MODELLING OF HYDROGEN DEFLAGRATIONS IN A PWR CONTAINMENT

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ABSTRACT

Hydrogen release and combustion during severe accident scenarios can impose considerable loadings to containment. To avoid damaging consequences the "Dual-Concept" has been developed. Within this concept spark igniters are used to burn the atmospheric hydrogen deliberately as early as possible.

The following paper describes a recently derived hydrogen deflagration model which is meant to estimate the combustion phenomena as part of an accident sequence in the containment. The model is an element of the integrated code RALOC and uses some of the available code environment.

The application of the deflagration model is exemplified with a special experiment carried out at Battelle model containment (MC).

1 INTRODUCTION

The hydrogen issue with existing PWR-containments is to avoid larger dynamic pressure and temperature loads caused by accelerated deflagrations or even detonations. With respect to new containment concepts combustion peak pressures directly influence the design pressure. Therefore the approach of older combustion models which only rely on empirical relations fitted to certain experiments no longer suffices.

In order to evaluate the complex of gas distribution, heat exchange, pyrolysis and combustion the concept of averaging multinode modelling is used with many containment codes. Such models are nondimensional and simulate existing dimensions by a subdivision of physical containment rooms. The presented deflagration model is one-dimensional because it is felt that during combustion often one direction is predominant or more complex propagation schemes shall be composed of the simpler one-dimensional one. As a standard tool a 2-D or 3-D model will not useful as the starting conditions can not be provided precise enough and computing time consumption would exceed tolerable quantities.

Deflagration is a extreme short term event and is in contrast to the long term processes occurring in parallel. For this reason the embedding code RALOC has been rewritten to temporarily include the differential equations of other models.

The field of application of the new deflagration model which is called DECOR (deflagration in a chain of rooms) is to give reliable predictions of combustion loads after having passed an extensive validation phase using series of vented burn experiments carried out in several countries.

2 HYDROGEN DEFLAGRATION MODEL

DECOR uses an approach illustrated in fig 1. As with turbulent deflagrations gas dynamic effects normally dominate, the model employs the concept of burning axes.
All available flow connections and igniters in a burning room must be related to the possible maximum number of three axes.

![Diagram showing flow connections and igniters in a burning room.](image)

**Figure 1** Principle Approach of the deflagration model RALOC-DECOR

The combustion model assumes a flame front which separates burned from the unburned gas. The flame front is only penetrable for the portion of gas being burned. The burning velocity is calculated by its own model to be presented in the next chapter. The combustion energy is fully attributed to the burned part. For the duration of the combustion heat exchange with adjacent rooms from the unburned part is neglected. Mass and energy flows across the room boundaries can take place at any time from both parts. Hydrogen combustion consists of a complicated set of chemical subreactions. But this model takes care only of the net changes in the species masses of hydrogen, oxygen and water on both sides of the flame front. Diluent portions remain unaffected by the chemical reaction.

Fig. 2 shows an overview of the calculations to be done. It starts with a specified burning velocity depending on the unburned gas conditions and the current deflagration situation. By the help of a burning area function derived from experiments the burning volume flow or reaction rate is fixed. This leads to mass changes in both parts and to energy input to the burned side. Using the mass and energy conservation equations that can be derived for a variable volume open thermodynamic system derivatives of temperature, component masses and of volume are obtained.

![Flow diagram showing calculations for the deflagration model.](image)

**Figure 2** Simplified flow diagram of the deflagration model
The derivatives of unburned and burned room parts are linked by their common volume change. As the deflagration processes to be investigated within the "Dual-Concept" are slow compared to the speed of sound complete pressure relief between the varying room parts can be stated. By this means the system of differential equations can be solved explicitly for the volume change. This volume change now represents a total volume change including burning and subsequent explosion. In older models the expansion normally is neglected, leading to an considerable underestimation of the resulting flame velocity and to a loss of predictability. The total volume change can be understood as the displacement of the flame front acting on a representative cross section along the actual burning axis. Now the set of differential equations is complete and can be submitted to the solver in RALOC. Compared to the situation without combustion only one new variable - the flame front location - has to be solved. The flame front position is used to determine the propagation into neighboring rooms. Fig. 3 shows the resulting code structure and the links to RALOC.

![Figure 3 Code structure of the deflagration model](image)

2.1 Burning velocity model

The burning velocity model contains all the empirical parts of the deflagration model either as the are not understood well enough by man or as they are too complicated to be dealt with in detail.

The burning volume flow is the product of a burning area and the burning velocity distribution normal to it. Fig. 4 illustrates the concept.

Numerous experimental investigations exist to describe the burning velocity under laminar and turbulent conditions. The laminar velocity obtained by Liu and MacFarlane /2/ is used here despite the measurements were carried out for mixtures containing only up to 18% of steam. But steam is a natural constituent in safety related analyses and is often present in higher concentrations. Therefore it is planned to employ alternatively measurements of Koroll and Mulpuru /3/. The more common case of turbulent velocity is modelled as proposed in /4/. Here again alternative investigations to enhance the reliability of velocity calculation are envisaged.

Burning area measurements are not known so far. This remains the open question of the model and needs to be adjusted to experiments especially designed to deflagrations in systems of interconnected rooms. Available series of experiments are at Battelle-MC /5/ and at HDR-Containment /6/. Next year at Battelle and at TU Munich a new experimental programme will be launched to get more information about burning velocity dependencies and reaction rates.

The actual burning area can be related to the normalized area by an area stretching function which itself is exclusively dependent on geometry. Hence, the main task that arises is to classify the stretching functions in an analysis of the mentioned
experiments to governing geometric parameters as opening ratios of orifices, length to area ratios of the burning room and others.

\[ S f^* A_N + \frac{dV^{\text{EXP}}}{dt} = \frac{dL_F}{dt} f^* A_N \]

burning + expansion \( \rightarrow \) total displacement

**Figure 4** Burning velocity modelling

3 APPLICATION OF THE DEFLAGRATION MODEL

As indicated earlier most of the validation work with this model will be done in the near future. An example of this procedure may be the application to the reference test of the test series at Battelle-MC I01.

3.1 Description of the experiment chosen

From fig. 5 the geometry of the test room arrangement can be seen. Rooms R7 and R5 are filled by hydrogen and room R9 serves as a relief volume around them to reduce the pressure loads. The two deflagration rooms exhibit a strong bending of about 170 degrees each. Ignition point by a spark igniter is the dead end of R7. With this test no water steam was injected and the starting temperature is near the environmental. The initial hydrogen concentration in both rooms is approximately 10%.

During the test run the flame speed in the starting room was moderate in the region of up to 10 m/s. The small opening between the test rooms and the strong bending of them made the second room to become strongly turbulent premixed before the flame propagated into it as a consequence of gas expansion in the first room. Thus flame speeds five to eight times larger than in the first room could be observed. This can also be seen from a comparison of the pressure peak width (fig. 7) in the two rooms.

**Figure 5** Principal arrangement of Battelle test I01

3.2 Results

Compared to the test room arrangement at HDR at MC one finds very tall deflagration rooms with about one fourth of the flow area at the same room length. Therefore the rough wall influence on turbulence is larger and by this means produces more acceleration. In the first room (R7) immediately after ignition the burning area
resembles a sphere and increases up to the point it reaches surrounding walls. Then the flame front is approximately plane and begins to fold and to stretch but as the atmosphere in front of the flame front is nearly calm, the extent of folding is restricted. Quite different in the second room (R5). The strong area restriction at the passage from R7 to R5 establishes a jet with intensive atmospheric mixing. The burning area is behind the opening in the region of the jet suddenly much larger and decreases to some extent when nearing the end of room. In fig. 6 the input burning area multipliers for both rooms are shown. Their simple shapes are deduced from the aforementioned ideas.

In fig. 7 the measured pressure history indicates the very rapid burning process in R5 compared to R7. It is worthwhile pointing to the fact that the larger dynamic pressure rise exists in R7.

The RALOC calculation of this pressure transient can be seen from fig. 8. The different behavior of the two combustion types in the experimental rooms is reflected properly. The maximum pressures are simulated well though the peak values are reached some tenth of seconds to late.

The calculated flame speeds amount in the first room up to 20 m/s near the orifice and jump to more than 80 m/s just behind it. This also corresponds to the experimental observations if the steep temperature gradients of the thermocouples installed are related to each other. Calculated burning velocities are only one fourth of the flame velocities. This demonstrates the large influence of the gas expansion process.

4 CONCLUDING REMARKS

The presented deflagration model is a more physical approach towards the aim to provide predictable dynamic containment load simulations caused by combustion. Of course, the deduction of geometric area stretching functions that can be extrapolated will be a tough job. It is felt that it should easier to relate geometrical functions than complete reaction rates to experimental boundary conditions. First results of the model
DECOR are promising and the pool of experimental data from different test facilities will be enlarged further more.

5 REFERENCES