Development of a Simple Scheme for Prediction of Flame Acceleration and DDT

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1. Introduction

Hydrogen combustion phenomenology during severe accidents in nuclear power plants has been a safety issue. Especially, flame acceleration (FA) and Deflagration-to-Detonation Transition (DDT) are important because of their possible destructive impact on the containment or plant systems in it. Accordingly, it is the design goal to avoid FA and DDT for the hydrogen mitigation system. As a result from extensive effort dedicated to resolve the hydrogen issue, compiled information on the FA and DDT has been provided by the NEA [1]. The FA criterion was suggested in terms of the mixture expansion ratio σ, and the criterion for onset of DDT was based on the greatness of the geometrical size of the reactive system compared with the detonation cell width λ of the average mixture composition. The DDT onset criterion reflects the current state of knowledge based on the experimental database; however, the criterion is not sufficient but a necessary condition. Therefore, it should be noted that satisfying this condition means that the possibility of DDT cannot be removed.

Based on this information, a simple in-house computer program for evaluation of the FA and DDT possibility, named DEFEND (Determination of Flame Evolution and DDT), is being developed. The database for the density of combustion products analyzed by KEPCO-E&C with the CHEMKIN code [2] was used for FA estimation [3]. The correlation developed by Chan and Wojciechoski is incorporated for determination of the critical expansion ratio $\sigma_{critical}$ [4].

2. Criterion for Flame Acceleration

Previous experimental studies show that the possibility of development of fast flames on a sufficiently large scale depends mainly on the value of mixture expansion ration σ [5]. Flame acceleration is possible in mixtures with large σ under favorable conditions, while it is inefficient with small σ even under favorable conditions. Therefore, a conservative criterion for FA may be defined with a requirement of a value of mixture expansion ratio σ larger than $\sigma_{critical}$, where σ is the ratio of densities of reactants and products. For a normal initial temperature and pressure, $\sigma_{critical}$ was determined to be 3.75. It may be a function of geometrical configuration, type of fuel, and changes of Zeldovich and Lewis number with initial conditions. However, Chan's correlation [4] used for DEFEND depends on mixture composition and initial temperature.

3. Criterion for Onset of DDT

The FA process can eventually lead to DDT through shock ignition or the shock wave amplification by coherent energy release. Detailed description of the turbulent flame propagation processes is very difficult. There are many factors and conditions that lead to DDT, such as hydraulic resistance which is affected by obstacle size, initial temperature, confinement or unconfined condition and the atmospheric state. The DEFEND program adopts the 7λ-criterion for onset of DDT: $L>7\lambda$ where L is characteristic geometrical size of a room filled with combustible mixture or the size of a mixture cloud. [1]

Despite a general agreement of the $L>7\lambda$ criterion with experimental data, definitions for L is not so clear for practical applications. Thus it is necessary to determine L with reasonable judgment of geometrical characteristics such as the aspect ratio and connectivity of rooms. At the same time technical development on the DDT issue should be continuously reflected in the simulation of DDT.

4. Comparison with FANDIA and GASFLOW

For verification of the model for the critical expansion ratio, σ values for the case of lean hydrogen-air-steam mixture is compared with those used in the GASFLOW model [1]. Table 1 shows that the values are in agreement.

Table 1 Comparison of critical σ-values

Temperature (K)	This study	GASFLOW
300	3.71	3.75
400	2.79	2.80
500	2.24	2.25
650	2.18	2.10

Flame acceleration and DDT estimation for a Station Blackout Sequence at Wolsong Unit 2,3&4 [6] were compared with the FANDIA code which was developed by KEPCO-E&C, and widely used by the utility for domestic hydrogen analysis.

Gas generation and concentration distribution in the containment were analyzed with the MELCOR code. Accumulated mass of combustible gases are shown in Fig. 1 and gas composition in the upper compartment in Fig. 2.

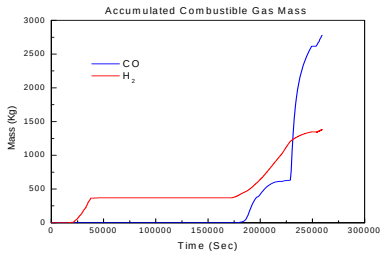

Fig. 1. Combustible gas production

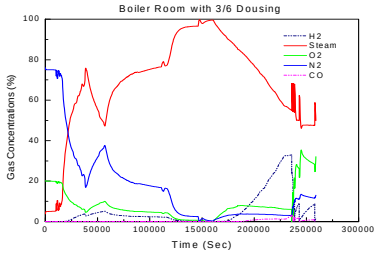

Fig. 2. Gas composition in the Boiler Room

The FA and DDT analyses with DEFEND, based on gas composition in the moderator room and the boiler room, were compared with FANDIA; the results are shown in Fig. 3 and Fig. 4. It is shown that the DDT estimation agrees well between the two analyses, while FA is quite different; since the insufficient database for expansion ratio seems to cause such a difference, the FA database for DEFEND should be greatly enlarged.

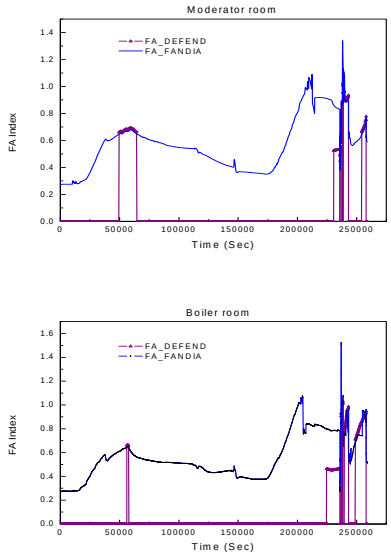

Fig. 3. FA index for moderator and boiler room

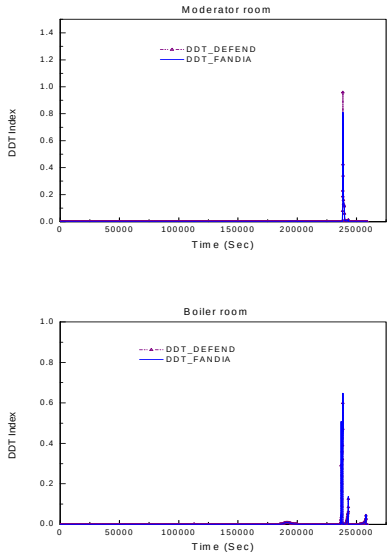

Fig. 4. DDT index for moderator and boiler room

5. Conclusion

A simple computer program, DEFEND for evaluation of the FA and DDT possibility is being developed, based on the NEA methodology and some constitutive correlation and database for FA. Comparative analyses for verification of its models using MELCOR and FANDIA show that the DDT estimation agrees well with that of FANDIA, while FA is quite different. Therefore, the FA database for DEFEND should be greatly enlarged. Technical development on the DDT issue should be continuously reflected in this program.

Acknowledgments

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