Norwegian University of Science and Technology
Department of Energy and Process Engineering

Contact during exam:
Ivar S. Ertesvåg, phone (735)93839

EXAM IN SUBJECT TEP4170
HEAT AND COMBUSTION TECHNOLOGY
(Varme- og forbrenningsteknikk)
5 June 2009 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)
-- What is a conserved scalar (Norw: ”konservert skalar”)?
-- Show that $(Y_{\mathrm{fu}} - \frac{1}{r} Y_{\mathrm{ox}})$ is a conserved scalar. (Norw. version: $(Y_{\mathrm{br}} - \frac{1}{r} Y_{\mathrm{oks}})$)

2)
-- Define the mixture fraction (Norw: ”blandingsfraksjon”)

For methane, CH_4, the stoichiometric (theoretical) amount of air is 17,16 kg/kg.
-- Determine the stoichiometric mixture fraction for methane in air.

3)
-- Determine the fuel mass fraction and air mass fraction as functions of the mixture fraction for methane in air, assuming infinitely fast and complete reactions.

4)
The equation for the variance of the mixture fraction can be written as

$$\frac{\partial}{\partial t}(\rho\overline{\xi'^2}) + \frac{\partial}{\partial x_j}(\rho\bar{u}_j\overline{\xi'^2}) = \frac{\partial}{\partial x_j}(\rho D\frac{\partial\overline{\xi'^2}}{\partial x_j} - \rho\overline{u'_j\xi'^2}) - 2\rho\overline{u'_j\xi'}\frac{\partial\bar{\xi}}{\partial x_j} - 2\rho D\overline{\frac{\partial\xi'}{\partial x_j}\frac{\partial\xi'}{\partial x_j}}$$

-- Show how this equation can be developed (the principle, not every detail).
-- What is the interpretation of each of the six terms in the equation?

5)
In the equation shown in Problem 4, some terms have to be modeled. The general gradient model (Norw: “generell gradient-modell”) can be used for one or more terms.

-- Which term(s) can be modeled with this model? Write this/these modeled term(s).

6)
The production of nitric oxide from the combustion of nitrogen-free fuels occurs by several mechanisms.
-- Describe these mechanisms with special focus on the chemistry involved, and how this is influenced by temperature, pressure, residence time, and flame type.

7)
A cylinder containing propane leaks its content of 0,464 kg into a (3,66m x 4,27m x 2,44m) room at 20 ºC and 1 atm. After a long time, the propane is well mixed with the air. Propane-air mixtures are flammable for $0{,}51 < \Phi < 2{,}83$. ($\Phi = \lambda^{-1}$ is the equivalence ratio, λ is the excess air ratio (Norw: "luftoverskotstal"))
Air can be assumed as 21% O_2 and 79% N_2. Universal gas constant: $R_u = 8{,}314$ kJ/(kmol K).

-- Is the mixture in the room flammable? Discuss the result.

8)
A well-stirred reactor is an ideal, steady-state reactor with perfect mixing.
Consider a non-adiabatic well-stirred reactor. Assume simplified chemistry, with the species fuel, oxidizer (air), and "product".
The inlet flow consists of fuel (mass fraction 0,2) and oxidizer (mass fraction 0,8). It has a temperature of 298 K and a mass flow rate of 0,5 kg/s.
The reactor has a volume of 0,003 m^3, operates at 1 atm, and has a heat loss of 2000 W.
The outlet stream has fuel and oxidizer mass fractions of 0,001 and 0,003, respectively.
Assume the following simplified thermodynamic properties:
Specific heat, $c_p = 1{,}1$ kJ/(kg K) (for all species), molar mass (mole weight) of 29 kg/kmol (all species), universal gas constant: $R_u = 8{,}314$ kJ/(kmol K).
Enthalpy of formation ($h^o_{f,i}$): −2000 kJ/kg for the fuel; 0 kJ/kg for the oxidizer; −4000 J/kg for the product.

-- Determine the temperature in the reactor and the residence time.

9)
-- Name the different pollutants emitted from premixed combustion.
-- Explain the exhaust gas recirculation (EGR) technique for NOx reduction.
-- Define emission index and mass specific emission.

A spark-ignition engine is running on a dynamometer test stand and the following measurements of the exhaust products are made: CO_2 = 12,47%, CO = 0,12%, O_2 = 2,3%, C_6H_{14} (equivalent) = 367 ppm, NO = 76 ppm.
All the concentrations are by volume on a dry basis. The engine is fuelled by isooctane.

-- Determine the emission index of the unburned hydrocarbons expressed as equivalent hexane.

10)
Pyrolysis, gasification and combustion are the three main thermochemical processes to convert biomass into electricity, heat and useful products.

-- Explain the difference between these processes and give some examples of equipment.
-- Which of these processes, and why, is best suited if you want to maximize the electricity production?

11)
-- What is the basic difference between gasoline and diesel combustion?
-- Draw a rate of heat release (ROHR) graph for diesel combustion showing different phases of combustion.
-- What is ignition delay?

"Nowadays many engine researchers are interested in alternative fuel research"
-- why?
-- Cite some examples of alternative fuels for diesel engines.

A 4-stroke single cylinder diesel engine has a bore and stroke of 80 mm and 110 mm respectively. The output power of the engine is 4 kW at 1500 rpm.
-- Calculate the brake mean effective pressure (BMEP) and torque of the engine.

12)
Pyrolysis of wood has been studied by a thermogravimetric analyzer (TGA) at a heating rate of 10°C/min in nitrogen (200 ml/min). The resulting mass loss and mass loss rate curves are shown in the figure below. The pyrolysis can be approximated by an n-th order reaction as

$$-\frac{d\left(m/m_0\right)}{dt} = k \cdot \left(\frac{m - m_{\text{char}}}{m_0}\right)^n, \qquad \text{where} \quad k = A \cdot \exp\left(\frac{-E}{R_u T}\right)$$

and $m_{\text{char}} / m_0 = 0{,}20$ is the char mass fraction at 500 °C. R_u = 8,314 kJ/(kmol K).

-- Assume a first order reaction and calculate the activation energy (E) and frequency factor (A) for the pyrolysis reactions (Hint: ln(k) vs. $1/T$).