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EXAM IN SUBJECT TEP4170 HEAT AND COMBUSTION TECHNOLOGY
(Varme- og forbrenningsteknikk)
5 June 2018 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)
--What are the differences between "global" and "elementary" reactions?
--What are "reaction orders" of a reaction?

--When a forward reaction rate coefficient is known for an elementary reaction, how can the reverse (backward) reaction rate coefficient be found?

2)
The Zeldovich mechanism for formation of NO from N_2 and O_2 can be described by

$$N_2 + O \underset{k_{1b}}{\overset{k_{1f}}{\rightleftarrows}} NO + N$$

$$N + O_2 \underset{k_{2b}}{\overset{k_{2f}}{\rightleftarrows}} NO + O$$

Make the following assumptions:
-backward reactions are slow
-monatomic nitrogen, N, is in steady state
-monatomic oxygen, O, is in equilibrium with O_2

Justify the assumptions and formulate a global reaction mechanism $N_2 + O_2 \xrightarrow{k_G} 2NO$ with the reaction rate

$$\frac{d[NO]}{dt} = k_G [N_2]^m [O_2]^n$$

That is, determine an expression for k_G, and determine m and n.

3)
What is the "flame surface" (aka. "stoichiometric contour") of a diffusion flame or non-premixed flame?

For a laminar fuel jet flame into quiet air, sketch the flame surface. Include the fuel nozzle in the sketch.
For the same flame, make sketches of radial profiles at the axial positions at the nozzle outlet (x=0), the flame tip ($x=L_f$) and halfway from nozzle to flame tip ($x=L_f/2$) of
-- mass fractions of fuel, oxidizer, and reaction products
-- temperature and mass fractions of soot

4)
Natural gas (here simplified to methane, CH_4) is burned with air in a gas turbine.
During testing, the following mole fractions ("wet") are measured in the exhaust gas:
CO_2: 0.037; H_2O: 0.074; O_2: 0.127; NO: 10 ppm; CO: 10 ppm.
Unburned hydrocarbons can be neglected.

--Calculate the NO emission index.

The relevant regulations specify the allowed NO emissions at 15% O_2 ("wet").
--Calculate the corrected NO emissions according to these regulations.

-What is the purpose of correcting the concentrations to a specific O_2 level in the exhaust gas when reporting emissions from combustion processes?

Air can be assumed as 21% O_2, 79% N_2, molar based.
Molar masses (kg/kmol): CH_4:16, CO: 28; CO_2: 44; H_2O: 18; O_2: 32; N_2: 28; NO: 30.

5)
--Formulate the general gradient model for turbulence diffusion of scalar quantities.
--What is the rationale for using the same model for different scalar quantities.

6)
--Define the energy spectrum of turbulence, $E(\kappa)$
--Make a sketch of this function.
--How does the turbulence energy, k, relate to the energy spectrum?

--When the turbulence Reynolds number decreases, how does the energy spectrum change? (sketch and explain)

7)
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 (show the principles; it is not required to show all terms of all intermediate equations).

(Hint: there are some similarities with the equation for turbulence energy, *k*)

8)
In the prescribed probability density function models, the mean and variance of the mixture fraction are resolved from “transport” equations.
A probability density function (pdf), $f(\xi)$, can be assumed as known as

$$f(\xi)=\frac{\xi^{a-1}(1-\xi)^{b-1}}{B(a,b)}, \quad \text{where } B(a,b)=\int_0^1 x^{a-1}(1-x)^{b-1}dx$$

--Demonstrate the operations to determine the parameters *a* and *b*.
--How can the mean and the variance of temperature be determined in this model.

9)
--Describe the cascade model of Magnussen’s Eddy Dissipation Concept (EDC).
--What is the purpose or motivation of this model?

10)
-- Describe the reactor model of Magnussen’s Eddy Dissipation Concept (EDC).
-- How does this model link to the cascade model?