Exam Number:

Department of Mechanical Engineering
Michigan State University
Thermodynamics
Ph.D. Qualifying Examination
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Instructions:

• Six Questions
  • Open Book, Open Notes
• All Problems Carry Equal Weight
• Solve five of the six questions

Examination Prepared By
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1. Water ($H_2O$) is contained in a perfectly insulated and perfectly rigid vessel on both sides of an impermeable membrane. On one side the initial conditions are $p = 3.0$ MPa, $T = 700 \, ^\circ C$, $m = 1 kg$, while on the other side the initial conditions are $T = 100 \, ^\circ C$, $x = 0$, $m = 2 \, kg$. The membrane is ruptured and the system achieves the final temperature $210\, ^\circ C$.

Using conservation of mass, the first law and the second law determine:

(a) (25) The specific internal energy $u_2$ in the final state.
(b) (10) The volume $V$ and the specific volume $v$ of the vessel.
(c) (15) Whether or not this process can occur.

2. A saturated air-water vapor mixture at $20\, ^\circ C$ and 100 kPa is contained in a closed $5 \, m^3$ tank in equilibrium with 1 kg of water. The tank is then heated to $80\, ^\circ C$. Is there any liquid water in the tank?

3. A spark ignites a mixture of methane gas ($CH_4$) and air ($O_2 + 3.76N_2$) according to the stoichiometric reaction $CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$. For a volume $\Delta V$ of gas with radius $\frac{1}{2} \, mm$ and initially at 300K ($\rho = 1.1 \, kg/m^3$) calculate:

1. The flame temperature.
2. The heat released to the gas in the volume $\Delta V$: use $\Delta h_C = 50,000 \, kJ/kgCH_4$ as the overall heat release for this reaction. Note that $\Delta h_C$ is written per kg of the fuel.
3. The heating rate, given that the heat release occurs in $10^{-2} \, sec$. 
4. An amount of ideal gas \( m \) (with known gas constants \( R, c_v \)) is confined by a rigid diathermal diaphragm and a floating piston in two compartments, see Figure. Each compartment contains \( \frac{1}{2} \) of the mass of ideal gas. The pressure differs in each compartment, being \( p_{1A} \) in (A) and \( p_{1B} \) in (b). The temperatures are constant and identical in both compartments, \( T = T_1 \).

An adiabatic process \( 1 \rightarrow 2 \) is initiated by rupturing the diaphragm. In the end state (2) the ideal gas has unique pressure \( p_2 \) and temperature \( T_2 \). Determine the final temperature \( T_2 \), writing your solution in the form

\[
\frac{T_2}{T_1} = f\left(\frac{R}{c_v} \cdot \frac{p_{1A}}{p_{1B}}\right)
\]

5. A power plant operates under the conditions shown in the Figure below.

(a) Calculate \( \eta_{\text{cycle}} \). Also calculate \( \eta_{\text{carnot}} \), disregarding the transfer of heat from the condenser to the water reservoir. Compare the two results and comment.

(b) What percentage of \( W_{\text{turbine}} \) is \( W_{\text{pump}} \)?

(c) Plot the cycle in the \( T-s \) plane and include as much information as possible. Show what the equivalent Carnot cycle would look like using dashed lines.

(d) Calculate the mass flow of cooling water required from the water reservoir if the water reservoir inlet temperature is \( 15^\circ C \) while its outlet temperature is \( 30^\circ C \). Use \( c_{H_2O} = 4.184 \text{ kJ/kg-K} \). Note that the counterflow heat exchanger consisting of condenser and water reservoir line is perfectly insulated. See the Figure below.
6. A 50-50 mass percent mixture of petroleum ($T_{\text{boil}} = 210 ^\circ C$) and jet fuel ($T_{\text{boil}} = 163 ^\circ C$) is injected into the combustion chamber of a jet engine at a pressure of 1 atm and a temperature of 500 $^\circ C$. At what temperature does the fuel mixture boil?