ИЗСЛЕДВАНЕ НА ИЗГАРЯНЕТО НА ВОДОРОДА В ЕКСПЕРИМЕНТА THAI HD-22 С КОМПЮТЪРЕН КОД ASTEC V2.1.1.4.

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HYDROGEN COMBUSTION STUDY IN THE EXPERIMENT THAI HD-22 WITH COMPUTER CODE ASTEC V2.1.1.4.

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1. Abstract

In this study a simulation of the behaviour of the environment in the THAI containment test facility during severe accident conditions is done.
This paper presents a comparison of ASTEC v2.1.1.4 calculated results with experimental data for the: experiment HD-22 in the test facility THAI. Two calculations have been made to investigate hydrogen ignition, combustion and possible detonation, which are characterized by a rapid increasing of pressure and temperature in containment. The prediction of hydrogen behaviour is important for hydrogen management and containment safety.
The hydrogen deflagrations cannot be ruled out completely by using the PARs. The aim of the Thai experiment is to develop high level of confidence that nuclear reactor containment systems and PARs establish an acceptable level of safety.

2. Introduction

The experiment was analyzed with computer code ASTEC v2.1.1.4. The main purposes of HD-22 test were to examine hydrogen deflagration in a steam-air atmosphere. A homogeneous air-steam-hydrogen mixture was ignited at the vessel bottom, and the upward and radial flame propagation was observed. THAI experiment is to investigate the influence of temperature, pressure and steam on the onset of H_2 recombination in case of low oxygen concentrations [1].

During a severe accident in a light water reactor nuclear power plant, substantial quantities of hydrogen may be generated by metal oxidation during the degradation of the reactor core. If the hydrogen concentration in the plant containment is within flammability limits, hydrogen combustion may occur, damage the containment integrity. For licensing and safety analyses one has to prove that the hydrogen release rate and total amount do not exceed limits for the considered power plant. The hydrogen generation rate must be known to design appropriately accident mitigation measures like passive autocatalytic recombiners and ignitors. The physical and chemical phenomena of the hydrogen release are, however, not sufficiently well understood [2].

The combustion of hydrogen, resulting in changes of the pressure and temperature in the facility containment are the primary objectives in the present paper. The hydrogen could be generated by the interaction of reactor core internals with water/steam/air and distributed to the containment environment through the possible pipe break. The achievement of proper simulation of the pressure and temperature peaks after ignition of the hydrogen is of particular importance. The ignition occurs at higher hydrogen concentration, which leads to by increasing saturated steam content. The evaluation of hydrogen-oxygen-steam concentrations at the different zone of the THAI vessel have been investigated.

3. Description of the THAI test facility

The THAI experimental is located at Becker Technologies GmbH in Eschborn (Germany). The THAI test facility [3], [4] presents the nuclear power plant containment and is simulated by the large cylindrical vessel with volume of 60 m^3 height of 9.2 m and diameter of 3.2 m. The vessel wall is 22 mm thick stainless steel. It can be operated up to 180 °C and 14 bar.

For the Hydrogen-Deflagration (HD) tests the THAI vessel is empty (inner cylinder and condensate trays are removed), except the instrumentation, the gas and steam feeding devices, a recirculation fan and the igniters. The vessel structures are made of stainless steel and are completely enveloped by a 120 mm rockwool thermal insulation. The cylindrical part of the THAI vessel wall (Inner Diameter (ID) = 3156 mm) is double-walled, the inner wall being 22 mm thick. The 16.5 mm gap between the walls is filled with thermal oil of the wall heating/cooling system. The bottom and top of the vessel are formed by dished heads (wall thickness 30 mm), both of which are penetrated in the vessel axis by cylinders with an ID of 1540 mm (wall thickness of 40 mm) for the upper cylinder and an ID of 1368 mm for the bottom cylinder (wall thickness of 30 mm).

The important initial conditions for selected THAI test are the volumetric percentage of hydrogen and oxygen, pressure and temperature. The boundary conditions at the beginning of the process, subjected to numerical simulation, suggest that combustion of hydrogen should take place in a homogeneous atmosphere. The mixture ignites in the centre of the bottom of the THAI housing and the flame spreads in the upward direction.

In HD-22 test hydrogen concentration is 10 vol.% and the hydrogen was ignited at the vessel bottom in zone 1. The test was performed at initial temperature of 92 °C. The cylindrical vessel was filled with homogeneous gas mixture of H_2-air- steam at initial pressure of 1.5 bar.

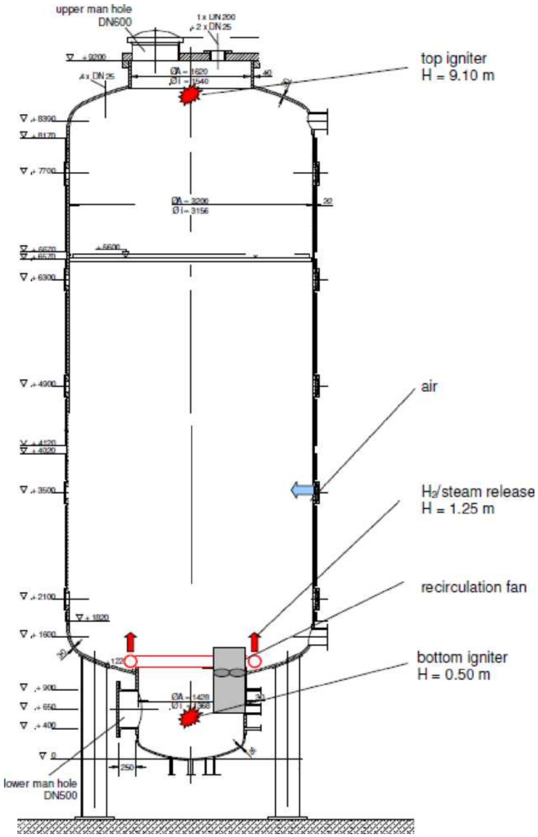

Figure 1 THAI test vessel configuration

4. Brief description of ASTEC v2.1.1.4 computer code

The computer ASTEC code is developed by IRSN (Institut de Radioprotection et de Secure Nuclear) together with (Gesellshaft Aus Anlagen und Reaktosicherheit) GRS [5], [6]. ASTEC is a lumped parameter fast running code performing numerical simulation. The code has a modular structure, in which each module simulates a section or set of physical phenomena flowing into the respective reactor installation.

Simulating the behavior of hydrogen in hazardous conditions by ASTEC, based on the THAI experiment, allows more detailed study of the thermal hydraulic behavior in an inhomogeneous atmospheric condition. This is very important for the assessment of the effects of combustion and ignition / detonation of hydrogen. Studying these processes leads to their better management through the use of hydrogen regeneration systems. The module CPA (Containment Part of ASTEC), which deals with phenomena in the containment atmosphere, uses a lumped-parameter description: the containment is simulated as a network of control volumes (sometimes called "cells" or "zones"), which are connected by flow paths ("junctions"). The control volumes of the input model may correspond to actual containment compartments or not. Thus, to model a non-homogeneous atmosphere, large volumes may be divided into several control volumes. In each control volume, conditions are modelled as homogeneous and "zero-dimension" description is used. The flow paths that connect control volumes are not repositories of mass or energy.

The ASTEC model of the THAI vessel was divided into 9 axial zones. In this 9-cells model, the main cylindrical part was divided into 7 levels and there are 2 additional cells: the first one is the bottom dished head and the other one cell is the upper dished head.

5. Analysis of the results

One of the most important parameters investigated in this analysis is combustion model. In the CPA structure of ASTEC input model was used a "COMB" structure for a simplified H_2 and CO combustion model. The FRONT propagation model "FRNT" was selected for simulation upstream flame propagation and for calculation of the duration of combustion [7], [8].

The exponential law of Liu Mac Farlane for laminar burning velocity to determine burning duration was activated in the combustion model. The ignition of hydrogen was selected to occur at 1.6 second from the beginning of the transient. The other parameters, which we considered that have also significant influence for hydrogen generation for the combustion model as FBURN - factor to modify combustion duration in the starting zone with the initial temperature, were used in two options: default - 1.0 and sensitivity - 0.12. Two calculations have been made using different factor to modify combustion model.

Containment pressure in cell 2-1

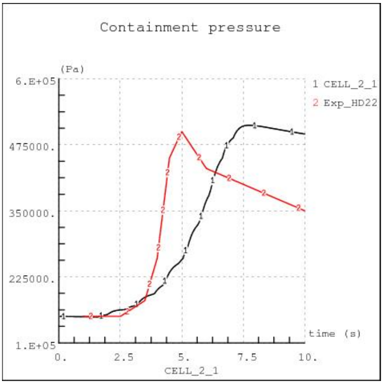

Figure 2 Case#1 with factor "combustion duration"= 1.0

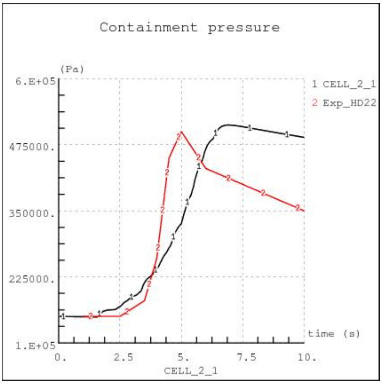

Figure 3 Case#2 with factor "combustion duration" = 0.12

A comparison of the containment pressure in the lower zone for the different calculations is shown in Figure 2 and Figure 3. The increasing of pressure in the lower part of the vessel starts for both cases almost in the same time as in the experimental data. For case#2 there is better agreement during the increasing phase. The difference between the increasing of pressure in both cases could be explained with the using of different factor "combustion duration" in the model.

The calculated temperature is over estimated in the lower zone and the increasing of calculated temperature starts earlier compare to measured data for both cases (see Figures 4 and 5). The calculations show good agreement with measured data during the first phase is shown on figures 6 and 7. In the case#2 there is better agreement with experimental data.

Containment temperature in Cell 2-1

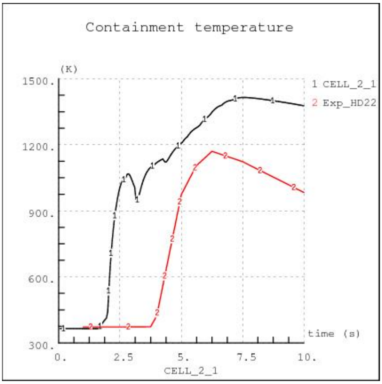

Figure 4 Case#1 with factor "combustion duration" = 1.0

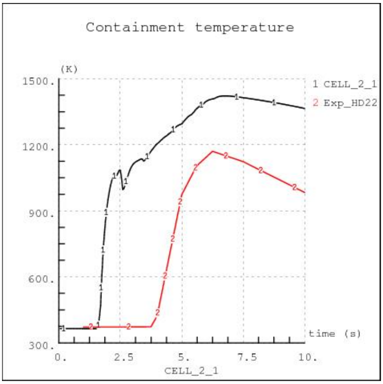

Figure 5 Case#2 with factor "combustion duration" = 0.12

Containment temperature in Cell 8-1

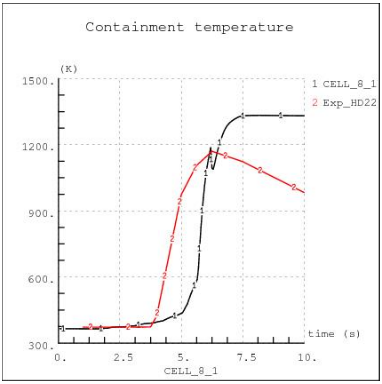

Figure 6 Case#1 with factor "combustion duration" = 1.0

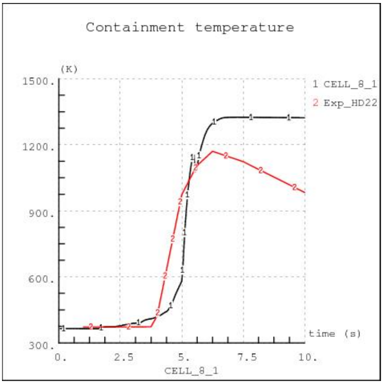

Figure 7 Case#2 with factor "combustion duration" = 0.12

Volume concentration of H2, O2 and steam in cell 9 (top)

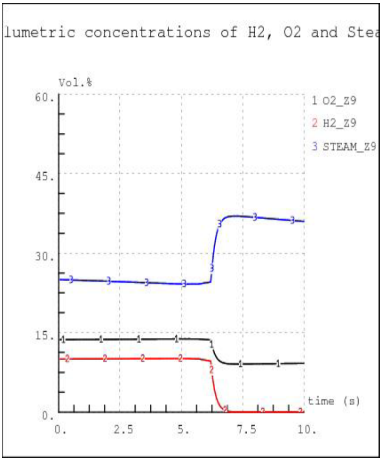

Figure 4 Case#1 with factor "combustion duration" = 1.0

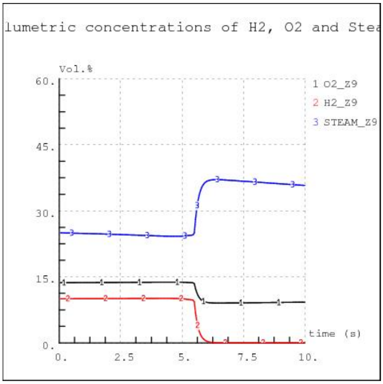

Figure 5 Case#2 with factor "combustion duration" = 0.12

It can be seen that the concentrations of hydrogen, oxygen and steam on the Figures 8 and 9. In the cell 9 the concentration of H_2, O_2 and steam starts changing with some delay in case#1 compare to case#2.

Volume concentration of H2 centrally in the axial division

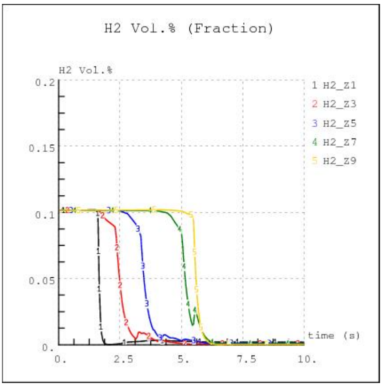

Figure 10 Case#1 with factor "combustion duration" = 1.0

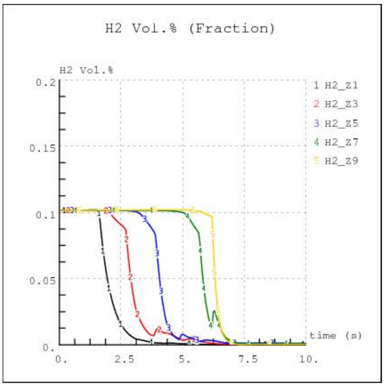

Figure 11 Case#2 with factor "combustion duration" = 0.12

On the Figure 10 and 11 is presented the volume concentration of hydrogen in the axial division. The burning of hydrogen starts at cell 1 at 1.6 second. The hydrogen burns completely at cell 9 in the 6-th second for the case#2 and after 7-th second for case#1, when it reaches the maximum pressures.

6. Conclusions

The calculations made in this work have shown the behaviour of the containment parameters such as pressure, temperature and flame propagation during hydrogen deflagration.

The calculated containment temperatures on top of vessel in both cases are in good agreement with the experimental data. For case#2 there is slightly better agreement in the phase of increasing (in first five seconds). The trend of pressure increasing in lower part of vessel in case#2 is close to the experimental data compare to the case#1. The temperature behaviours in the lower part for both cases over predict experimental data.

The impact of investigated factor is mainly on burning of hydrogen and changing this way the volumetric concentration of containment gases (H_2, O_2 and steam). Reducing the value of «combustion duration» leads logically to acceleration of hydrogen burning.

7. Literature

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