controlled heating or cooling of the walls. It can be operated up to 14 bar at 180 °C. Between the heights H = 2.155 m and H = 6.245 m an inner cylinder of 10 mm stainless steel, open at both ends, is installed with an outer diameter of 1400 mm. Measuring flanges on five levels at five circumferential positions allow to install thermocouples mounted on the inner vessel walls or in gas space and the steam sampling system, Fig. 1.

In TH24, the lower and middle vessel mantles are heated, while the upper mantle is simultaneously cooled. Due to these thermal boundary conditions, a specific distribution of flow velocity and temperature in the atmosphere is formed which is characterized by turbulent forces of buoyancy and friction. Saturated steam is injected into the upper third of the plenum forming a stratification layer which is then gradually mixed by the thermal convection. Test TH24.3 was selected as basis for the blind and open simulation exercise from the TH24 series of experiments with parametric variations (Gupta et al., 2012).

2.2. Experimental results of test TH24.3

The test TH24.3 started by closing the THAI vessel at ambient conditions. The wall temperature of the lower two vessel mantles was adjusted to 100 °C and the upper mantle was cooled to 55 °C during a preconditioning phase. This differential heating generates a natural circulation motion which leads to a

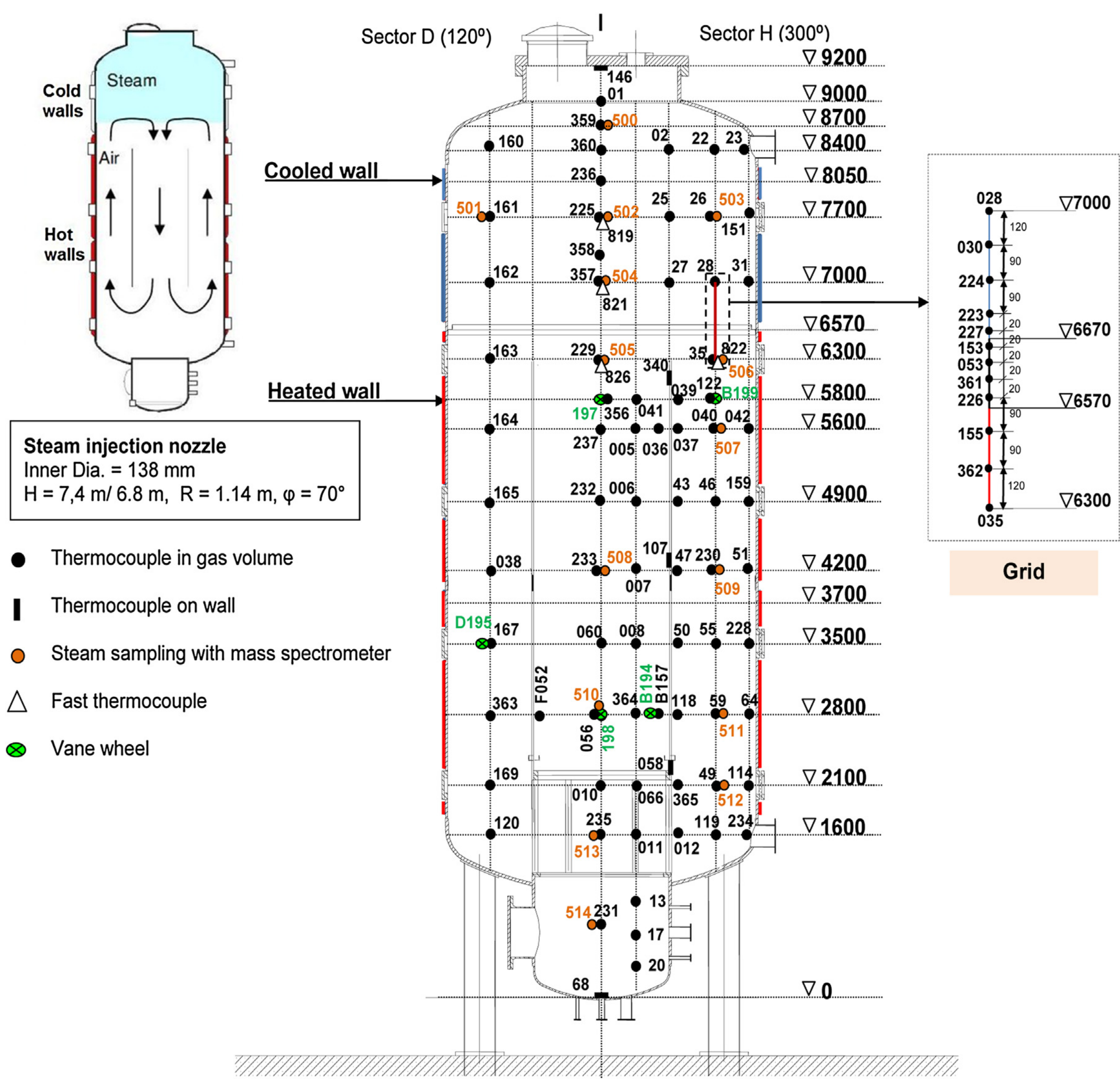

Fig. 1. Configuration and selected instrumentation of the THAI vessel.