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EXAM IN SUBJECT TEP4170 HEAT AND COMBUSTION TECHNOLOGY
(Varme- og forbrenningsteknikk)
21 May 2012 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!

NOTE: The decimal sign is comma.

Problems:

1)
--Explain what is meant by "global" reactions and "elementary" reactions.
--What is meant by "unimolar" , "bimolar" and "trimolar" in this context?
--What is meant by "reaction order" (in this context)? What distinguishes global and elementary reactions in this respect?

2)
Given the following set of three reaction pairs

$$\mathrm{H} + \mathrm{O}_2 \xrightarrow{k_{1f}} \mathrm{OH} + \mathrm{O}$$
$$\mathrm{OH} + \mathrm{O} \xrightarrow{k_{1r}} \mathrm{H} + \mathrm{O}_2$$
$$\mathrm{O} + \mathrm{H}_2 \xrightarrow{k_{2f}} \mathrm{OH} + \mathrm{H}$$
$$\mathrm{OH} + \mathrm{H} \xrightarrow{k_{2r}} \mathrm{O} + \mathrm{H}_2$$
$$\mathrm{OH} + \mathrm{H}_2 \xrightarrow{k_{3f}} \mathrm{H}_2\mathrm{O} + \mathrm{H}$$
$$\mathrm{H}_2\mathrm{O} + \mathrm{H} \xrightarrow{k_{3r}} \mathrm{OH} + \mathrm{H}_2$$

--Each pair can be assumed to be in equilibrium (Norw: "jamvekt"). Express the molar concentration of the radical species O, H and OH in terms of the kinetic rate coefficients (Norw: "reaksjonskoeffisientar") and the molar concentrations of H_2, O_2 and H_2O.
--What are the conditions for the assumption that the three pairs of reactions are in equilibrium, and when will this be satisfied?

3)
-- Define isotropic turbulence.
--The turbulence equations can be simplified for isotropic turbulence. Put up the equations for turbulence energy (k) and its dissipation rate (ε).
--Will k and ε increase or decrease? Explain!
--Put up expressions for all the Reynolds stresses (turbulence stresses), $-\rho\overline{u_i'u_j'}$, for isotropic turbulence, assuming that k and ε are known.

4)
-- Describe the principle for determining the flammability limits (Norw:"flammegrenser").
-- How are flammability limits specified? (i.e. in which form are the values given)

5)
The axes of the Borgi diagaram are a length-scale ratio (horizontal axis) and a velocity-scale ratio (vertical axis).
--Sketch the Borghi diagram.
--Include lines for the turbulence Reynolds number, for the Damköhler number, and for the small-scale Damköhler number (i.e. based on the Kolmogorov microscales).
--Define the quantities used.

6)
-- Identify different regimes of non-premixed flames in the Borghi diagram.
-- Locate a (conventional) wood stove, a (conventional, non-premixed) gas turbine, a large furnace/boiler, and a large open-air fire in the sketched diagram. Explain the locations.

7)
In a part of the boundary layer, the following approximate relation is found: $\frac{\partial \overline{u}_1}{\partial x_2} = \frac{u_\tau}{\kappa x_2}$
Use this expression, and (if required) other approximations/assumptions to develop wall functions (Norw: "vegglover") for the non-dimensional velocity and for the dissipation rate of turbulence energy.

8)
The transport equation for the variance of the mixture fraction (Norw.: "blandingsfraksjon"), ξ, can be written (assuming constant density) as

$$\frac{\partial}{\partial t}(\rho\overline{\xi'^2}) + \frac{\partial}{\partial x_j}(\rho\overline{\xi'^2}\overline{u}_j) = \frac{\partial}{\partial x_j}\left(D\frac{\partial\overline{\xi'^2}}{\partial x_j} - \rho\overline{\xi'^2 u'_j} \right) - 2\rho\overline{\xi' u'_j}\frac{\partial\overline{\xi}}{\partial x_j} - 2D\overline{\frac{\partial\xi'}{\partial x_j}\frac{\partial\xi'}{\partial x_j}}$$

--Write the transport equation for the instantaneous mixture fraction, on which the equation above is based.
-- Show the development of the variance equation above (the principle, all terms of all intermediate equations are not required).

9)
Air is flowing in a straight duct (channel) with a square cross-section. The width of the duct is 0,1 m, and the volumetric flow is 0,1 m^3/s. The viscosity can be assumed at ν =1,5 ·10^{-5} m^2/s.

--Verify that this flow is turbulent, and estimate values for the turbulence energy, k, the dissipation rate of turbulence energy, ε, the Kolmogorov length scale, η, and the turbulence Reynolds number.

10)
Sketch a mass-time diagram appearing from a thermo-gravimetric analysis (TGA) of a biomass fuel sample. Describe the stages seen in the diagram.