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EXAM IN SUBJECT TEP4170
HEAT AND COMBUSTION TECHNOLOGY
(Varme- og forbrenningsteknikk)
30 May 2011 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)
A relation known as “law of the wall” (Norw: “vegglov”) is expressed as

$$u_1^+ = \min\left(x_2^+ , \frac{1}{\kappa} \ln x_2^+ + C \right)$$

-- Define the quantities involved here.
-- Show the development of the given relation and state the assumptions made during the development.
-- What practical use is made of this expression?

2)
The following equation is given

$$\frac{\partial}{\partial t}(\rho \bar{u}_i) + \frac{\partial}{\partial x_j}(\rho \bar{u}_i \bar{u}_j) = -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j}(\bar{\tau}_{ij}) + \frac{\partial}{\partial x_j}(-\rho \overline{u_i' u_j'}) + \rho \bar{f}_i$$

-- Put up the relevant basic equation, and show how the given equation is developed. Mention the assumptions made during the development.

-- Explain the interpretation of each of the six terms in the equation
-- Which of the six terms have to be modelled, and why (why not)?

3)
Simplify the equation given in Problem 2 to the equation that describes a steady-state, two-dimensional boundary-layer (Norw: “grensesjikt”). State the simplifications made.

4)
What are the main (principal) differences between the modelling represented by the equation given in Problem 2 and Large Eddy Simulation (Norw: “storevje-simulering”)?

5)
-- Use a sketch of a one-dimensional laminar premixed flame to illustrate the interpretation of the burning velocity (aka. flame speed), the flame thickness and the chemical timescale.

-- In some instances we have to consider a multitude of (chemical) velocity scales, length scales and timescales for a flame. Explain this in relation to the first part of this problem.

6)
For a detailed analysis of a one-dimensional laminar premixed flame:
-- put up the equations that have to be solved.
-- mention/specify the quantities that have to be modelled (you need not formulate these models) in these equations.
-- specify the boundary conditions of the equations.

7)
Oxidation of CO can (on certain conditions) be described by the following reactions:

$CO + O_2 \rightarrow CO_2 + O$, (CO.1)
$O + H_2O \rightarrow OH + OH$, (CO.2)
$CO + OH \rightarrow CO_2 + H$, (CO.3)
$H + O_2 \rightarrow OH + O$, (CO.4)

-- What are the role(s) of each of these reactions?
-- What have to be added to the system of reactions if H_2 is present in the system?

8)
Chemical mechanisms can sometimes be simplified by applying the steady-state approximation.
– Describe and explain this simplification.

You can, for instance, use for illustration the mechanism

$O + N_2 \rightarrow NO + N$, (NO.1)
$N + O_2 \rightarrow NO + O$, (NO.2)

9)
The product of methane combustion contains 3,6% CO_2, 7,2% H_2O, 13,0% O_2 and 76,1% N_2 (mole fractions). In addition, 100 ppm (mole fraction $100 \cdot 10^{-6}$) of CO is found.
--Determine the emission index, EI, for CO.

Emissions regulations are specified as ppm (parts per million) at 15% O_2
--Determine the CO emissions corrected to 15% O_2

For sake of order (and simplicity): Here, all mole fractions are with H_2O included (“wet”).
Molar masses (kg/kmol): CO_2: 44; CO: 28; H_2O: 18; O_2: 32; N_2: 28; CH_4: 16

12)
-- Describe the two-film model for carbon combustion. Draw a sketch of the profiles of temperature and relevant species mass fractions.
-- What are the main differences between the two-film and one-film models?