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Validation of Standard and Extended Eddy Dissipation Concept Model for the Delft Jet-in Hot Coflow (DJHC) Flame

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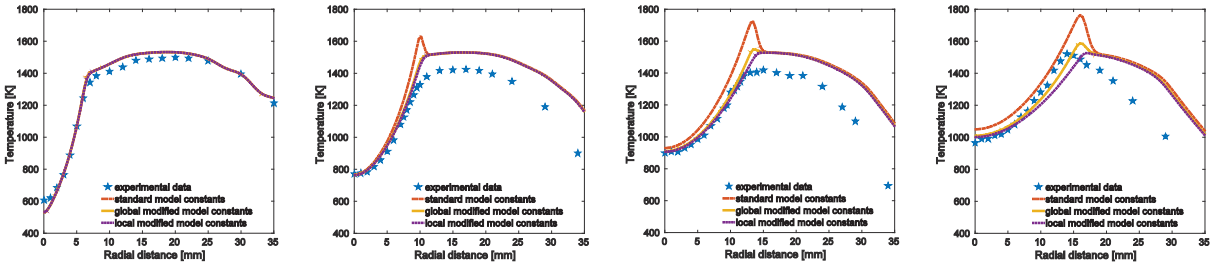
The Delft Jet-in Hot Coflow (DJHC) burner is used to investigate flameless combustion by imitating the recirculation flow characteristics appearing in a real complex furnace via a hot diluted coflow[1]. A well-defined stream of high temperature, low oxygen concentration combustion products is injected around the fuel jet as oxidizer in order to obtain 'Moderate and Intense Low-oxygen Dilution (MILD)' combustion conditions. For a range of jet and coflow conditions detailed experiments were made [2] and also several numerical validation studies, see e.g. [4,5]. The Eddy Dissipation Concept (EDC) model for turbulence chemistry interaction modeling has been widely used for modeling MILD combustion. EDC is providing a closure for the mean chemical source term based on a proposed microstructure of the reacting flow following from energy cascade concepts. It assumes that chemical reactions can only happen in the smallest eddies, whose size are of the same order of magnitude as the Kolmogorov scales, the so-called fine structures. Thus, the fraction of fine structure γ^* and mean residence time τ^* (the reciprocal of it denotes the mass exchange between reactants inside fine structure and the surrounding) are necessary for EDC simulation. They are related to turbulent kinetic energy k and eddy dissipation rate ε (which are calculated from turbulent models) via two constants C_{D1} and C_{D2}. It has been confirmed that $\varepsilon = 2C_{D1}u^{*3}/L^* = 4C_{D2}u^{*2}/3L^{*2}$.

It has been found that the standard EDC model tends to predict too early ignition and too high peak temperature for the JHC systems [3,4]. But by a global change of a model constant ('residence time scale' C_τ) from its original value 2.1377 to the value 3 too early ignition can be avoided [5-7] and better predictions were obtained. Recently, Parente et al. [8] published an extension of the EDC model containing position dependent values of model constants, depending on a turbulent Reynolds number and a Damköhler number. In standard EDC, Kolmogorov scales are used as fine structure characteristics. However, due to "distributed" reaction zone and thus reduced temperature and species gradients in MILD conditions, the relevant characteristics γ^* and τ^* can be different. In the extended EDC model the assumption of reaction zones as small scale eddies of the Kolmogorov length scale $\eta = (\nu^3/\varepsilon)^{1/4}$ is kept. But the velocity scale is replaced by the turbulent flame speed $S_T = S_L\sqrt{Re_T + 1}$, where S_L is the laminar flame speed and the Reynolds number Re_T is only related to fluid motion properties ($Re_T = k^2/\nu\varepsilon$). Defining the chemical time scale as the time needed to traverse the fine structure with the laminar flame speed S_L, a Damköhler number based on the fine structure time scale and the chemical time scale can be defined and after some derivation two adjusted fluid motion based model constants are obtained:

$$C_\tau = \frac{1}{2}\frac{1}{\sqrt{Re_T+1}Da} \quad (1)$$

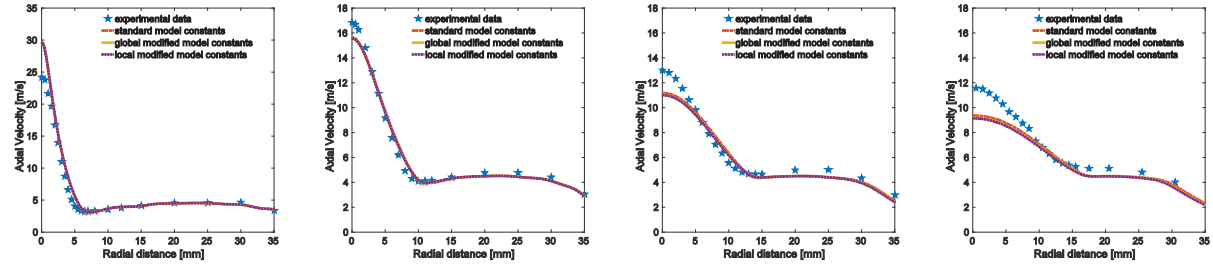
$$C_\gamma = [\frac{3}{2}(Re_T + 1)]^{1/2}Da^{3/4} \quad (2)$$

where C_τ and C_γ denote residence time constant and fine structure volume constant, respectively. Compared to Parente et al. [8] the exponent of *Da* has increased from ½ to ¾ by taking into account that the time scale needed to cross the small scale structure is not identical to the time scale needed to traverse the laminar flame thickness. In the EDC model the fine scale structures react as plug flow reactor over the Kolmogorov time and the mixing with the surroundings is controlled by the large scale turbulence time. The chemical time scale used in *Da* is derived from a one step mechanism [9]. A comparison of standard EDC, global modified EDC constants based on experimental data and extended EDC model are shown below. The new extended EDC model shows better agreement with the experimental data.



(a) Height 30 mm (b) Height 60 mm (c) Height 90 mm (d) Height 120 mm

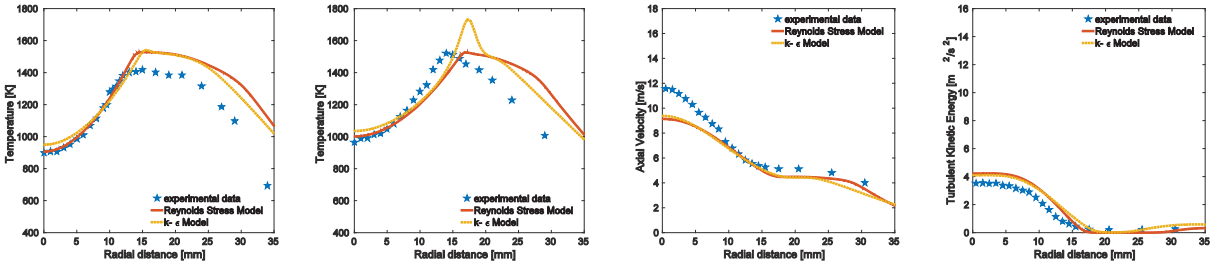
Fig. 1. Measurements and EDC model predictions of mean temperature at different heights



(a) Height 30 mm (b) Height 60 mm (c) Height 90 mm (d) Height 120 mm

Fig. 2. Measurements and EDC model predictions of mean axial velocity at different heights

The overestimation of peak temperature is reduced significantly in the case of the extended EDC model, especially for further downstream area. The temperature on the axis is also in better agreement with experiment. It should be pointed out that different EDC models do not change the fluid field a lot, which respects to the concept that fluid motion dominates the reaction zones, only standard EDC model shows slightly difference.



(a) Height 90 mm (b) Height 120 mm (c) Height 120 mm (d) Height 120 mm

Fig. 3. Turbulence model effect

The effect of turbulence model has also been investigated. It has been found that using the standard $k-\varepsilon$ model the temperature peak is more overpredicted than using the Reynolds Stress Model (RSM). The prediction of the flow field (mixing) around the momentum shear layer is sensitive to the choice of turbulence model.

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