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EXAM IN TEP4170 HEAT AND COMBUSTION TECHNOLOGY
(Varme- og forbrenningsteknikk)
19 May 2023 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)
"Oxy-combustion" is a technology used to capture CO_2 from combustion. Fuel is burned with pure oxygen (not air). To reduce the temperature to a feasible level, CO_2, water vapour or water (liquid) is added (this is usually the role of nitrogen and surplus air).

Methane CH_4 is burned with stoichiometric oxygen together with 7 mol H_2O per mol methane. Assume a simple, global and complete reaction. The products are all in gas phase.

- Put up the reaction balance.
- Determine the composition of the product mixture (mole fractions).

The flow of products is cooled to 40 °C at constant pressure 1 bar, and some water is condensed and removed.

- How much water is condensed (mol liquid H_2O per mol methane burned).

Data: the saturation pressure of water at 40 °C is 0.0738 bar.

2)
The species mass balance equation on "transport" form can be written as

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

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

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

3)
Oxidation of “syngas” (a mixture of CO, H_2 and CO_2) is assumed described by the following set of reactions

$$CO + \tfrac{1}{2}O_2 \rightleftarrows CO_2 \quad (1)$$
$$H_2 + \tfrac{1}{2}O_2 \rightleftarrows H_2O \quad (2)$$

For this problem, all other reactions can be neglected. The forward rate coefficients $k_{1f}(T)$ and $k_{2f}(T)$ can be assumed as known as functions of temperature and a set of parameters (*A,b,E*) for each forward reaction. In principle, another set of parameters can be specified for each of the reverse rate coefficients $k_{1r}(T)$ and $k_{2r}(T)$, as well. However, this is (usually) not done.

-Explain how the reverse rate coefficients $k_{1r}(T)$ and $k_{2r}(T)$ can be determined, and why can this simplification be made.

-Express the reaction rate for O_2 based on this mechanism.

-Describe how to determine a time scale for Reaction (1).

4)
A quantity is known as the “three-dimensional energy spectrum”, $E(\kappa)$. Make a sketch of $E(\kappa)$. What is κ? What characterizes high values of κ, and low values of κ?

A range of the spectrum is called “dissipative”, and Kolmogorov proposed quantities known as “Kolmogorov microscales” for length, velocity and time.

-Explain the basis for these quantities.
-Express the scales for length, velocity and time.

5)
- Define the mixture fraction (Norw: “blandingsfraksjon”).
- Determine the stoichiometric mixture fraction for CO burning with (pure) O_2.

For CO (as fuel) and O2 (as oxidizer): The mixture fraction has the value 0.2, and no fuel has reacted (i.e. pure mixing): - What is the mass fraction of CO? Explain.

Data, molar masses (kg/kmol): CO: 28, O_2: 32, CO_2: 44

6)
Premixed flames: -What is the laminar flame speed and how could you measure it using a Bunsen burner?

7)
- Briefly explain what are turbulence-chemistry interactions: what is their physical meaning and what is the core problem of turbulence-chemistry interaction closure from the mathematical perspective?
- Describe the idea of presumed-PDF method for turbulent non-premixed combustion modelling,

8)
-What is the main assumption behind the Eddy Dissipation Concept (EDC), which is shared with Eddy Dissipation Model?
- Briefly describe what is a cascade model and why do we need it?
- How is the mean reaction rate formulated in EDC? Provide expression and explain each term.

9)
- Describe what nitrogen oxides (NOx) are and what are their main formation paths.
- For which conditions are each formation path (or “mechanism”) more important.

10)
- The main component of particulate matter is soot. What are the main formation and destruction steps of soot? Describe the soot formation in a diffusion flame.