Comparative study of RANS-EDC, LES-CSE and LES-FGM simulations of Delft jet-in-hot-coflow (DJHC) natural gas flames

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Comparative study of RANS-EDC, LES-CSE and LES-FGM simulations of Delft jet-in-hot-coflow (DJHC) natural gas flames

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We report on a comparative study of model predictions of jet-in-hot-coflow flames. The Delft Jet-in-Hot-Coflow (DJHC) burner was built to mimic the important characteristics of flameless combustion without the complications of a real furnace [1,2]. The DJHC burner has been used to create a turbulent diffusion flame of Dutch Natural Gas in a coflowing oxidizer stream of high temperature with low oxygen concentration. The experimental database contains the results of high speed chemiluminescence imaging, velocity statistics from LDA measurements and temperature statistics from CARS_measurements. In recent years several computational studies have been made using the DJHC burner as validation database [3-9]. It has been shown before that predictions are sensitive to the coflow radial profiles of temperature and oxygen concentration, to the representation of effects of entrained air, and to turbulence-chemistry interaction and this is also the focus of the present study. Table 1 gives a summary of the models used.

Table 1: Overview of submodels and boundary conditions

	RANS-EDC	RANS-CSE [8]	LES-CSE [9]	LES-FGM
Domain (mm) Axial-radial	2D 225 x 80	2D 225 x 80	3D cylindrical 225 x 80	3D Cartesian 250x43x43
Grid size (#)	27175	31250	1.5 10^6	7.5 10^6
Platform	ANSYS	OpenFOAM	OpenFOAM	In-house
Turbulence	RANS	RANS	LES	LES
Closure model	RSM	Realisable k-$\boldsymbol{\varepsilon}$	Smagorinsky	Vreman (2009)
Kinetic scheme	GRI 1.2	GRI 2.11	GRI 2.11	GRI 3.0
Reduction	DRM19	TGLDM	TGDLM	FGM: Igniting mixing layer Le=1 flamelets
Turb-chem-interaction	EDC C_τ**=3**	Multistream CSE (two mixture fractions, $\boldsymbol{\beta}$-pdf)	Multistream CSE (two mixture fractions, $\boldsymbol{\beta}$-pdf))	SGS fluctuations neglected
Scalar equations	Mean of species Mean of enthalpy	Mean and variance of two mixture fractions	Resolved mixture fractions and SGS variances Resolved enthalpy	Resolved mixture fraction and resolved progress variable Resolved enthalpy
Radiation	Not included	Not included	Optically thin. TRI not included.	Not included
Scalar BC				
Coflow mean T	From expt.	From expt.	From expt.	From expt.
Coflow Trms	Set to 0	Set to 0	Set to 0	Set to 0
Coflow O_2 mass %	Mean 7,6% Profile from expt.	Mean 7.6% Coupled to mean T	Mean 7.6% Coupled to mean T	Mean 9.5% Flat profile
Surrounding‘Air’	Air 300K	Air 300K	Air 300K	Coflow comp. at 300K

In the EDC model a model constant was changed from its default value to obtain the correct lift-off height. The CSE model [8,9] uses a double conditioned conditional source term estimation (CSE) formulation of turbulence chemistry interaction including two mixture fractions. The FGM model is based on flamelets computed using one-dimensional igniting mixing layers with constant unity Le. The progress variable is based on CO_2, H_2O and H_2. In the FGM model, the SGS-variance of mixture fraction and progress variable are obtained from algebraic equations, but this information has not been used in calculation of subgrid scale influences on resolved properties (density, resolved temperature).

Representation of the non-uniform radial profile of scalar properties at the inflow boundary is an issue for the mixture fraction based approaches. In the LES-CSE a second mixture fraction is used to represent temperature variation and oxygen variation is coupled to the same mixture fraction. In the LES-FGM temperature variation is included via the enthalpy equation and considering flamelets with heat loss at the oxidizer side. The oxygen variation is not taken into account. This simplification is based on a separate study showing that ignition delay is much more sensitive to temperature variation than to oxygen concentration variation. Figure 1 shows snapshots of scalar fields from LES-FGM. The poster presents comparisons of predicted velocity and scalar statistics, also compared to experiments, at the heights 15, 30, 60 and 90 mm above the burner exit. Figure 2 shows the good agreement obtained for mean temperature at 30 mm but for large axial distance significant differences are observed. Overall best results are obtained with the LES-CSE model of [9]. Additional results on the case studied here are presented at this meeting in the presentation by A. Vasavan and J.A. van Oijen and the poster by H. Bao et al..

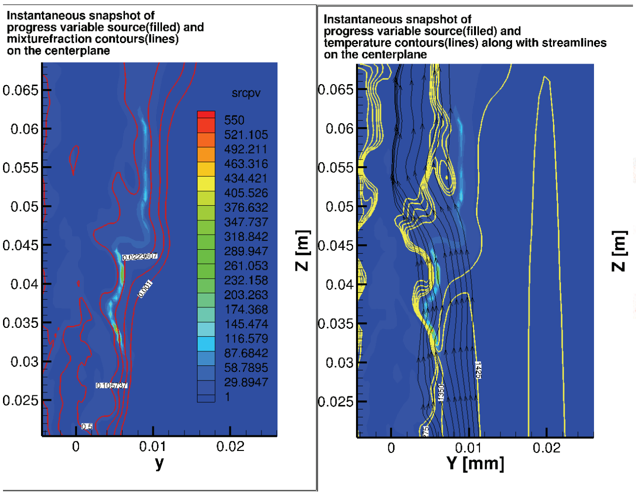

Figure 1

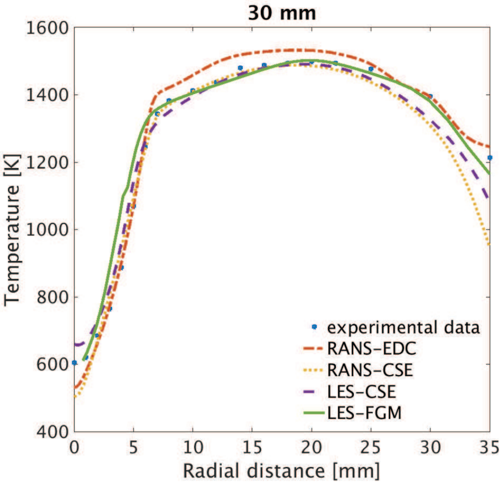

Figure 2

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