THE FLAMELET GENERATED MANIFOLD METHOD FOR THE SIMULATION OF INDUSTRIAL COMBUSTION PROCESSES

L. Romagnosi, J. E. Anker, K. Claramunt, Ch. Hirsch

NUMECA Int., Chaussée de la Hulpe/Terhulpsesteenweg 189
BE-1170 Brussels, Belgium
www.numeca.com

Introduction

The Flamelet Generated Manifold (FGM) method has reported considerable success over the last decade and has caught the attention of the combustion modelling research community for its versatility and reliability. Compared to more complex detailed chemical reaction modeling approaches, the FGM method is faster and computationally more efficient since the method allows to parameterize the thermo-chemical process by only a few variables. The method has furthermore the advantage that the CFD solver will not be faced with stiff source terms and that the turbulence-chemistry interaction can be modelled more easily.

The FGM combustion model has been implemented within NUMECA's unstructured, multi-physics multi-purpose CFD solver FINE$^{\text{TM}}$/Open and has been validated extensively on test cases ranging from elementary flames to complex industrial configurations. Satisfactory results have been achieved for all combustion regimes, ranging from purely premixed to non-premixed combustion modes, and for a variety of fuels and conditions [1]. The results for a few selected elementary flames as well as two industrial applications will be presented. A comparison with measurement data will be used as basis for discussion of the strength and weaknesses of the modeling approach. In addition, different aspects related to the table generation and the different approaches to account for heat loss will be exposed.

The Flamelet Generated Manifold method

The FGM method combines the principles of two main classes of models: premixed and non-premixed combustion models [2,3]. The mixing of fuel and oxidizer and/or variation of stoichiometry are described by solving a conserved scalar equation for the mixture fraction f, together with the progress variable transport equation c to trace the flame front and/or the reactiveness of the flow. The thermo-physical states of the mixture are then retrieved by looking-up the combustion tables with two (or more) independent quantities during the numerical simulation. To account for the turbulence effects on the flame structure, a β-PDF approach is used and an additional transport equation for mixture fraction variance g is solved. Non-adiabatic cases require a further entry in the table expressed in terms of enthalpy defect dh and a 4-dimensional look-up is needed to retrieve the thermodynamic properties and the source terms at each grid point.

Table generation and the inclusion of heat loss effects

The combustion tables are generated automatically using TabGen/Chemistry, which is NUMECA's combustion table generation tool. It is based on TU Eindhoven's 1D chemistry solver CHEM1D [4]. A series of steady and unsteady laminar flamelets are generated and remapped onto a manifold in dependence of the mixture fraction f and one, or several, progress variables c. The turbulence-chemistry interaction is modeled employing a presumed probability density function (PDF) with a β-distribution for the mixture fraction. Various methods of accounting for heat-losses are discussed [3,5] and the methods used are compared. In the current work, heat losses were included by either decreasing the sensible enthalpy (assuming frozen chemistry) or by successively lowering the inlet temperature of the streams in the generation process of the flamelets. While the method of assuming frozen chemistry has the advantage that it can account for large heat losses, the method of lowering the temperature of the streams in the table generation process leads to more physically reliable results, wherefore the authors suggest to combine the two methods (hereinafter referred to as the hybrid method).

Results

The numerical results of elementary flames, such as the Sydney/Sandia Bluff-body Stabilized flame [6] and the TU Darmstadt's Stratified burner [7], together with industrial test cases, as the IFRF glass melting furnace [8] and the Siemens cannular gas turbine combustor [9], are presented and compared against the experiments (Fig. 2,4). The FGM has shown to be robust and reliable regardless of complexity: a good agreement with measurement data was achieved for all the test cases.

In figure 1, the simulated temperature fields in the IFRF furnace of two table generation methods for heat losses are presented and the respective temperature profiles on the bottom wall compared against the experiments (Fig. 2). Figure 4 shows a comparison of the FINE$^{\text{TM}}$/Open simulation results for the axial temperature distribution in the Siemens model combustor at four different radial stations with experimental [9] and computational [10] reference data.

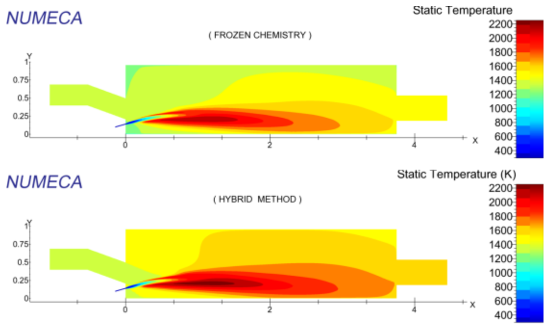

Fig. 1: Temperature distribution at the symmetry plane of the IFRF glass melting furnace using frozen chemistry (top) and the hybrid method (bottom).

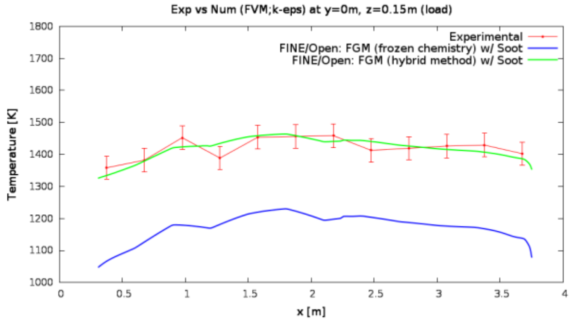

Fig. 2: Comparison of measured and simulated temperatures on the bottom wall of the furnace using frozen chemistry (blue line) and the hybrid method (green line).

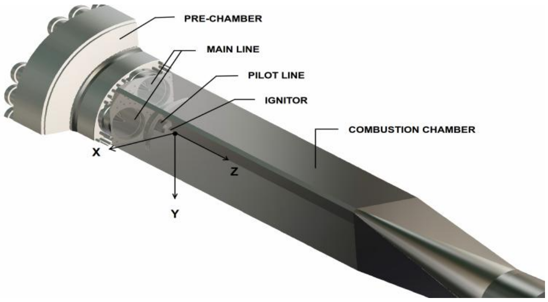

Fig. 3: 90° section of the Siemens lean premixed combustor.

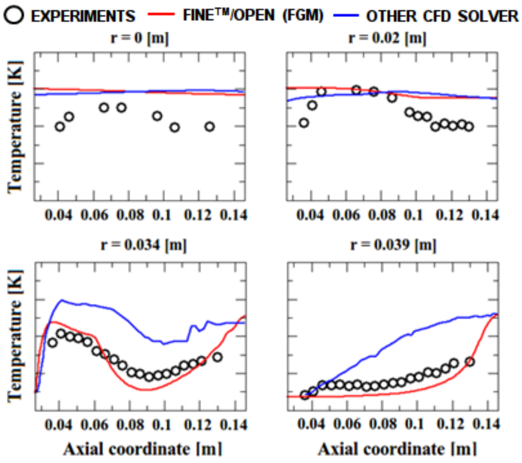

Fig. 4: Axial profile of temperature in the Siemens combustor at four radial stations.

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