**PROBLEMS 1-3 [2 POINTS EACH]. Please select one answer for each question.**

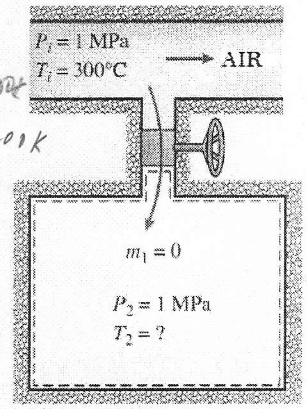
(1) Which of the following is **always** true for an **unsteady-flow** process?
(A) The total energy of the system changes over time.
(B) The flow rate into the system is equal to the flow rate out of the system.
(C) The control volume always expands or contracts.
(D) The process is adiabatic.

$Q_1 = C_v 600$
$Q_2 = C_v \cdot 1200$

(2) One kg of an ideal gas initially at 300K is contained in (i) 1 m³ **rigid** tank at 200kPa or (ii) 2 m³ **rigid** tank at 100kPa. Heat is transferred to the tank and the final pressure is 400 kPa. If the specific heat is constant, which statement is true

$PV = m R_u T \quad P \propto T$
$m_1 = m_2$
$T_1 = \frac{400}{200} \times 300 = 600K$
$T_2 = \frac{400}{100} \times 300 = 1200K$

a) More heat is needed for (i)
b) More heat is needed for (ii)
c) The same heat is needed for (i) and (ii)
d) Insufficient information is provided.




(3) Flow of **air at 300°C** into an evacuated tank as shown on the right and the temperature at State 2 is denoted by $T_2$. Air can be treated as an ideal gas and
a) $T_2 = 300°C$
b) $T_2 > 300°C$
c) $T_2 < 300°C$

**SELECT ALL THAT APPLY SECTION, PROBLEMS 4-5 [2 POINTS EACH]**
**Select all answers that are correct. You may circle more than one answer.**

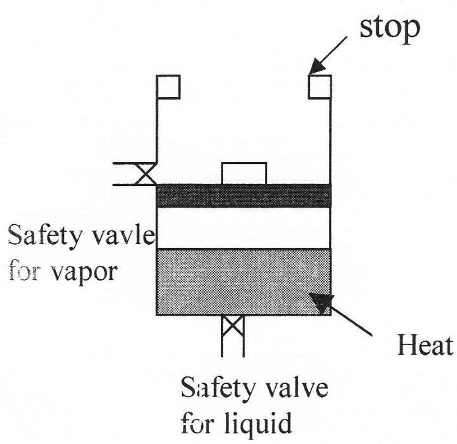
(4) Saturated water vapor passes through an adiabatic throttle device. Which of the following statement is true? **Select all that apply**. You may circle more than one answer.
(A) Internal energy is unchanged after throttling.
(B) Temperature is decreased after throttling.
(C) Pressure is decreased after throttling.
(D) None of the above

(5) An adiabatic **rigid** container is divided into two equal chambers (same volume) by a thin membrane. Initially, one of these chambers is filled with argon at 700 kPa and 300K while the other is evacuated (i.e. vacuum). The membrane is ruptured and the container reaches equilibrium. Argon is assumed to be an ideal gas and which statement about the final state is true? **Select all that apply**. You may circle more than one answer.
(A) Final temperature is 150 K.
(B) Final pressure is 350 kPa.
(C) The internal energy is increased.
(D) The enthalpy remains the same.

| | |
|---|---|
| 1-5 | |
| 6 | |
| 7 | |
| Total | |

Please do not write in this table.

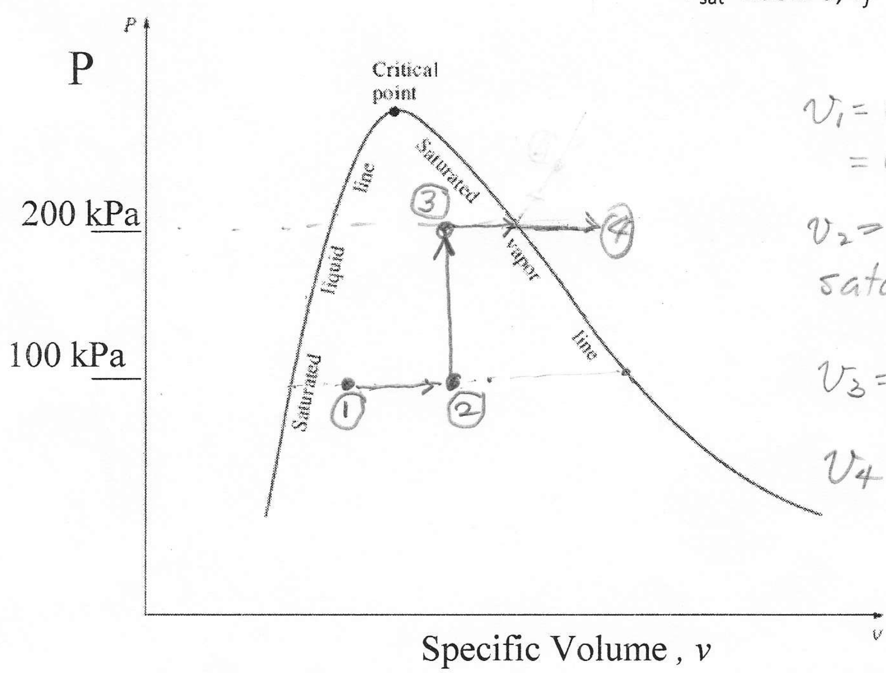
(6) [10 points total] A **frictionless** piston-cylinder device with a set of stops on the top contains initially 1 kg of saturated water at 100 kPa and 20 percent quality (State 1) as sketched below. The weight on the top of piston keeps the pressure inside the cylinder at 100 kPa. Heat is transferred to the water inside the cylinder during the entire process. The piston can move freely and when the piston reaches the stops, the volume is **doubled** (State 2). Two safety valves are installed in the cylinder: one is located at the upper portion of the cylinder to vent vapor and the other at the bottom to release liquid. Both valves open when the pressure reaches 200 kPa (State 3). At the end, the mass of water is 0.5kg (State 4). Fill in the missing state information below and sketch the entire process qualitatively (State 1 → State 4) on the P-*v* diagram below labelling all states.




| State | P (kPa) | v(specific volume) ($m^3/kg$) | Condition |
|---|---|---|---|
| 1 | 100 | 0.3396 | Saturated Mixture |
| 2 | 100 | 0.6792 | Saturated Mixture |
| 3 | 200 | 0.6792 | Saturated mixture |
| 4 | 200 | 1.358 | Supuheated |

Saturation states: $P_{sat}$=100kPa; $v_f$=0.0010 (liquid) $v_g$=1.694 (vapor) $m^3/kg$

$P_{sat}$=200kPa, $v_f$= 0.0011 (liquid), $v_g$=0.8860 (vapor) $m^3/kg$



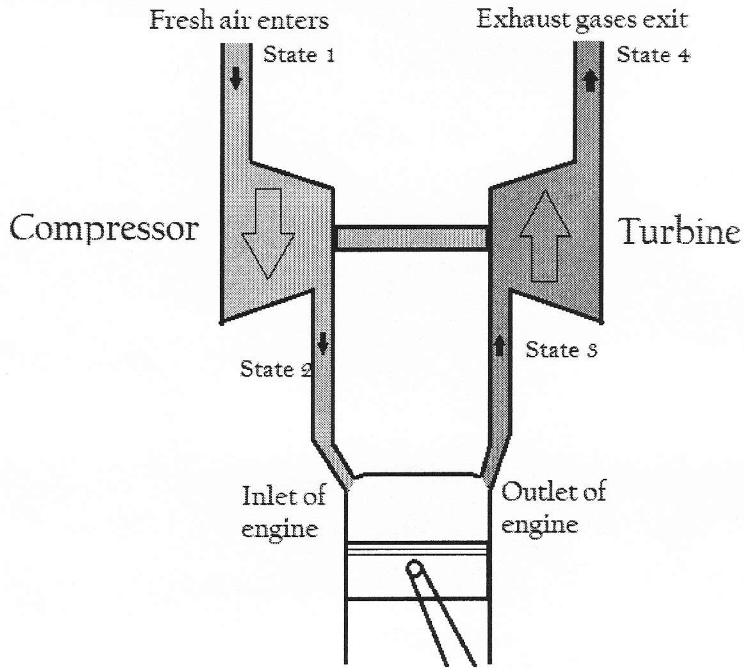

$v_1 = 0.2 \cdot v_g + 0.8 v_f$
$= 0.2 \times 1.694 + 0.8 \times 0.0010 = 0.3396$

$v_2 = 2 \cdot v_1 = 0.6792 < 1.694 = v_g$
saturated mixture

$v_3 = v_2 = 0.6792 < 0.8860 = v_g$

$v_4 = 2 \times v_3 = 1.3584 > 0.8860$

(7) **[10 points total]** A turbocharger (see sketch) is used to increase **air** pressure at the inlet of a car engine (State 2) so that more power is produced. The turbine powers the compressor since they are mounted on the same shaft. Assuming 1) there is no leakage in the engine and both turbine and compressor are adiabatic; 2) the turbocharger reaches a steady-flow condition and there is no mechanical friction or loss; 3) the pressure P and specific volume, $v$, during the compression process follows the polytropic relation $Pv^{1.4}$ = constant. 4) Air is considered an ideal gas with constant specific heat at constant pressure: $c_p$=1kJ/kg-K, and gas constant R=0.287 kJ/kgK.




Given the following state information
Compressor Inlet State 1: $T_1$=300K $P_1$=100 kPa
Turbine inlet State 3: $T_3$=600K, $P_3$=120kPa
Turbine exit State 4: $T_4$=550K, $P_4$=100kPa

A) Determine the temperature at the compressor exit State 2: $T_2$
B) With the ideal gas law (Pv=RT) and the polytropic relation ($Pv^{1.4}$= constant), calculate the pressure at State 2.

A) $w_{turbine} = h_3 - h_4 = c_p(T_3 - T_4) = \frac{1\,kJ}{kg\text{-}K}(600-550)K = 50\,\frac{kJ}{kg}$

$w_{compressor} = h_2 - h_1 = c_p(T_2 - T_1) = w_{turbine} = 50\,\frac{kJ}{kg}$

$T_2 - T_1 = 50K \qquad T_2 = 350\,K$

B) $Pv^{1.4} = constant, \quad v_1 = \frac{RT_1}{P_1} = \frac{0.287\times300}{100} = 0.861\,\frac{m^3}{kg}$

$P_1 v_1^{1.4} = 100 \times (0.861)^{1.4} = 81.1 = P_2 v_2^{1.4}$

$P_2 v_2^{1.4} = 81.1 \qquad (I)$

$P_2 v_2 = RT_2 = 0.287 \times 350 = 100.45 \qquad (II)$

$(I)\,\&\,(II) \Rightarrow v_2^{0.4} = \frac{81.1}{100.45} \qquad v_2 = \left(\frac{81.1}{100.45}\right)^{\frac{1}{0.4}} = (0.807)^{2.5} = 0.586\,\frac{m^3}{kg}$

Ideal gas law $P_2 = \frac{RT_2}{v_2} = \frac{100.45}{0.586} = 171.5\,kPa$