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EXAM IN SUBJECT TEP4170 HEAT AND COMBUSTION TECHNOLOGY
(Varme- og forbrenningsteknikk)
10 August 2019 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)
-- Define homogeneous turbulence.

-- Define isotropic turbulence.
-- How are the individual Reynolds stresses related to each other in isotropic turbulence?

--Put up the equations for turbulence energy (k) and its dissipation rate (ε) for isotropic turbulence based on the k-ε model.

2)
For isentropic turbulence (previous problem):
-- Solve the equations and determine k and ε as functions of time.

--Experiments show $k \sim t^{-1.25}$. Use this information to determine one of the constants in the k-ε model.

3)
--How is the (3-dimensional) energy spectrum of turbulence, $E(\kappa)$, defined?
--Make a sketch of this function. Assume high turbulence Reynolds number.
--How does the turbulence energy, *k*, relate to the energy spectrum?
--When the turbulence decays (Reynolds number decreases), how does the energy spectrum change? (sketch and explain)

4)
For a turbulent flow, undisturbed by solid surfaces (i.e. “free”), of average velocity 10 m/s with a transverse velocity gradient of 5 s^{-1}:
--Make (quantitative) estimates of a “large” turbulence length scale, the turbulence energy, the kinematic turbulence viscosity, the dissipation rate of turbulence energy, the turbulence thermal diffusivity, and turbulence Reynolds number and the Kolmogorov time scale.

5)
-- Make a sketch that shows the profiles of temperature and mass fractions of major species of a one-dimensional, steady-state laminar premixed flame.
-- Use the sketch to define flame speed, the flame thickness and the chemical time scale.

6)
For the laminar premixed flame (previous problem):
-- Put up the equations for continuity, momentum, energy and species mass based on a "simplified" approach (one-step global reaction, constant material properties).
-- Specify the necessary boundary conditions for these equations.

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

$CO + O_2 \rightarrow CO_2 + O$, (1)

$O + H_2O \rightarrow OH + OH$, (2)

$CO + OH \rightarrow CO_2 + H$, (3)

$H + O_2 \rightarrow OH + O$, (4)

The reaction rate coefficient can be assumed known for each reaction.

--Express the reaction rates of CO and OH based on these reactions.

--Identify chain-initiating and chain-branching reactions among these reactions.

--Reaction (1) is slow. Explain its role as an initiator for the conversion of CO to CO_2 in a mixture of CO, O_2 and H_2O.

8)
--Describe the cascade model of EDC. Show how the quantities L^* and u^* are expressed from k and ε.

9)
--Define flammability limits (upper/higher and lower).

For propane, C_3H_8, in air the lower and upper flammability limits are specified at 2.1% and 10.1%, respectively.
--To which values of the air-excess ratio λ (alternatively: of the equivalence ratio, ϕ) do these percentages correspond?

The professor of this course has a bottle of propane in his office. Someone fears a leakage.
-- What is the mass of propane that is needed to reach the lower flammability limit in this office. The office has a volume of 60 m^3.
The temperature and pressure can be assumed at 22 °C and 1 bar (100 kPa), respectively.

Air can be assumed as 21% O_2, 79% N_2 (mole based). Molar mass of propane: 44 kg/kmol
Universal gas constant: R_u= 8.314 kJ/(kmol K)

10)
A diesel engine operates with a mass-based air-to-fuel ratio of 21 kg/kg, a fuel mass flow rate of $4.9 \cdot 10^{-3}$ kg/s. It produces 80 kW of (brake)power. The fuel can be represented by the equivalent formula $C_{12}H_{24}$ (molar mass: 168 kg/kmol).

The unburned hydrocarbon (HC) concentration is measured in the exhaust stream to 120 ppm C_1 (wet basis).

--Determine the emission index (kg/kg) of unburned hydrocarbons for the engine. Assume that the H-to-C-ratio in the unburned hydrocarbon is the same as in the original fuel, and that the molar mass is 14 kg per kmol of C.
-- Determine the mass-specific emission (kg/kWh) for unburned hydrocarbons.