

**THE EDDY DISSIPATION CONCEPT
A BRIDGE BETWEEN SCIENCE AND
TECHNOLOGY**

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Abstract The challenge of the mathematical modelling is to transfer basic physical knowledge into a mathematical formulation such that this knowledge can be utilized in computational simulation of practical problems.

The combustion phenomena can be subdivided into a large set of interconnected phenomena like flow, turbulence, thermodynamics, chemical kinetics, radiation, extinction, ignition etc. Combustion in one application differs from combustion in another area by the relative importance of the various phenomena. The difference in fuel, geometry and operational conditions often causes the differences.

The computer offers the opportunity to treat the individual phenomena and their interactions by models with wide operational domains. The relative magnitude of the various phenomena therefore becomes the consequence of operational conditions and geometry and need not to be specified on the basis of experience for the given problem.

In mathematical modelling of turbulent combustion, one of the big challenges is how to treat the interaction between the chemical reactions and the fluid flow i.e. the turbulence.

Different scientists adhere to different concepts like the laminar flamelet approach, the pdf approach or the Eddy Dissipation Concept. Each of these approaches offers different opportunities and problems.

The merits of the models can only be judged by their ability to reproduce physical reality and consequences of operational and geometric conditions in a combustion system.

The present paper demonstrates and discusses the development of a coherent combustion technology for energy conversion and safety based on the Eddy Dissipation Concept (EDC) by Magnussen. It includes a complete review of the concept and its physical basis. Some modifications of the concept in relation to previous publications are included and discussed. These modifications do not alter the computational results but hopefully clarifies the EDC concept to the readers.

Keywords Modelling turbulence structure – chemical kinetic interaction

INTRODUCTION

The Eddy Dissipation Concept (EDC) of Magnussen is a general concept for treating the interaction between the turbulence and the chemistry in flames which offers the opportunity to treat the turbulence-chemical kinetic interaction in a stringent conceptual way at the same time as it takes care of many of the important characteristics of the turbulence.

The EDC has been applied, without the need for changing constants, for a great variety of premixed and diffusion controlled combustion problems, both where the chemical kinetics is faster than the overall fine structure mixing as well as in cases where the chemical kinetics has a dominating influence. It is widely used for combustion modelling for a great variety of combustion environments with great success, and it is included in a number of commercially available computer codes, unfortunately, not always implemented in the conceptual best way.

The following includes some important features of the concept: it is based on the philosophy of the non-homogeneous, localized, intermittent characteristics of the dissipation, it is a reactor concept including a fine structure reactor and its surrounding where reactions may take place both in the surroundings and in the fine structures. Key factors are: mass fraction contained in the fine structures, mass transfer rate between the fine structures and the surrounding fluids, reacting fraction of the fine structures.

The connection between the fine structure behaviour and the larger scale characteristics of turbulence like the turbulence kinetic energy, k , and its dissipation rate, ϵ , is in the EDC concept based on a turbulence energy cascade model first proposed by the author in 1975 [1], further reported in [2] and several other publications, and finally extensively reviewed in [3]. The EDC has been extensively reported including ref. [4-7].

The present paper reviews the different features of the EDC and demonstrates and discusses the development of a coherent combustion technology for energy conversion and safety.

TURBULENCE

Characteristics of turbulence

Turbulent behaviour of inertial systems at every level in the space – time continuum seems to display similar characteristics, like vortex structures and structural inhomogeneities. Consequently one may conceive that the interaction between turbulence in fluid flow at different scale can be modelled by the same concept at every structural level.

This philosophy has formed the basis for the ensuing energy cascade model and the fine structure models in the Eddy Dissipation Concept.

Turbulence energy production and dissipation

In turbulent flow energy from the mean flow is transferred through the bigger eddies to the fine structures where mechanical energy is dissipated into heat. This process is schematically described in Figure 1.

In general, high Reynolds number turbulent flow will consist of a spectrum of eddies of different sizes. Mechanical energy is mainly transferred between neighbouring eddy structures as indicated in Figure 1. For the same reason the main production of turbulence kinetic energy will be created by the interaction between bigger eddies and the mean flow.

The dissipation of kinetic energy into heat, which is due to work done by molecular forces on the turbulence eddies, on the other hand mainly takes place in the smallest eddies.

Important turbulent flow characteristics can for nearly isotropic turbulence be related to a turbulence velocity, u' , and a turbulent length, L' . These quantities are linked to each other through the turbulent eddy velocity:

$$v_t = u' \cdot L' \quad (1)$$

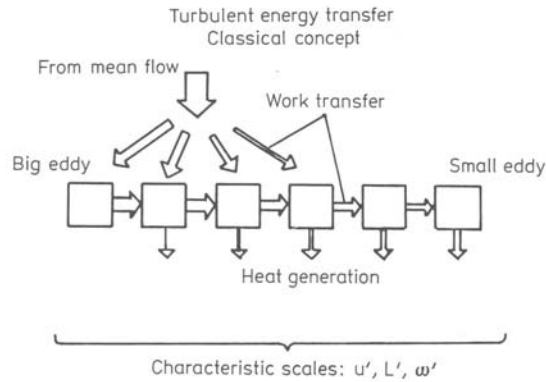


Figure 1: Turbulent energy transfer

Modelling interstructural energy transfer

The connection between the fine structure behaviour and the larger scale characteristics of turbulence like the turbulence kinetic energy, k , and its dissipation rate, ε , is in the EDC concept based on a turbulence energy cascade model first proposed by the author in 1975 [1], further reported in [2] and several other publications, and finally extensively reviewed in [3].

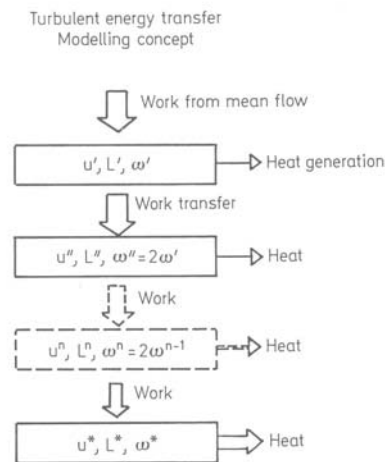


Figure 2: A modelling concept for transfer of energy from bigger to smaller turbulent structures

Figure 2 schematically illustrates the transfer of mechanical energy from bigger to smaller turbulent structures.

The first structure level represents the whole spectrum of turbulence which in an ordinary modelling way is characterized by a turbulence velocity, u' , a length scale, L' , and vorticity, or characteristic strain rate

$$\omega' = u' / L'. \quad (2)$$

The rate of dissipation can for this level be expressed by

$$\varepsilon' = \zeta^2 \left(12 \frac{u'}{L'} \cdot u'^2 + 15 \cdot \nu \left(\frac{u'}{L'} \right)^2 \right) \quad (3)$$

where ζ is a numerical constant.

The next structure level represents part of the turbulent spectrum characterized by a velocity, u'' , a length scale, L'' , and a vorticity.

$$\omega'' = 2\omega' \quad (4)$$

The transfer of energy from the first level to the second level is expressed by

$$w' = \zeta^2 12 \frac{u'}{L'} u'^2. \quad (5)$$

Similarly the transfer of energy from the second to the third level where

$$\omega''' = 2\omega'' \quad (6)$$

is expressed

$$w'' = \zeta^2 12 \frac{u''}{L''} \cdot u''^2. \quad (7)$$

The part which is directly dissipated into heat at the second level is expressed

$$q'' = \zeta^2 \cdot 15\nu \left(\frac{u''}{L''} \right)^2. \quad (8)$$

The turbulence energy balance for the second structure level is consequently given by

$$\zeta^2 12 \frac{u'}{L'} u''^2 = \zeta^2 \left(12 \frac{u''}{L''} \cdot u''^2 + 15 \cdot \nu \left(\frac{u''}{L''} \right)^2 \right). \quad (9)$$

The sequence of turbulence structure levels can be continued down to a level where all the produced turbulence kinetic energy, i.e. mechanical energy transferred from the level above, is dissipated into heat. This is the fine structure level characterized by, u^* , L^* , and ω^* .

The turbulence energy transferred to the fine structure level is expressed by

$$w^* = \zeta^2 \cdot 6 \frac{u^*}{L^*} \cdot u^{*2} \quad (10)$$

and the dissipation into heat by

$$q^* = \zeta^2 \cdot 15\nu \left(\frac{u^*}{L^*} \right)^2. \quad (11)$$

According to this model nearly no dissipation of energy into heat takes place at the highest structure level. Similarly it can be shown that $\frac{3}{4}$ of the dissipation takes place at the fine structure level.

Taking this into account, and by introducing $\zeta=0.18$ the following three equations are obtained for the dissipation of turbulence kinetic energy for nearly isotropic turbulence:

$$\varepsilon = 0.2 \frac{u'^3}{L'} \quad (12)$$

$$\varepsilon = 0.267 \frac{u^{*3}}{L^*} \quad (13)$$

$$\varepsilon = 0.67 \nu \left(\frac{u^*}{L^*} \right)^2. \quad (14)$$

Introducing the Taylor microscale a fourth equation is obtained

$$\varepsilon = 15 \nu \left(\frac{u'}{\lambda} \right)^2. \quad (15)$$

By combination of Equations (13) and (14) the following characteristics (scales) for the fine structures are obtained

$$u^* = 1.75 (\varepsilon \cdot \nu)^{1/4} \quad (16)$$

$$L^* = 1.43 \nu^{3/4} / \varepsilon^{1/4} \quad (17)$$

and the Reynolds number

$$\text{Re}^* = \frac{u^* \cdot L^*}{\nu} = 2.5$$

where u^* is the mass average fine structure velocity. The scales are closely related to the Kolmogorov scales.

In a detailed review and analysis of the cascade model by Ertesvåg and Magnussen [3] the cascade model was compared to experimental data and models found in the literature. It was shown to be in accordance with Kolmogorov's model for the energy spectrum of the inertial subrange, the 5/3 law. Moreover, it was found to be in close resemblance with the, however, relatively sparse, data and models for the viscous dissipation range.

MODELLING THE FINE STRUCTURES AND THE INTERSTRUCTURAL MIXING

The fine structures

The tendency towards strong dissipation intermittency in high Reynolds number turbulence was discovered by Batchelor and Townsend [14], and then studied from two points of view: different statistical models for the cascade of energy starting from a hypothesis of local invariance, or

selfsimilarities between motions of different scales, and then by consideration of hydrodynamic vorticity production due to the stretching of vortex lines.

It can be concluded that the smallscale structures who are responsible for the main part of the dissipation are generated in a very localised fashion. It is assumed that these structures consist typically of large thin vortex sheets, ribbons of vorticity or vortex tubes of random extension folded or tangled in the flow, as schematically illustrated in Figure 3.

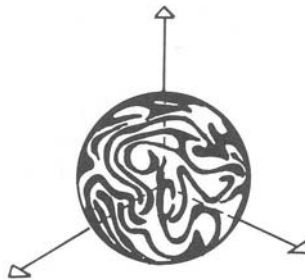


Figure 3: Schematic illustration of fine structures developed on a constant energy surface

These small structures are localised in certain fine structure regions whose linear dimensions are considerably larger than the fine structures therein [11]. These regions appear in the highly strained regions between the bigger eddies.

The reaction space

Chemical reactions take place when reactants are mixed at molecular scale at sufficiently high temperature [2]. It is known that the microscale processes which are decisive for the molecular mixing as well as dissipation of turbulence energy into heat are severely intermittent i.e. concentrated in isolated regions whose entire volume is only a small fraction of the volume of the fluid.

These regions are occupied by fine structures whose characteristic dimensions are of the same magnitude as Kolmogorov microscales or smaller [8-13].

The fine structures are responsible for the dissipation of turbulence energy into heat as well as for the molecular mixing. The fine structure regions thus create the reaction space for non-uniformly distributed reactants, as well as for homogeneously mixed reactants in turbulent flow.

The non-homogeneity of the reaction space has been demonstrated in a number of laser-sheet fluorescence measurements.

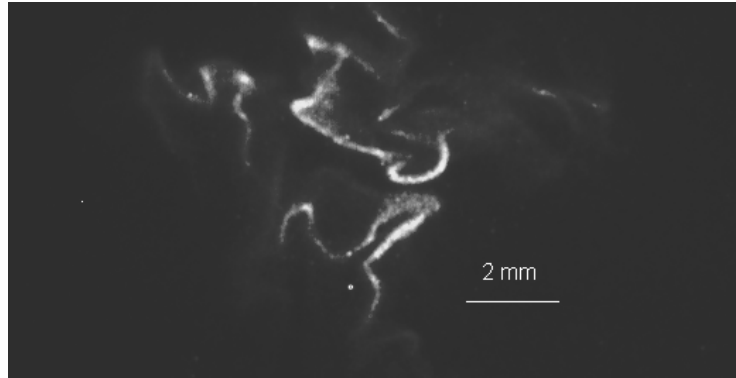


Figure 4: Reacting structures of a premixed acetylene flame created by two opposing jets, Magnussen, P. [15]

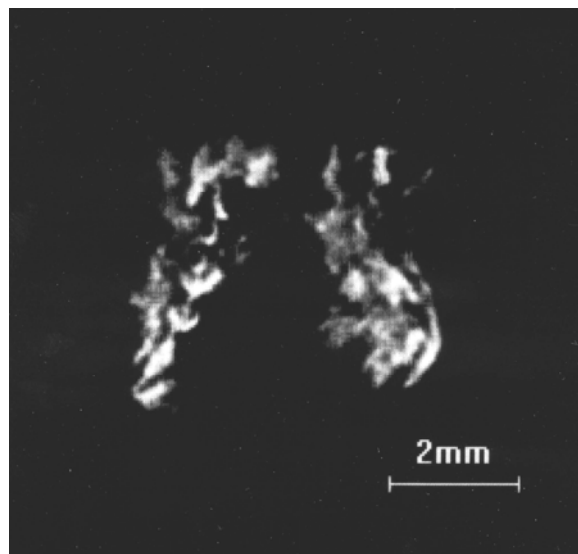


Figure 5: Reacting fine structure in a lifted turbulent diffusion flame, showing a thin vortex structure surrounded by two vortex rings, Tichy, F. E. [16]

Modelling characteristics of the fine structures

An important assumption in the EDC is that most of the reactions occur in the smallest scales of the turbulence, the fine structures. When fast chemistry is assumed, the state in the fine structure regions is taken as equilibrium, or at a prescribed state. In the detailed chemistry calculations, the fine structure regions are treated as well-stirred reactors.

In order to be able to treat the reactions within this space, it is necessary to know the reaction mass fraction and the mass transfer rate between the fine structure regions and the surrounding fluid.

It is assumed that the mass fraction occupied by the fine structure regions can be expressed by

$$\gamma^* = \left(\frac{u^*}{u'} \right)^2 \quad (18)$$

This is based on the conception that the fine structures are localized in nearly constant energy regions where the turbulence kinetic energy can be characterized by u'^2 .

This implies that the dissipation into heat is non homogeneous and for the major part taking place in the fine structure regions ($\varepsilon^* \sim \tilde{\varepsilon} / \gamma^*$).

We can consequently characterize the internal fine structures by velocity and length scales

$$u^{**} = u^* / \gamma^{*1/4} \quad (19)$$

and

$$L^{**} = L^* \cdot \gamma^{*1/4} \quad (20)$$

giving

$$\text{Re}^{**} = 2.5$$

Assuming nearly isotropic turbulence and introducing the turbulence kinetic energy and its rate of dissipation the following expression is obtained for the mass fraction occupied by the fine structure region.

$$\gamma^* = 4.6 \cdot \left(\frac{\nu \cdot \varepsilon}{k^2} \right)^{1/2} \quad (21)$$

On the basis of simple geometrical considerations the transfer of mass per unit of fluid and unit of time between the fine structures and the surrounding fluid can be expressed

$$\dot{m} = 2 \cdot \frac{u^*}{L^*} \cdot \gamma^* \quad [1/s] \quad (22)$$

Expressed by k and ε for nearly isotopic turbulence eq. (22) turns into

$$\dot{m} = 11.2 \cdot \frac{\varepsilon}{k} \quad [1/s] \quad (23)$$

The mass transfer per unit of mass of the fine structure region may consequently be expressed as

$$\dot{m}^* = 2 \cdot \frac{u^*}{L^*} \quad [1/s] \quad (24)$$

or expressed in terms of ε and ν as

$$\dot{m}^* = 2.45 (\varepsilon / \nu)^{1/2} \quad [1/s] \quad (25)$$

A fine structure regions residence time may also be expressed as

$$\tau^* = \frac{1}{\dot{m}^*} = 0.41 (\nu / \varepsilon)^{1/2} \quad [s] \quad (26)$$

The internal mixing timescale for the fine structure regions may be characterized by

$$\tau^{**} = \tau^* \cdot \gamma^{*1/2} = \frac{L^*}{2u'} \quad (27)$$

The mass transfer rate between the surrounding fluid and the fine structures within the fine regions is consequently

$$\dot{m}^{**} = \frac{1}{\tau^{**}} \cdot \gamma^{**} \quad (28)$$

γ^{**} , the mass fraction of the fine structure region contained in the fine structures, can be expressed as

$$\gamma^{**} = \left(\frac{u^{**}}{u'} \right)^2 = \gamma^{*1/2} \quad (29)$$

Thus the internal mass transfer rate

$$\dot{m}^{**} = \frac{1}{\tau^*} = \dot{m}^* \quad (30)$$

Modelling the molecular mixing processes

The rate of molecular mixing is determined by the rate of mass transfer between the fine structure regions and the surrounding fluid.

The various species are assumed to be homogeneously mixed within the fine structure regions.

The mean net mass transfer rate, \bar{R}_i , between a certain fraction, χ of the fine structure regions and the rest of the fluid, can for a certain specie, i , be expressed as follows:

$$\bar{R}_i = \bar{\rho} \cdot \dot{m} \cdot \chi \left(\frac{c_i^o}{\rho^o} - \frac{c_i^*}{\rho^*} \right) \quad [\text{kg/m}^3/\text{s}] \quad (31)$$

where * and ^o refer to conditions in the fine structure regions and the surrounding.

The mass transfer rate can also be expressed per unit volume of the fine structure fraction, χ , as

$$R_i^* = \rho^* \cdot \dot{m}^* \cdot \left(\frac{c_i^o}{\rho^o} - \frac{c_i^*}{\rho^*} \right) \quad [\text{kg/m}^3/\text{s}] \quad (32)$$

Finally, the concentration of a specie, i , in the fraction, χ , of the fine structure regions, and in the surrounding is related to the mean concentration by:

$$\frac{\bar{c}_i}{\bar{\rho}} = \frac{c_i^*}{\rho^*} \cdot \gamma^* \cdot \chi + \frac{c_i^o}{\rho^o} \cdot (1 - \gamma^* \cdot \chi) \quad (33)$$

By substitution from eq. (33) into eq. (31) one can express the mass transfer rate between a certain fraction, χ , of the fine structure regions and the surrounding fluid as

$$\bar{R}_i = \frac{\bar{\rho} \cdot \dot{m} \chi}{1 - \gamma^* \cdot \chi} \left(\frac{\bar{c}_i}{\bar{\rho}} - \frac{c_i^*}{\rho^*} \right) \quad [\text{kg/m}^3/\text{s}] \quad (34)$$

and consequently per unit volume of the fraction, χ , of the fine structure regions as

$$R_i^* = \frac{\rho^* \cdot \dot{m}^*}{1 - \gamma^* \cdot \chi} \left(\frac{\bar{c}_i}{\bar{\rho}} - \frac{c_i^*}{\rho^*} \right) \quad [\text{kg/m}^3/\text{s}] \quad (35)$$

MODELLING THE TURBULENCE CHEMICAL KINETIC INTERACTION

The reaction processes

The net mean transfer rate of a certain species, i , from the surrounding fluid into the fine structure regions equals the mean consumption rate of the same specie within the fine structures.

On the basis of the assumption of the fine structure reactor being homogeneously mixed, the net consumption rate of a specie, i , is determined by the reaction rate within the fine structure regions, taking into consideration all relevant species and their chemical interaction and the local conditions, including the temperature, within the reactor. Thus in addition to solving the necessary equations for the chemistry one has to solve an additional equation for the energy balance as follows:

$$q^* = \frac{\rho^* \cdot \dot{m}^*}{1 - \gamma^* \cdot \chi} \cdot \sum_1^N \left(\frac{\bar{c}_i}{\bar{\rho}} \cdot \bar{h}_i - \frac{c_i^*}{\rho^*} \cdot h_i^* \right) \quad (36)$$

where h_i , and h_i^* are the total enthalpies for each specie, and q^* the net energy being stored in the reacting fine structure regions or transferred from the fine structure regions to the surroundings by other mechanisms like radiation.

The reacting structures

When treating reactions, χ designates the reacting fraction of the fine structure regions. Only the fraction, χ , which is sufficiently heated will react. Several approaches may be applied to quantify the fraction, χ , which certainly is dependent on whether ignited or not.

The following rather simple approach has been applied with considerable success.

The fraction of the fine structure regions which may react can be assumed proportional to the ratio between the local concentration of reacted fuel and the total quantity of fuel that might react.

This leads to the following expression for χ :

$$\chi = \frac{\tilde{c}_{pr} / (1 + r_{fu})}{\tilde{c}_{\min} + \tilde{c}_{pr} / (1 + r_{fu})} \quad (37)$$

\tilde{c}_{pr} is the local mean concentration of reaction products, \tilde{c}_{\min} , the smallest of \tilde{c}_{fu} and \tilde{c}_{o_2}/r_{fu} , and r_{fu} the stoichiometric oxygen requirement.

Equation (37) gives a probability of reaction that is symmetric around the stoichiometric value.

The EDC and detailed chemical kinetics

According to the EDC the preceding gives the necessary quantitative format for full chemical kinetic treatment of the reacting fine structure regions in turbulent premixed and diffusion flames. The method can readily be extended to treatment of reactions also in the surrounding fluid, which may be necessary for the treatment of for instance NO_x formation especially in premixed flames.

The mean reaction rate can in this case be expressed as

$$\frac{\bar{R}_i}{\bar{\rho}} = \gamma^* \cdot \chi \frac{R_i^*}{\rho^*} + (1 - \gamma^* \cdot \chi) \frac{R_i^o}{\rho^o} \quad (38)$$

where R_i^o is the reaction rate in the surrounding fluid.

It is always important to bear in mind where the participating species are mixed on a molecular scale. For the fast, thermal, reactions the reaction space will certainly be within the fine structure regions. For some slow reactions the reaction space may extend to outside the fine structure regions. This is especially the case for the post-flame region of premixed flames where the temperatures of the surrounding fluid may approach the temperatures in the fine structure regions.

The fast chemistry limit

In a great number of combustion cases, the infinite fast chemistry limit treatment of the reactions is sufficient. This can be done by prescribing the burnt conditions of the part-taking major species and look for the limiting major component.

Let us assume that one of the major components, oxygen or fuel will be completely consumed in the fine structure reactor, the eqs. (34) and (35) will transform into

$$\tilde{R}_{fu} = \frac{\tilde{\rho} \cdot \dot{m} \cdot \chi}{1 - \gamma^* \cdot \chi} \cdot \tilde{c}_{\min} \quad [\text{kg/m}^3/\text{s}] \quad (39)$$

$$\tilde{R}_{fu}^* = \frac{\rho^* \cdot \dot{m}^*}{1 - \gamma^* \cdot \chi} \cdot \tilde{c}_{\min} \quad [\text{kg/m}^3/\text{s}] \quad (40)$$

where \tilde{c}_{\min} is the smallest of \tilde{c}_{fu} and \tilde{c}_{02}/r_{fu} , and \tilde{R}_{fu} the consumption rate of fuel.

The temperature of the reacting fine structure regions and the surrounding fluid may be expressed as

$$T^* = T + \frac{\bar{c}_{\min} \cdot \Delta H_R}{\bar{\rho} \cdot c_p} - \frac{q^*(1 - \gamma^* \cdot \chi)}{\rho^* \cdot c_p \cdot \dot{m}^*} \quad (41)$$

and

$$T^o = T - \frac{\bar{c}_{\min} \cdot \Delta H_R}{\bar{\rho} \cdot c_p} \frac{\gamma^* \cdot \chi}{1 - \gamma^* \cdot \chi} + \frac{q^* \cdot \gamma^* \cdot \chi}{\rho^* \cdot c_p \cdot \dot{m}^*} \quad (42)$$

where, ΔH_R is the heat of reaction (kJ/kg fuel) and c_p the local specific heat (kJ/kg/K).

One interesting approach to avoid detailed chemical kinetic treatment, is to precalculate equilibrium concentrations of major species as a function of mixture fraction and temperature, and assume that these values are reached in the fine structure reactor.

When the fast chemistry approach is applied, extinction timescales, τ_{ext} , must be precalculated on the basis of detailed chemical kinetics, and taken into consideration in the computations. Extinction occurs when $\tau^* < \tau_{ext}$.

Discussions

- In earlier versions of the EDC the mass fraction of the fine structure was defined by

$$\gamma_{fs}^* = \left(\frac{u^*}{u'} \right)^3 \quad (43)$$

and the fine structure region by

$$\gamma_\lambda = \frac{u^*}{u'} \quad (44)$$

The reaction rate was expressed proportional to

$$R \sim \gamma_{fs}^* \cdot \chi$$

with

$$\chi = \frac{1}{\gamma_\lambda} \cdot \frac{\tilde{c}_{pr} / (1 + r_{fu})}{\tilde{c}_{\min} + \tilde{c}_{pr} / (1 + r_{fu})} \quad (45)$$

The implication of the first term in χ

$$\chi \sim \frac{1}{\gamma_\lambda}$$

was to take into consideration that the reaction space could extend to a wider space than γ_{fs}^* given by eq. (43).

This is in the present version taken care of by the new definition of γ^* , essentially a new definition of the fine structure region, which equals $\gamma_{fs}^* / \gamma_\lambda$.

Finally the mass fraction of the total fluid mass according to eq. (29) contained in the fine structures

$$\gamma_{fine\ structures} = \gamma^{**} \cdot \gamma^* \quad (46)$$

where

$$\gamma^{**} = \gamma^{*1/2}$$

thus giving

$$\gamma_{fine\ structures} = \gamma^{*3/4} = \left(\frac{u^*}{u'} \right)^3 \quad (47)$$

is in fact the same as in the original version of the EDC.

- The mass fraction of the fine structure regions γ^* eq. (18) can be expressed by the Taylor Reynolds number $Re_\lambda = u' \lambda / \nu$ as

$$\gamma^* = 11.9 \cdot Re_\lambda^{-1} \quad (48)$$

This is consistent with the functional relationship proposed by Tennekes [11].

If we utilize the relationship between the flatness factor and intermittency factor proposed by Batchelor and Taylor [14]

$$F = 3 / \gamma \quad (49)$$

we arrive at

$$F^* = 0.25 \cdot \text{Re}_\lambda \quad (50)$$

The relationship between the intermittency factor and the flatness factor is, however, uncertain. A best fit to experimental data for flatness factor and the intermittency factor of Wygnanski and Fiedler [17] gives the following empiric relationship

$$F = 3 / \gamma^{2/3} \quad (51)$$

If γ^* according to eq. (48) is introduced into eq. (51) we arrive at

$$F^* = 0.58 \cdot \text{Re}_\lambda^{2/3} \quad (52)$$

This is functionally in accordance with the findings of Kuo and Corrsin [12].

- The development of the fine structure regions is a purely hydrodynamic process as expressed by γ^* . The fine structures within the fine structure regions are similarly developed, as expressed by γ^{**} .

These internal structures have a formation and a dissipation timescale as expressed by eq. (27) which means that it may be substantially smaller than the Kolmogorov timescale. This means that the mixing rate within the fine structure regions are much faster than the exchange rate between the fine structure regions and the surrounding fluid. This is the basis for the treatment of the fine structure regions as well stirred reactors.

The internal mixing between different species inside the reactor may be influenced by differential molecular diffusivities of various species. However, for Schmidt numbers smaller than the order of unity such diffusivities will enhance the internal mixing. These diffusivities do not influence the exchange rate between the fine structure regions and the surrounding fluid.

COMPUTATIONS

Comparison with experimental data

Figure 6 gives an example of comparison between experimental data from a bluff-body stabilized flame and calculations based on the EDC [18, 19, 20]. Fast refers to fast chemistry limit eqs. (39) and (40). Detail 1, refers to computations based on the EDC with detailed chemical kinetics. Detail 2 is equal to detail 1, but with $\chi=1$.

As can be seen, the correlation is excellent.

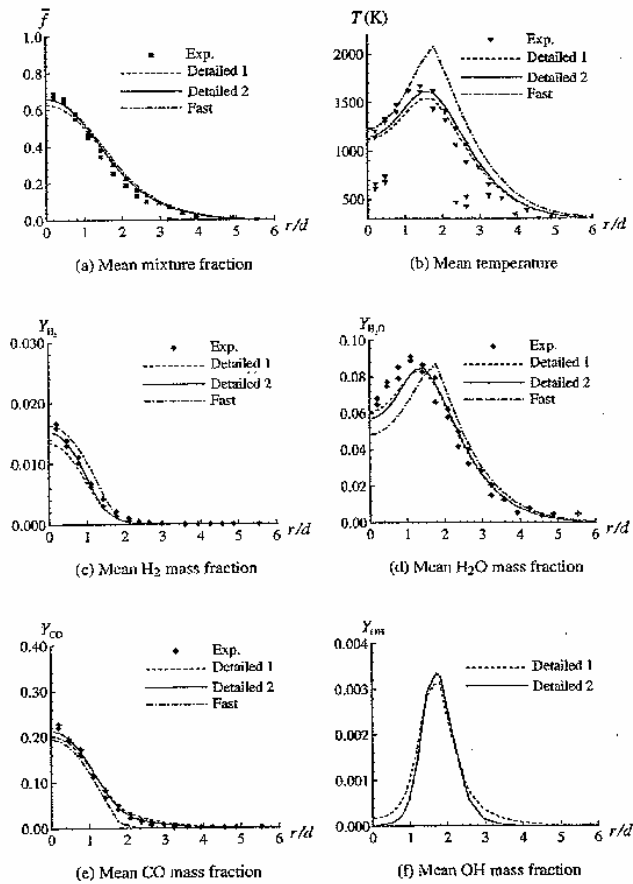


Figure 6: Radial profiles of mixture fraction, temperature and H_2 , H_2O , CO and OH mass fractions at axial position $x/d = 20$. Comparison of predicted results based on EDC with detailed and fast chemistry and a Reynolds stress model.

Practical computations

When performing practical computations it is always a question about the level of complexity to justify the needed accuracy.

This opens for several options in the computations of reactive systems like

- infinite fast chemistry to equilibrium
- separation of fast and slow reactions
- tabular chemistry
- full chemistry

A practical computation involves a lot of variables like turbulence characteristics, energy or enthalpy, chemical species, soot, radiation, droplets etc.

It is essential that these variables, except for the turbulence characteristics, are treated rigidly according to the EDC in order to have a consistent solution and not a problem adjusted result.

An example is the treatment of radiation which is dependent on the correlation between species concentrations and temperatures. This means that both the fine structure region values and the surrounding fluid values must be taken into consideration.

In addition we have to take into consideration complexities of geometries and operational conditions. Examples of such computations will be shown in the presentation and can be made available contacting the author. Additionally confer ref. [21-32]

CONCLUSION

The preceding has presented the most updated version of the EDC of Magnussen. It may be concluded that this concept offers the opportunity to include chemistry at various complication levels, in a straight forward way and there is no need for problem dependent adjustments of any constant according to the concept.

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