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EXAM IN SUBJECT TEP4170 HEAT AND COMBUSTION TECHNOLOGY
(Varme- og forbrenningsteknikk)
15 May 2015 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)
For an engine running on fuel oil (approximated as $C_{12}H_{26}$), the NOx emissions are measured as 200 ppm (parts per million) at 3% O_2 in "wet" flue gas. The air can be assumed as 21% O_2 and 79% N_2 mole based.

--The regulations are specified for emissions at 15% O_2 in "dry" flue gas. Recalculate the measured emissions to these conditions.

Hint: 200 ppm is a relatively small fraction.

2)
For the engine of Problem 1, the overall efficiency based on LHV is 25%. The combustion can be assumed complete. In this problem NOx can be assumed as NO.

--Determine the mass specific emissions (mass flow of emissions per power produced) of CO_2 and NO.

3)
-- Define the mixture fraction (Norw: blandingsfraksjon).

Assume infinitely fast and complete reaction of $C_{12}H_{26}$ with air. Air is assumed as 21% O_2 and 79% N_2 mole based.

--Determine the mixture fraction of a stoichiometric mixture of of $C_{12}H_{26}$ and air.
--Express the fuel and oxygen mass fractions as functions of the mixture fraction.

4)
For a well stirred reactor (WSR, also known as perfectly stirred reactor, PSR),
--sketch the reactor with system boundary (control surfaces) and in/outflows
--put up the mass balance (continuity), species mass balance and energy balance for the reactor. Define all symbols/quantities used and give units of measurement.

--What are the simplifications made in these equations for the WSR compared with the general partial differential equations ("transport equations").

5)
The following set of reactions is an excerpt of a larger chemical mechanism:

1 $\mathrm{O + O + M \rightarrow O_2 + M}$

2 $\mathrm{O + H + M \rightarrow OH + M}$

…

31 $\mathrm{O_2 + CO \rightarrow O + CO_2}$

...

The forward and reverse (backward) reaction rate coefficients, k_f and k_r, can be assumed known for each reaction.

--Express the reaction rate of O (monatomic oxygen) based on these three reactions.

6)
In the chemical mechanism of Problem 5, the forward reaction rate coefficients are determined from constants given in the mechanism, and are assumed known (i.e. already determined) here. The reverse reaction rate coefficients are determined from the corresponding equilibrium constant.

--Show the relation between the reaction rate coefficients and the equilibrium constant.

--Express the reverse reaction rate coefficient of reaction No.1 above, k_{r1}, from the concentrations ([O], etc.) and the forward coefficient, k_{f1}.

7)
The "exact" equation for the turbulence energy can be written as

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho k\bar{u}_j)=\frac{\partial}{\partial x_j}\left(\mu\frac{\partial k}{\partial x_j}\right)+\frac{\partial}{\partial x_j}\left(-\tfrac{1}{2}\rho\overline{u_i'u_i'u_j'}-\overline{p'u_j'}\right)-\rho\overline{u_i'u_j'}\frac{\partial\bar{u}_i}{\partial x_j}-\mu\overline{\frac{\partial u_i'}{\partial x_j}\frac{\partial u_i'}{\partial x_j}}$$

--The equation is used in a turbulence model. Which terms have to be modeled and which can be retained? Explain why.

--Formulate the three last terms of the equation
a) for a one-equation model.
b) for the k-ε model.
In both a) and b) the turbulence viscosity can be regarded known, and in b) also the ε can be regarded known. Other quantities introduced should be defined/explained.

8)
-- Define isotropic turbulence.

--Put up the equations of the k - ε model for isotropic turbulence (appropriately simplified).

--When these equations are solved (i.e. k and ε determined and, hence,"known") for isotropic turbulence, express the Reynolds stresses (all), $-\overline{u_i'u_j'}$.

9)
--Make a sketch of a graph with the turbulence energy spectrum, $E(\kappa)$, and the dissipation spectrum, $D(\kappa)$. Place the length scales ℓ_e and η, in the graph.

-- How do k and ε relate (mathematically) to the graph?

10)
Develop and express mathematically the Kolmogorov length, velocity and time scales.

<u>Information:</u>

Molar masses (kg/kmol), $C_{12}H_{26}$: 170.3; O_2: 32.0, N_2:28.0, NO: 30.0

Lower heating value, $C_{12}H_{26}$: 44.1 MJ/kg