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EXAM IN SUBJECT TEP4170 HEAT AND COMBUSTION TECHNOLOGY
(Varme- og forbrenningsteknikk)
18 May 2013 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!

Problems:

1)
In the k - ε model ("standard", constant density), the modeled equation for turbulence energy can be written as

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho k\bar{u}_j)=\frac{\partial}{\partial x_j}\left(\mu\frac{\partial k}{\partial x_j}\right)+\frac{\partial}{\partial x_j}\left((\frac{\mu_t}{\sigma_k})\frac{\partial k}{\partial x_j}\right)-\rho\overline{u_i'u_j'}\frac{\partial\bar{u}_i}{\partial x_j}-\rho\varepsilon$$

-- Show how the "exact" (not modeled) equation is developed.
(You should demonstrate the the principle, not every detail for all terms.)

In the equation displayed above, some terms are modelled.
-- Which terms are modelled, and which are retained from the "exact" equation?

2)
-- How is the ε equation modeled (in the "standard" k - ε model)?
(hint: similarities with the k equation)

3)
A gas flow has a bulk velocity of U=10 m/s and a width of 1 m. The kinematic viscosity of the gas is 10^{-5} m^2/s.
--Verify that the flow is turbulent and estimate the turbulence energy (k), its dissipation rate (ε) and the Kolmogorov length scale (η).
--What can be the physical (or technical) significance of the quantity η / U ?

4)
Reactions occur in a flow like the one in Problem 3, and the relevant reactions have time scales from 10^{-6} s to 10^{-2} s.
--Estimate the maximum timestep of a numerical simulation with full resolution (no modelling) of the reacting flow?

5)
--Make a sketch of the 3-dimensional (3D) energy spectrum *E* as a function of the wave number κ. Mark the following ranges of scales in the sketch: “dissipative range”, “energy containing range”, “equilibrium range”, “inertial (sub-)range”.

6)
In the “inertial subrange”, the energy spectrum can be expressed as a function of the dissipation rate and the wave number. --Explain why.
--Put up (or develop) the expression for the energy spectrum in this range according to Kolmogorov’s theory.

7)
-- Make a sketch that illustrates/defines the flame speed, the flame thickness and the chemical time scale of a one-dimensional laminar premixed flame.

-- How can the flame speed, the flame thickness and the chemical time scale be defined/determined for a non-premixed flame?

8)
-- Put up the equations for continuity, momentum, energy and chemical species mass in the (simplified) form that describe the one-dimensional laminar premixed flame.
-- Specify the boundary conditions for these equations.

9)
The laminar flame speed can be determined experimentally from a Bunsen burner.
--Describe the experiment; including which quantities that are measured and the mathematical relation(s) between the flame speed and the measured quantities.

10)
Assume that the shrinking core model shown Figure 25.6 (next page), in which the resistance to diffusion through the ash controls the rate of conversion, is applied for coal combustion. To develop an expression between conversion time and radius requires a two-step analysis.
--What are the two steps? In addition, one assumption is needed for the analysis. What is the assumption? Why is the assumption needed? And what consideration makes the assumption reasonable?

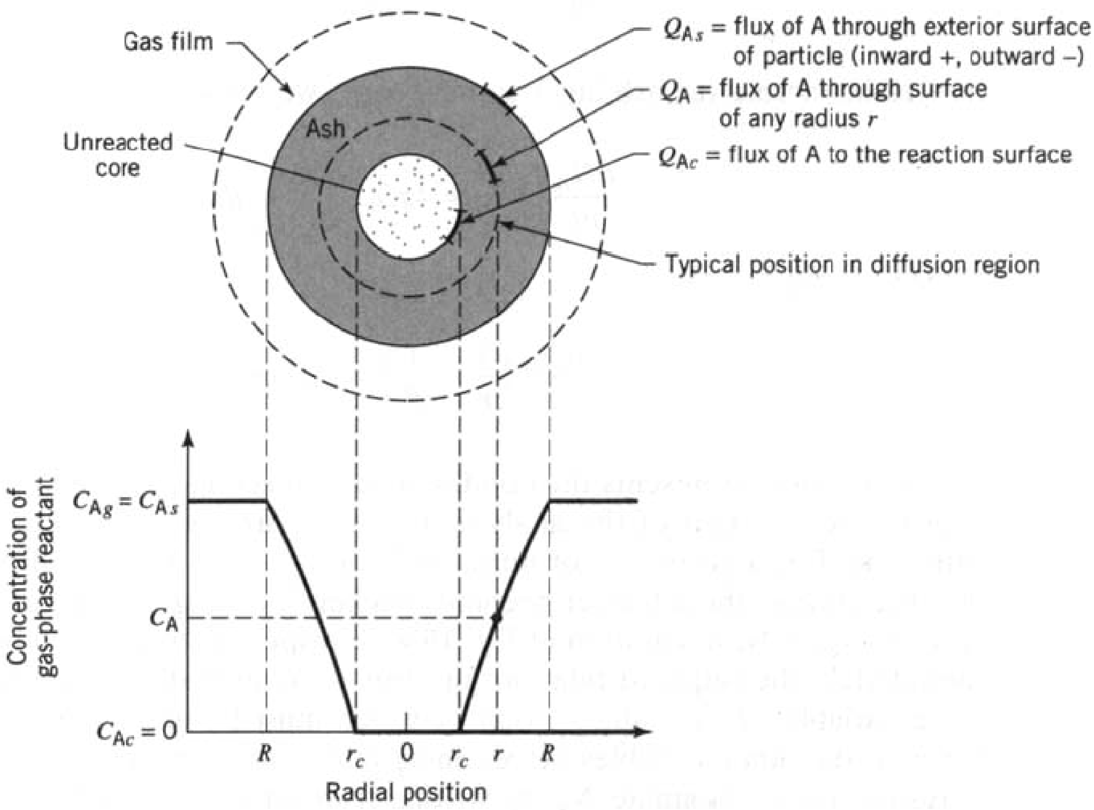

Figure 25.6 Representation of a reacting particle when diffusion through the ash layer is the controlling resistance.