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EXAM IN SUBJECT TEP4170
HEAT AND COMBUSTION TECHNOLOGY
(Varme- og forbrenningsteknikk)
9 August 2010 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)
--Write the transport equation for a species (mass fraction, Y_k) for a 2-dimensional, turbulent boundary layer along a wall (the wall is normal to the x_2 direction; the main flow is in the x_1 direction).

-- Explain the approximations you did here .

2)
In the equation in Problem 1, there is a term containing the quantity $-\rho\overline{Y_k' u_2'}$.
-- Make use of Prandtl's mixing length model (Norw: blandingsvegmodell) to develop a model for this quantity.
-- If you, for some reason, have an (other) model for the turbulence viscosity: How can the quantity above be modeled? Explain.

3)
-- Show that the relation $u_1^+ = \frac{1}{\kappa}\ln x_2^+ + C$ is valid for a region of a boundary layer along a wall (the x_1 and x_2 directions as in Problem1).

4)
For the region where the expression given in Problem 3 is valid:
-- Develop an expression for Prandtl's mixing length (Norw: blandingsveg).
-- Develop an expression for the dissipation (dissipation rate of turbulence energy, ε).

5)
The Borghi diagram is a two-dimensional presentation of different "regimes" of combustion. The axes are the logarithms of u'/u_L (vertical) and l'/δ_L (horizontal).
The diagram have lines for the Reynolds number $\mathrm{Re}_{l'} = u'l'/\upsilon$ and the Damköhler numbers $Da = \theta/\tau_c$ and $Da_K = \tau/\tau_c$.
-- Define/explain the mentioned quantities and sketch the Borghi diagram with the lines mentioned.

6)
Explain the differences between premixed and non-premixed flames (key words: form, outlook, physical/chemical processes, analysis, pollution/emissions, etc.)

7)
Put up the conceptual reaction balances for unimolecular (single-), bimolecular (two-) and termolecular (three-) reactions. Describe/discuss these with respect to important characteristica such as reaction order.

8)
In a counterflow non-premixed (diffusion) flame, the oxidizer (air) and fuel (pure methane) are supplied through axisymmetric nozzles.

- Sketch the nozzles, the flow, and the flame.
- Sketch the profiles of temperature and mole fractions of CH_4, H_2, CO, CO_2, H_2O O_2 and N_2 along the axis of the nozzles.

9)
HCCI or homogeneous charge compression ignition engines is a new type of engine concept. -- Describe the HCCI concept in comparison with the Diesel and Otto (gasoline) engine concepts.

10)
A gas mixture contains 90% methane and 10% ethane on a molar base. It burns with 250% theoretical air ($\lambda = 2{,}5$), and the combustion is virtually complete. There is, however, a small amount of NO in the exhaust, measured to 15 ppm (mole fraction $15 \cdot 10^{-6}$) on a “dry” basis. The combustion takes place in a gas turbine with thermal efficiency of 40%.

- Determine the emission index for NO, EI_{NO}, in this case.
- Determine the mass specific emission for NO, $(MSE)_{NO}$, in this case

Air can be assumed as 21% O_2 and 79% N_2.
Molar masses (kg/kmol): CH_4: 16; C_2H_6: 30; CO_2: 44; H_2O: 18; N_2: 28; O_2: 30, NO: 30.
Lower heating values (MJ/kmol): CH_4: 802; C_2H_6: 1429.

11)
--What are the 4 global surface (heterogeneous) reactions within the reacting boundary layer of a carbon particle burning in air?
-- What is the main difference between the film model and shrinking-core model for carbon combustion?

12)
Consider a spherical solid fuel particle burning in an oxygen stream with a constant size mode. On doubling the particle size from R to $2R$, the time for complete conversion (τ) triples. Given Table 25.1 (next page) and assumed that film diffusion does not give any resistance, what is the contribution (%) of ash diffusion to the overall resistance for particles of size R?

Table 25.1 Conversion-Time Expressions for Various Shapes of Particles, Shrinking-Core Model

		Film Diffusion Controls	Ash Diffusion Controls	Reaction Controls
Constant Size Particles	**Flat plate** $X_B = 1 - \frac{1}{L}$ L = half thickness	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B L}{b k_g C_{Ag}}$	$\frac{t}{\tau} = X_B^2$ $\tau = \frac{\rho_B L^2}{2b \mathscr{D}_e C_{Ag}}$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B L}{b k'' C_{Ag}}$
	Cylinder $X_B = 1 - \left(\frac{r_c}{R}\right)^2$	$\frac{t}{\tau} = X_B$ $\tau = \frac{\rho_B R}{2b k_g C_{Ag}}$	$\frac{t}{\tau} = X_B + (1 - X_B)\ln(1 - X_B)$ $\tau = \frac{\rho_B R^2}{4b \mathscr{D}_e C_{Ag}}$	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/2}$ $\tau = \frac{\rho_B R}{b k'' C_{Ag}}$
	Sphere $X_B = 1 - \left(\frac{r_c}{R}\right)^3$	$\frac{t}{\tau} = X_B$ **(11)** $\tau = \frac{\rho_B R}{3b k_g C_{Ag}}$ **(10)**	$\frac{t}{\tau} = 1 - 3(1 - X_B)^{2/3} + 2(1 - X_B)$ **(18)** $\tau = \frac{\rho_B R^2}{6b \mathscr{D}_e C_{Ag}}$ **(17)**	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/3}$ **(23)** $\tau = \frac{\rho_B R}{b k'' C_{Ag}}$ **(22)**
Shrinking Sphere	**Small particle** Stokes regime	$\frac{t}{\tau} = 1 - (1 - X_B)^{2/3}$ **(30)** $\tau = \frac{\rho_B R_0^2}{2b \mathscr{D} C_{Ag}}$ **(29)**	Not applicable	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/3}$ $\tau = \frac{\rho_B R_0}{b k'' C_{Ag}}$
	Large particle (u = constant)	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/2}$ **(31)** $\tau = (\text{const})\frac{R_0^{3/2}}{C_{Ag}}$	Not applicable	$\frac{t}{\tau} = 1 - (1 - X_B)^{1/3}$ $\tau = \frac{\rho_B R}{b k'' C_{Ag}}$

Table 25.1 from Levenspiel