Simulation of Turbulent Reactive Flow in Combustion Chamber of a Domestic Owen using ILDM Chemistry

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INTRODUCTION

Results of present research are expected to show that the pollutant production of partially-premixed flame in a domestic owen can be controlled to a large extent by turbulence so that low CO, NO_x and soot levels appear feasible by appropriately arranging mixing in the combustion chamber. A numerical study was performed to accommodate a reaction mechanism of 43 species and 393 reactions, which was reduced with Homogeneous Reaction Approach (HRA) at low temperature ranges and with Intrinsic Low Dimensional Manifolds (ILDM) technique to proceed the combustion at higher temperatures. The data base formed by the chemical kinetics was used together with a turbulence-chemistry reciprocity model in a 3D flow simulation of a real owen geometry. The Computational Fluid Dynamics – CFD – algorithm was able to calculate balance equations on a mesh with sufficient resolution. The turbulence-chemistry reciprocity will be based on the concept of the "time-layered ILDM". This model requires a time scale from a 3-D turbulent reacting flow, and is able to retrieve the corresponding local mean source values from a pre-processed data base. The main advantage of this method is to take into account non-equilibrium states of the combustion thermo-chemistry.
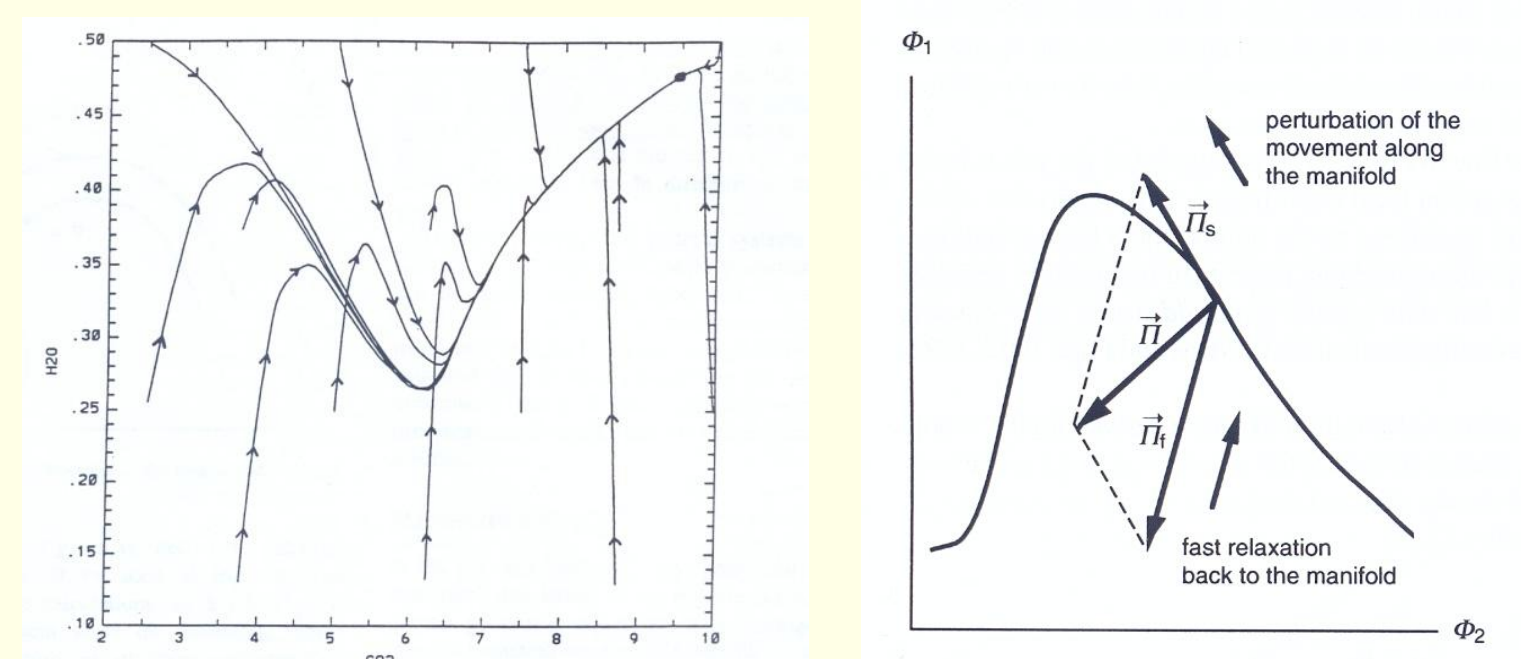
ILDM CHEMISTRY

Figure 1. Fast reactions are relaxed to manifold of slow reactions [1].

From the system dynamics perspective, a chemical process with n_s species will be governed by n_s different time scales. ILDM, in principle, tries to find out the directions in which the chemical source term vector will rapidly reach a steady-state [1]. If n_f fast processes are assumed in dynamic equilibrium, the system can be described by $n_r = n_s - n_f$ degrees of freedom by mixture fraction, pressure, enthalpy and n_r progress variables which parameterize the slow movement on the manifold. This reduces the chemical system in the composition space and the number of transport equations that need to be solved and, also, reduces the dimension of the probability density function that the reaction rate needs to be integrated over in turbulent flows.

CFD IMPLEMENTATION

For steady flow, main Eulerian equations expressing conservation of mixture mass, momentum, enthalpy have the form,

$$\frac{\partial \bar{\rho} \tilde{u}_j}{\partial x_j} = 0$$

$$\frac{\partial \bar{\rho} \tilde{u}_i \tilde{u}_j}{\partial x_j} = -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial \left(\bar{\tau}_{ji} + \tau_{T, ji} \right)}{\partial x_j} + \bar{\rho} g_i$$

$$\frac{\partial \bar{\rho} \tilde{u}_j \tilde{h}}{\partial x_j} = \tilde{u}_j \frac{\partial \bar{p}}{\partial x_j} + \mu \left(\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i} \right) \frac{\partial \tilde{u}_i}{\partial x_j} + \bar{\rho} \tilde{\varepsilon} - \frac{2}{3} \mu \frac{\partial \tilde{u}_i}{\partial x_i} \frac{\partial \tilde{u}_j}{\partial x_j}$$
$$+ \frac{\partial}{\partial x_j} \left[\left(\frac{\lambda}{C_p} + \frac{\mu_T}{Pr_{T,h}} \right) \right] \frac{\partial \tilde{h}}{\partial x_j} + \Sigma_{\alpha=1}^{n_S} \overline{\rho h_\alpha \dot{Y}_\alpha}$$

The equation for the mean mixture fraction,

$$\frac{\partial \bar{\rho} \tilde{u}_j \tilde{\xi}}{\partial x_j} = \frac{\partial}{\partial x_j} \left(\frac{\mu_T}{Sc_{T,\xi}} \frac{\partial \tilde{\xi}}{\partial x_j} \right)$$

is solved together with the equation for its variance, $\tilde{\xi}_v = \widetilde{\xi'^2}$

$$\frac{\partial \bar{\rho} \tilde{u}_j \tilde{\xi}_v}{\partial x_j} = \frac{\partial}{\partial x_j} \left(\frac{\mu_T}{Sc_{T,\xi_v}} \frac{\partial \tilde{\xi}_v}{\partial x_j} \right) + \frac{2\mu_T}{S_{T,\xi_v}} \left(\frac{\partial \tilde{\xi}}{\partial x_j} \right)^2 - 2\bar{\rho} \frac{\tilde{\varepsilon}}{\tilde{k}} \tilde{\xi}_v.$$

For reaction progress variables, α (for the present case CO_2 and H_2O), the transport is given as,

$$\frac{\partial \bar{\rho} \tilde{u}_j \tilde{Y}_\alpha}{\partial x_j} = \frac{\partial}{\partial x_j} \left(\bar{\rho} D_T \frac{\partial \tilde{Y}_\alpha}{\partial x_j} \right) + \bar{\rho} \tilde{Y}_\alpha$$

where averaged quantities are defined using four one-dimensional presumed PDFs.

The computational setup was designed to match the standart rig for efficiency tests of domestic owen burners, where an Arçelik burner was used (Figure 2).
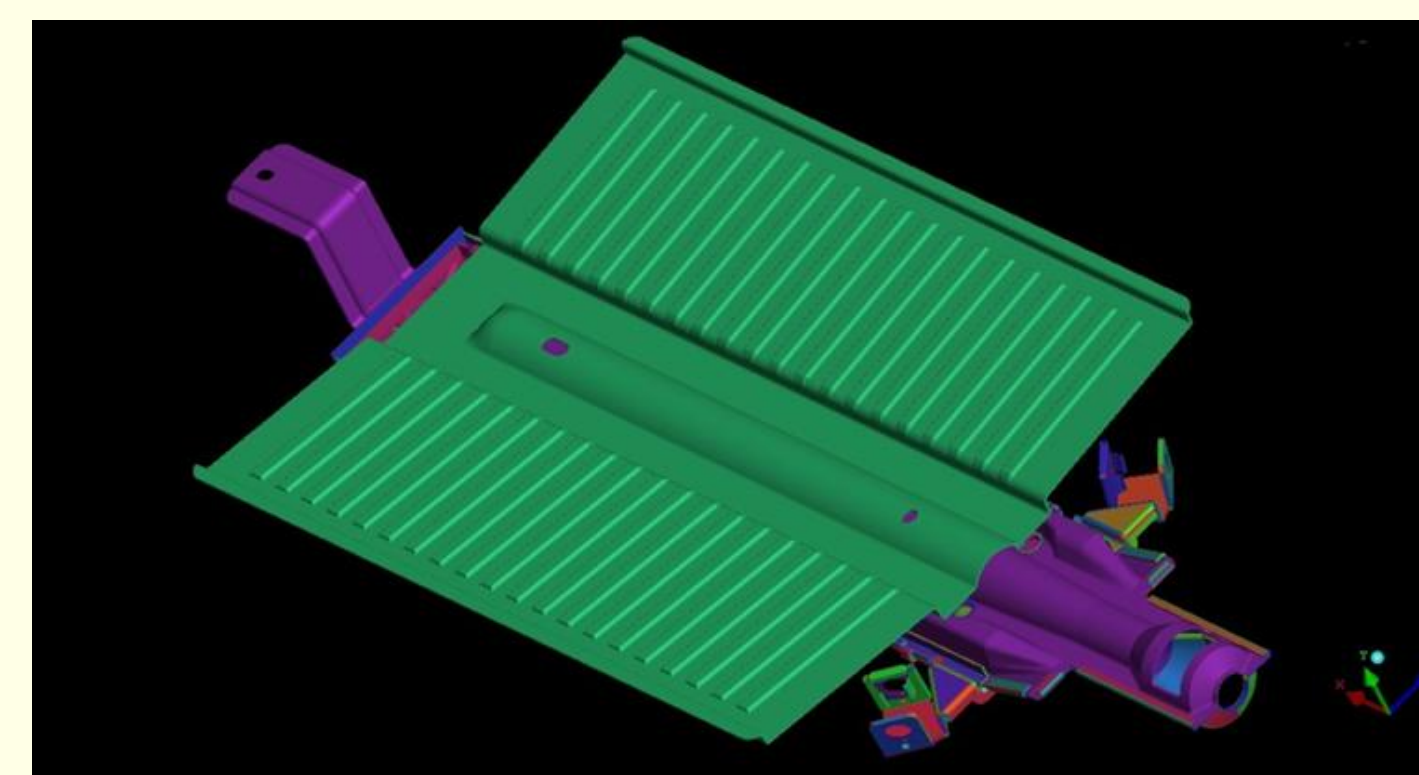

Figure 2. Arçelik owen burner.

The 3D computational domain comprised of a burner and combustion chamber shown in Figure 3, and the calculations were made with 260 lt/h fuel (methane) mass flow rate.
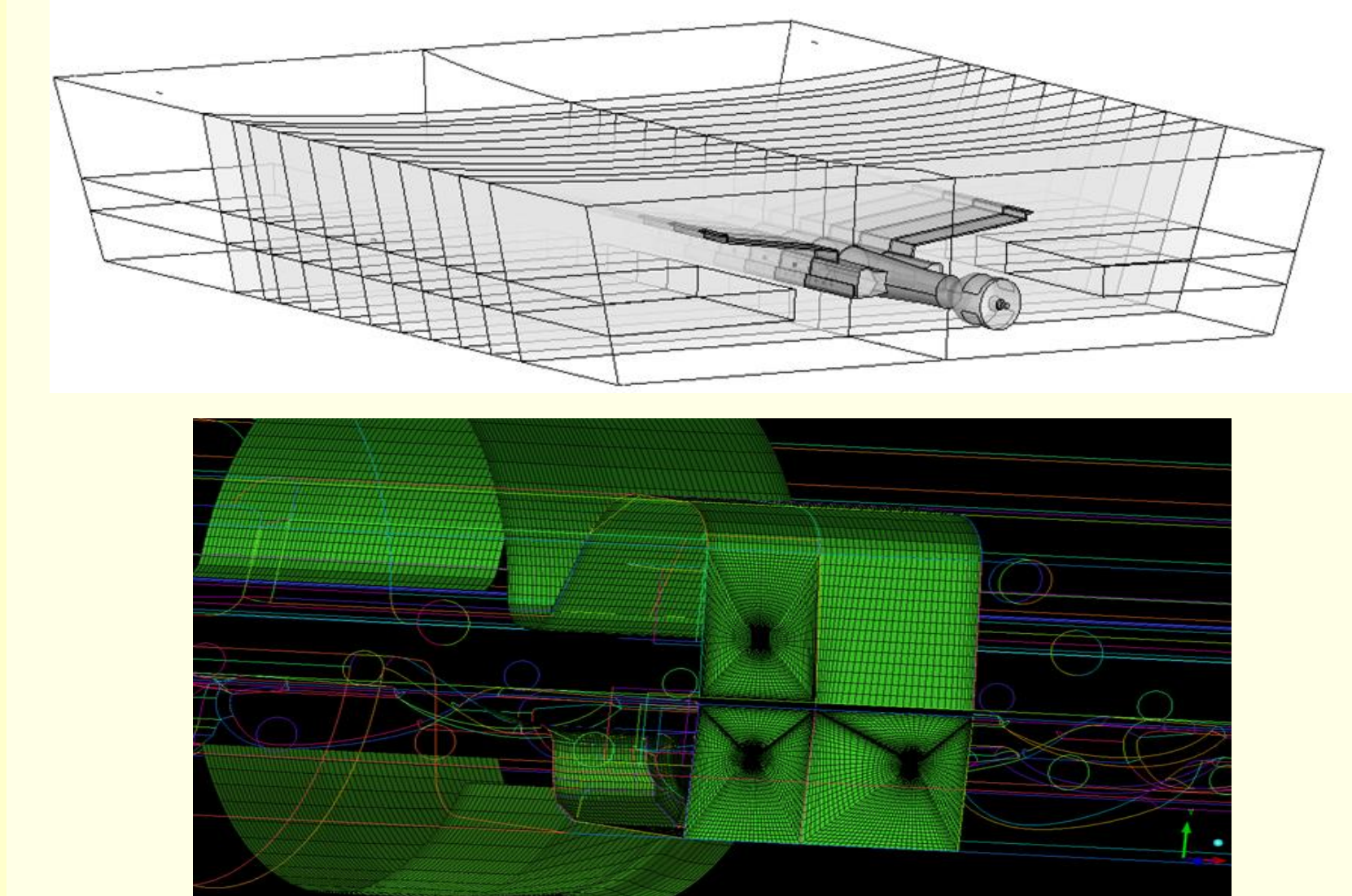

Figure 3. Mesh structure of the computational domain.

RESULTS

Temperature 20.96 460.677 600.395 740.112 879.83 1019.55 1159.26
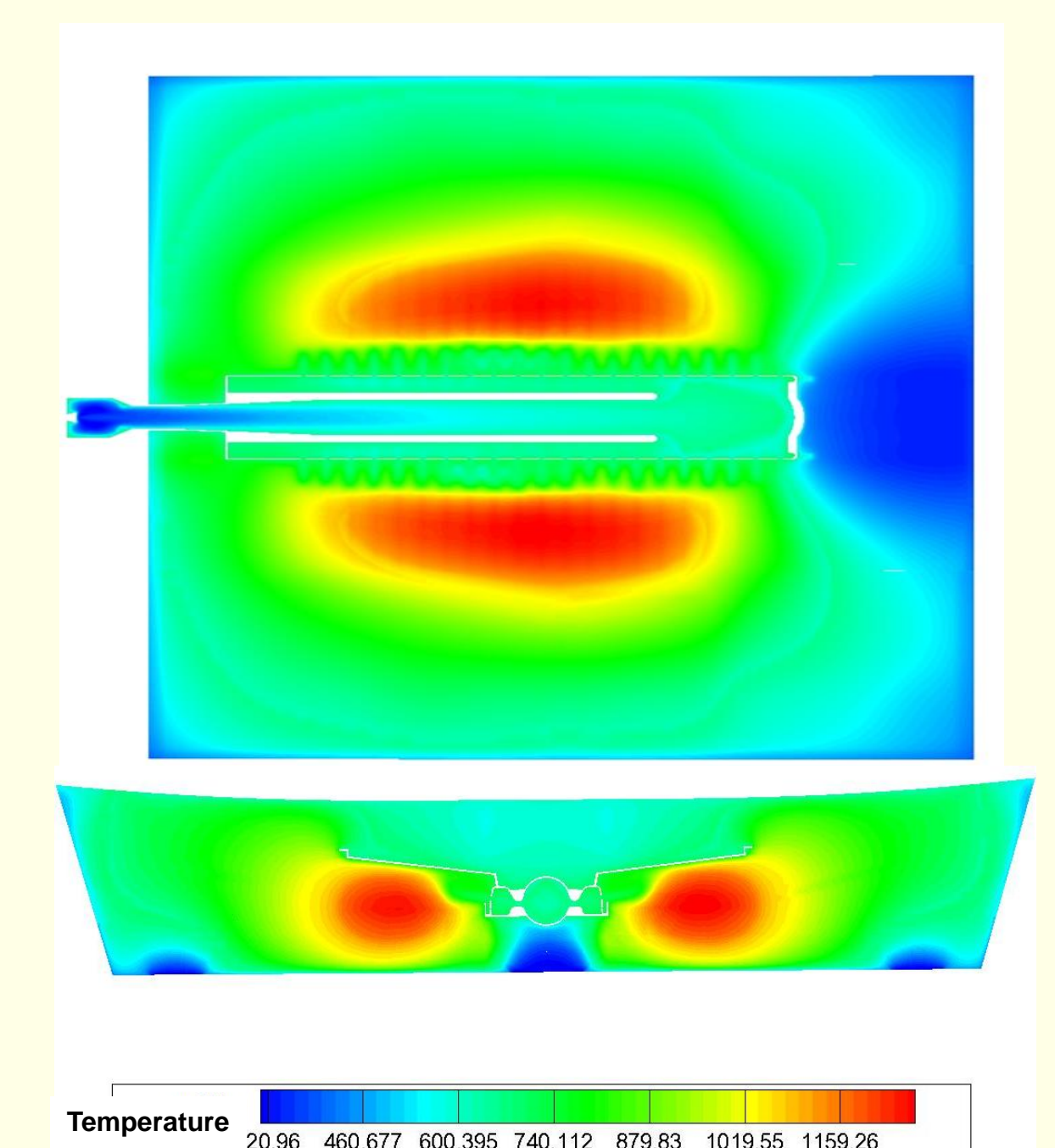
Figure 4. Temperature contours in and around the burner inside the combustion chamber.

REFERENCES

[1] U. Maas, S.B. Pope, Simplifying chemical kinetics: Intrinsic low-dimensional manifolds in composition space, Comb. Flame 88 (1992) 239-264.

ABSTRACT

Simulation of turbulent reactive flow in the combustion chamber of a domestic owen was performed. The numerical modeling included turbulence/chemistry interaction, mathematical simplification of kinetics and non-premixed reactants in three-dimensional computations, where presumed-pdf approach was combined with the ILDM technique. An Eulerian solution strategy was implemented in a CFD code on a structured mesh. The objective was to understand the generation and depletion of the pollutants, CO, NO_x and particulate matter emission from domestic owens.

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