1. A system undergoes a reversible cycle while exchanging heat with three thermal reservoirs, as shown below. Compute the magnitude and direction of $Q_3$ and $W$.

   ![Diagram](image)

   - $T_1 = 400K$
   - $T_3 = 300K$
   - $T_2 = 200K$

2. A tank contains 2 kg of nitrogen at 100 K with a quality of 50%. Through a valve, 0.5 kg is now removed while the temperature remains constant. Find the final quality inside the tank and the volume of nitrogen removed if the valve is located at:
   a) the top of the tank,
   b) the bottom of the tank.

   Hint: a table for saturated nitrogen is given on page 5.

3. Saturated water vapor enters a reversible, adiabatic turbine at a pressure of 10 MPa. At exit the pressure is 0.1 MPa. A table for steam properties is given on page 6.
   a) What are the inlet and exit temperatures?
   b) What are the inlet and exit entropy per unit mass?
   c) What are the inlet and exit qualities?
   d) What is the turbine work per unit mass?

   Suppose now that the turbine adiabatic efficiency is 0.8:
   
   e) Draw both the ideal and non-ideal processes on T-s and h-s diagrams and sketch isobars and isotherms through the inlet and exit states for the liquid region, inside the vapor dome and for superheated vapor.
   f) What is the turbine work per unit mass for the non-ideal expansion?
   g) What is the exit quality for the non-ideal expansion?
4. Hydrogen and oxygen in gaseous form flow into a combustion chamber and react with each other to produce $\text{H}_2\text{O}$, also in gaseous form. The flow rate of oxygen is 1 kmol/second and the proportions of the hydrogen and oxygen are such that all the incoming gas is involved in the reaction. The temperature of the reactants entering the combustion chamber is 298 K.

   a) What is the equation that describes the reaction?
   
   b) Assuming that all gases involved in the reaction can be considered perfect, what is the adiabatic flame temperature?
   
   c) If the maximum temperature that can be tolerated in the combustion chamber is 1798 K, what is the rate at which heat would have to be removed from the combustion chamber?

**Useful Information:**

The enthalpy of formation for $\text{H}_2\text{O}$ is $\bar{h}_{f,\text{H}_2\text{O}} = -242,000 \text{ kJ/kmol}$ and the specific heats can be approximated as follows:

- $c_p$ for $\text{H}_2$ and $\text{O}_2$ can both be taken as constant and equal to 30 kJ/kmol-K
- $c_p$ for $\text{H}_2\text{O}$ can be taken as constant and equal to 40 kJ/kmol-K

5. The figure below shows a 30-ohm electrical resistor located in an insulated duct carrying a stream of air. At steady state, an electric current of 15 amp passes through the resistor, whose temperature remains constant at 28°C. The air enters the duct at 15°C, 1 atm and exits at 25°C with a negligible change in pressure. Kinetic and potential energy changes can be ignored and the flow in the duct can be considered frictionless. The specific heat of air can be assumed $c_p = 1000 \text{ J/kg-K}$.

   a) For the resistor as the system, determine the rate of entropy production, in kW/K if the electrical power needed to pass a current through a given resistance is $P=I^2R$.
   
   b) For a control volume enclosing the air in the duct and the resistor, determine the mass flow rate of the air, in kg/s.
c) Determine the lost work if the current flows for 10 seconds (the amount of work that is unavailable to us).
6. A turbojet engine can be operated with or without afterburning. The cycle is shown in the figure below. Operated without an afterburner, it consists of reversible, adiabatic compression from 0 to 1, constant pressure burning from 1 to 2, then reversible adiabatic expansion through the turbine and the nozzle from 2 to 4, where the pressure at state 4 is atmospheric. The isentropic temperature ratio \( T_1/T_0 \) where \( T_1 \) is the temperature at the compressor exit and \( T_0 \) is the atmospheric temperature) is \( \tau_s \), which is equal to 2. The ratio of maximum temperature to atmospheric temperature is 10. The kinetic energy changes across the turbine and compressor can be neglected, as can any temperature rise produced in the inlet and diffuser ahead of the compressor. *If necessary, express your answers in terms of \( T_0 \) and \( c_p \).*

a) Sketch the non-afterburning cycle in a T-s diagram and label all states.

b) What is the thermal efficiency of the non-afterburning cycle?

c) What is the net mechanical work produced per unit mass flow?

In the afterburning mode, expansion takes place in the turbine from state 2 to state 3, and then the flow is passed through an afterburner where it undergoes constant pressure combustion from state 3 to state 5. The maximum temperature at the afterburner is the same as the maximum temperature at the combustor exit. On leaving the afterburner, the flow expands through a nozzle to atmospheric pressure at state 6.

d) Sketch states 3, 5 and 6 in the same T-s diagram.

e) The afterburner entrance is at the turbine exit. What is the afterburner inlet temperature \( T_3 \)?

f) The afterburner exit temperature, \( T_5 \), is the nozzle inlet temperature. What is the nozzle exit temperature, \( T_6 \)?

g) What is the thermal efficiency of the afterburning engine cycle?
7. In a manufacturing process, a transparent film is being bonded to a substrate as shown in the sketch below. To cure the bond at a temperature $T_0$, a radiant source is used to provide a heat flux $\dot{q}_0$ (W/m²), all of which is absorbed at the bonded surface ($\dot{q}_0$ is completely transmitted in the transparent film). The back of the substrate is maintained at $T_1$ while the free surface of the film is exposed to air at $T_\infty$ and a convection heat transfer coefficient of $h$. The thickness of the bond can be neglected.

![Thermal Circuit Sketch](image)

$L_f = 0.25\text{mm}$  
$k_f = 2.5 \times 10^{-2} \text{W/mK}$  
$L_s = 1.0\text{mm}$  
$k_s = 5.0 \times 10^{-2} \text{W/mK}$

a) Sketch the thermal circuit representing the steady-state heat transfer situation. Be sure to label all elements, nodes, and heat rates.

b) Calculate all thermal resistances in your thermal circuit.

c) For conditions of $T_\infty = 20\degree C$, $h = 50 \text{ W/m²K}$ and $T_1 = 30\degree C$, calculate the heat flux $\dot{q}_0$ required to maintain the bonded surface at $T_0 = 60\degree C$.

8. Two parallel plates are at temperatures $1000\degree C$ and $500\degree C$. The space between the plates is evacuated. Calculate the net radiation heat transfer per m² if

a) the plates are black,

b) the plates are gray with an emissivity=0.6.

A third plate is inserted between the two plates that are again at temperatures $1000\degree C$ and $500\degree C$. The third plate can be assumed thin.

c) Explain in a sentence or two what "thin" implies in the context of this heat transfer problem.

d) Calculate the net radiation heat transfer per m² if all three plates are black.
## Properties of Saturated Nitrogen

Refer to:
Wiley. pp. 714, Table B.6.1.

### Properties of Saturated Steam (Liquid-Vapor)

<table>
<thead>
<tr>
<th>Press., MPa</th>
<th>Temp., C</th>
<th>Specific Volume $m^3/kg$</th>
<th>Internal Energy $kJ/kg$</th>
<th>Enthalpy $kJ/kg$</th>
<th>Entropy $kJ/kgK$</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Sat. Liquid $v_f$</td>
<td>Sat. Vapor $v_g$</td>
<td>Sat. Liquid $u_f$</td>
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