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EXAM IN SUBJECT TEP4170 HEAT AND COMBUSTION TECHNOLOGY
(Varme- og forbrenningsteknikk)
7 June 2019 Time: 0900 – 1300

The exam is only available in English. The answers can be written in Norwegian or English.

Permitted aids: D – No printed or handwritten aids. Certain simple calculator.

- Please do not use red pencil/pen, as this is reserved for the censors.
- Read through the problems first. Begin with the problem where you feel that you have the best insight. If possible, do not leave any problems blank. Formulate clearly, it pays off!
- Some information is given at the end.

Problems:

1)
The species mass balance equation on "transport" form can be written as

$$\frac{\partial}{\partial t}(\rho Y_k)+\frac{\partial}{\partial x_j}(\rho Y_k u_j)=\frac{\partial}{\partial x_j}\left(D\frac{\partial Y_k}{\partial x_j}\right)+R_k$$

--Introduce Reynolds' decomposition and develop the equation for the mean species mass. For simplicity, you can assume that denisity and molecular transport properties do not fluctuate.

--Explain the meaning of each term of the resulting equation, and of the new quantities that appear.

2)
--Explain what is a conserved scalar.
--Formulate two examples of conserved scalars, and demonstrate that these are conserved scalars.

--Define the mixture fraction.

3)
Assume that methane reacts with air in a non-premixed, one-step, irreversible and infinitely fast reaction.
--Express the mass fractions of fuel (methane), air and product as functions of the mixture fraction.

Data, molar mass (kg/kmol): CH_4: 16; O_2: 32; N_2: 28; air: 28.8
Air can be assumed as 21% O_2, 79% N_2 molar based or 23.3% O_2, 76.7% N_2 mass based.
The stoichiometric air requirement of methane is 17.2 kg/kg.

4)
The source term of the resulting equation of Problem 1 is a challenge for computational modeling.
-- Describe a model that avoids the expression of this source term.
-- What are the conditions and limitations of this model?

5)
The source term of the resulting equation of Problem 1 was expressed by Magnussen and Hjertager (1976) in the simple "Eddy Dissipation Model"

-- Formulate the source term according to this model. Define all quantities involved and describe how each quantity is determined. (For sake of order: if a quantity is determined from an equation, just say so – you need not put up the equation.)
-- What are the limitations of this model.

6)
In a certain region of a flow, the expression

$$\frac{d\bar{u}_1}{dx_2} = \frac{u_\tau}{\kappa x_2}$$

is assumed to be valid.

--Which region is this, and what do the symbols of the expression denote?

--For this region, develop expressions for the turbulence energy dissipation rate (ε), the turbulence energy (k) and the turbulence viscosity (ν_t). Specify additional assumptions when necessary and define the symbols used.

7)
For the region of Problem 6, develop a similar expression for the dimensionless temperature.

8)
Consider the following mechanism for ozone reactions:

$$O_3 \underset{k_{1r}}{\overset{k_{1f}}{\rightleftarrows}} O_2 + O$$

$$O + O_3 \underset{k_{2r}}{\overset{k_{2f}}{\rightleftarrows}} 2O_2$$

--What are the reaction orders of these reactions (notice: all individual reactions)?
--Express the consumption rates of the three species, (i.e. the quantities $d[\mathrm{O}_3]/dt$ etc.) based on this mechanism.

You can apply a steady state approximation for one of the species in the mechanism
--Which one, and why?
--Express the concentration of this species based on the steady-state approximation.

9)
The exhaust of a gasoline car engine contains 3.5% CO (molar based, "wet"). The fuel-air mixture is stoichiometric. The fuel can be approximated as octane (C_8H_{18}), and air can be assumed as 21% O_2 and 79% N_2 (molar based).

--Determine the amount substance (mol) of emitted CO per mole of fuel burned.
--Determine the emission index of CO.
--Determine the fraction of fuel lower heating value lost with heating value of CO.

Data:
CO: heating value for: 283 kJ/mol, molar mass: 28 kg/kmol
C_8H_{18}: lower heating value 5075 kJ/mol, molar mass: 114 kg/kmol

10)
A well stirred (aka. "perfectly stirred", steady state) reactor has inlet conditions Y_k^o, T^o , which can be assumed known, outlet conditions Y_k^*, T^* , and residence time τ^*.

--Describe (mathematically and graphically) the conditions for possible outlet states.
--Which states are stable and which are not?

For the discussion, you can assume that the chemistry is described by a one finite-rate global reaction.