FIRST LAW OF THERMODYNAMICS-Part 2

FLOW

IDEAL GAS

Flow systems or open systems

$\dot{m}$ = mass flowrate (kg/sec) = constant

$\dot{m} = (A_i * C_i)/v_i = (A_e * C_e)/v_e$

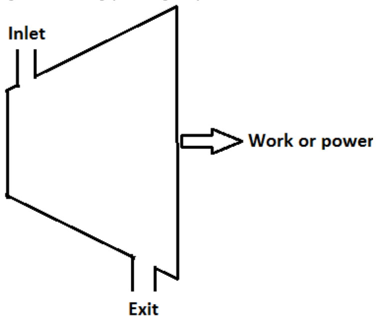
specific volume(v)=m^3/kg

v is calculated using $P*v = R*T$

1. work producing device

Turbine

high energy, high pressure and temperature



low energy, low pressure and low temperature

Work out (kJ/kg) or power out (kJ/s = kW) has positive sign.

Diameter of the turbine increases in flow direction between inlet and exit

a- normal turbine

Flow energy equation

$Q - W = (h_e - h_i) + ½ (C_e^2 - C_i^2) + G (Z_e - Z_i)$

$Q - W = cp(T_e - T_i) + ½ (C_e^2 - C_i^2) + G (Z_e - Z_i)$

in rate form

$\dot{Q} - \dot{W} = \dot{m}*[cp(T_e - T_i) + ½ (Ce^2 - Ci^2) + g(Ze - Zi)]$

b- adiabatic turbine (thermally insulated)

Q = 0

$Q - W = cp(T_e - T_i) + ½ (C_e^2 - C_i^2) + G (Z_e - Z_i)$

WATER

Flow systems or open systems

$\dot{m}$ = mass flowrate (kg/sec) = constant

$\dot{m} = (A_i * C_i)/v_i = (A_e * C_e)/v_e$

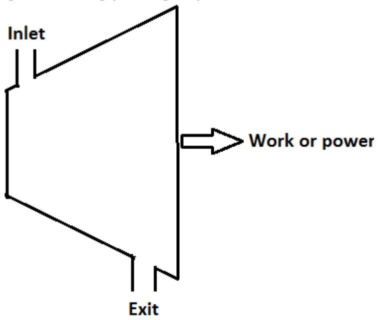
specific volume(v)=m^3/kg

v is obtained from steam table

1. work producing device

Turbine

high energy, high pressure and temperature



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$\dot{Q} = 0$

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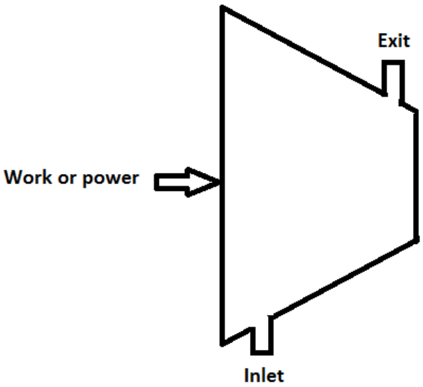
based on information given in the problem, Sometimes Kinetic and Potential energy changes are negligible.

2. work consuming device

Compressor

high energy, high pressure and temperature



low energy, low pressure and low temperature

Work in (kJ/kg) or power in (kJ/s = kW) has negative sign.

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a- normal compressor

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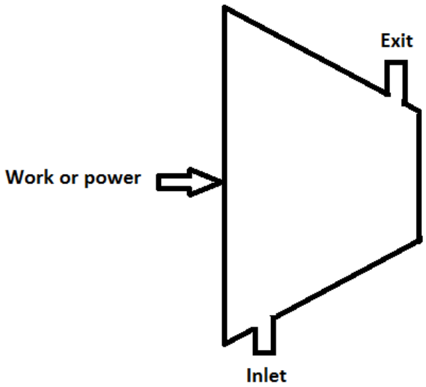

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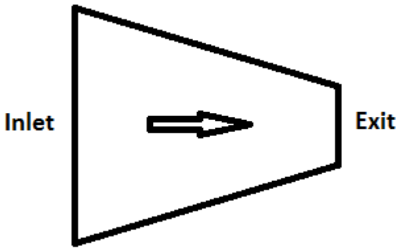
3. other flow devices (no work)

Nozzle



Diameter of the nozzle decreases in flow direction between inlet and exit.

Velocity of the working fluid increases.

No work or power and potential energy change

Sometimes heat transfer is negligible

Flow energy equation

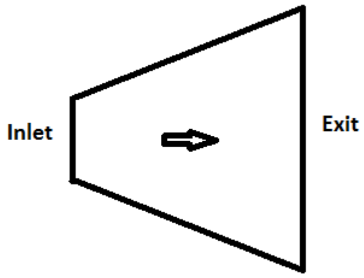
$Q – W = cp(T_2 - T_1) + ½ (C_2^2 – C_1^2) + G (Z_2 - Z_1)$

in rate form

$\dot{Q} - \dot{W} = \dot{m}*[cp(T_e - T_i) + ½ (Ce^2 – Ci^2) + g(Ze-Zi)]$

Necessary simplifications should be made on the flow energy equation.

Diffuser



Diameter of the diffuser increases in flow direction between inlet and exit.

$\dot{Q} = 0$

$\dot{Q} - \dot{W} = \dot{m}*[(he – hi) + ½ (Ce^2 – Ci^2) + g(Ze-Zi)]$

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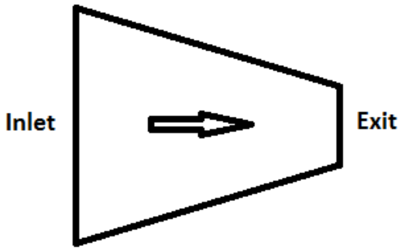

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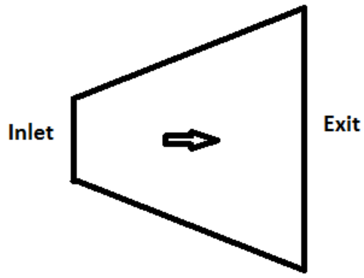

Diameter of the diffuser increases in flow direction between inlet and exit.

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<td>
Velocity of the working fluid decreases.
No work or power and potential energy change
Sometimes heat transfer is negligible
Flow energy equation
$Q - W = cp(T_2 - T_1) + \frac{1}{2}(C_2^2 - C_1^2) + G(Z_2 - Z_1)$
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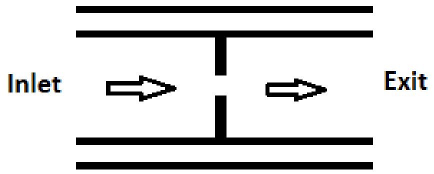
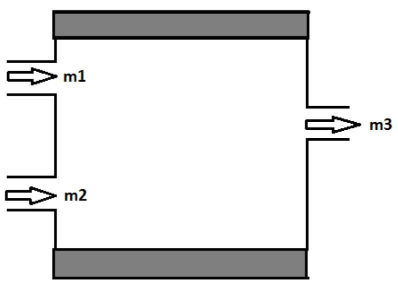
Necessary simplifications should be made on the flow energy equation.

Throttling
Throttling valves are any kind of flow-restricting devices that cause a significant pressure drop in the working fluid. Adiabatic system.


$P_{inlet} >> P_{exit}$
$Q = 0$, $W = 0$, $\Delta KE = 0$, $\Delta PE = 0$ $h_i = h_e$

Adiabatic mixing chamber


$\dot{m}1 + \dot{m}2 = \dot{m}3$
$\dot{m}1 * h1 + \dot{m}2 * h2 = \dot{m}3 * h3$
Mixing chambers are usually well insulated (Q=0) and usually do not involve work (W= 0). Also, the kinetic and potential energies of the working fluid streams are usually negligible.
</td>
<td>
Velocity of the working fluid decreases.
No work or power and potential energy change
Sometimes heat transfer is negligible
Flow energy equation
$Q - W = (h_2 - h_1) + \frac{1}{2}(C_2^2 - C_1^2) + G(Z_2 - Z_1)$
in rate form
$\dot{Q} - \dot{W} = \dot{m} * [(he - hi) + \frac{1}{2}(Ce^2 - Ci^2) + g(Ze - Zi)]$
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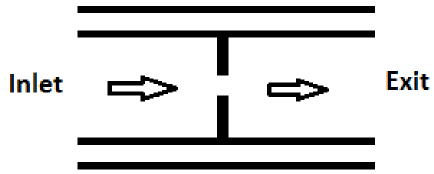

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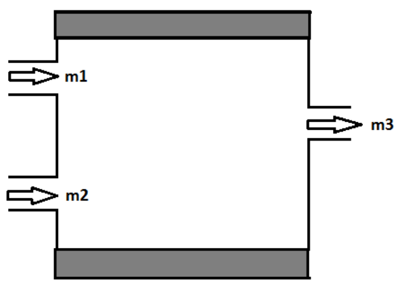

$\dot{m}1 + \dot{m}2 = \dot{m}3$
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NON-FLOW	
IDEAL GAS $Q – W = U_2-U_1 = c_v*(T_2 - T_1)$ Non-flow processes 1. Reversible constant volume 2. Reversible constant pressure 3. Reversible constant temperature (isothermal) 4. Reversible adiabatic 5. Polytropic **Mass is constant** Non-flow systems or closed devices 1. Piston cylinder (boundary work) 2. Rigid vessel or constant volume vessel (no boundary work) General approximation for ideal gases $P*v^n$ = constant **1. Reversible constant volume** V = constant; P and T change during process depending on the amonut of heat transfer $V_1 = V_2$ $m_1 = m_2$ $v_1 = v_2$ $P*v^n$ = constant **n = ∞** for v = constant $P_1/T_1 = P_2/T_2$ non-flow energy equation $Q – W = U_2-U_1 = c_v*(T_2 - T_1)$	**WATER** $Q – W = U_2 - U_1$ Non-flow processes 1. Reversible constant volume 2. Reversible constant pressure 3. Reversible constant temperature (isothermal) 4. Reversible adiabatic 5. Polytropic (*** to use this law state must be gas or vapor ***). Polytropic approximation is used for water in vapor phase (saturated water vapor and superheated water vapor) **Mass is constant** Non-flow systems or closed devices 1. Piston cylinder (boundary work) 2. Rigid vessel or constant volume vessel (no boundary work) **1. Reversible constant volume** V = constant ; P and T change during process depending on the amonut of heat transfer $V_1 = V_2$ $m_1 = m_2$ $v_1 = v_2$ non-flow energy equation $Q – W = U_2-U_1$ V is constant $W_b = 0$ $Q = U_2-U_1$

V is constant $W_b = 0$ $Q = U_2-U_1 = c_v*(T_2 - T_1)$	
2. Reversible constant pressure P = constant; V and T change during process $P_1 = P_2$ $P*v^n$ = constant **n = 0** for P = constant $V_1/T_1 = V_2/T_2$ non-flow energy equation $Q – W = U_2-U_1 = c_v*(T_2 - T_1)$ P is constant $W_b = P*(V_2 - V_1)$ $Q - P*(V_2 - V_1)= U_2-U_1$ $Q = (U_2 + PV_2) – (U_1 + PV_1)$ $Q = h_2 – h_1 = cp (T_2 –T_1)$	**2. Reversible constant pressure** P = constant; V and T change during process $P_1 = P_2$ non-flow energy equation $Q – W = U_2-U_1$ P is constant $W_b = P*(V_2 - V_1)$ $Q - P*(V_2 - V_1)= U_2-U_1$ $Q = (U_2 + PV_2) – (U_1 + PV_1)$ $Q = h_2 – h_1$
3. Reversible constant temperature (isothermal) T = constant: P and V change during process non-flow energy equation $P*v^n$ = constant **n = 1** for T = constant $P_1*V_1 = P_2*V_2$ non-flow energy equation $Q – W = U_2-U_1 = c_v*(T_2 - T_1)$ $U_2-U_1 = c_v*(T_2 - T_1) = 0$ Q = W dW = PdV P*V = R*T P = R*T/V dW = R*T*dV/V $Q = W = R*T*ln(V_2/V_1) = R*T*ln(P_1/P_2)$	**3. Reversible constant temperature (isothermal)** T = constant: P and V change during process non-flow energy equation $Q – W = U_2-U_1$ Unlike ideal gases $U_2-U_1 \neq 0$ because of phase change of water during process.

4. Reversible adiabatic process **Q = 0** $P*v^n$ = constant **n = ϒ** $T_1/T_2 = (P_1/P_2)^{(\Upsilon-1)/\Upsilon}$ $T_1/T_2 = (V_2/V_1)^{(\Upsilon-1)}$ $P_1/P_2 = (V_2/V_1)^{\Upsilon-1}$ non-flow energy equation $Q - W = U_2-U_1 = c_v*(T_2 - T_1)$ $W = U_1-U_2 = c_v*(T_1 - T_2)$ or $W = R*(T_1 - T_2)/(\Upsilon-1)$ or $W = (P_1V_1 - P_2V_2)/(\Upsilon-1)$	**4. Reversible adiabatic process** **Q = 0** non-flow energy equation $Q - W = U_2-U_1$
5. Polytropic process $P*v^n$ = constant **n ≠ 0, 1,** ϒ, ∞ **n = n** $T_1/T_2 = (P_1/P_2)^{(n-1)/n}$ $T_1/T_2 = (V_2/V_1)^{(n-1)}$ $P_1/P_2 = (V_2/V_1)^{n-1}$ non-flow energy equation $Q - W = U_2-U_1 = c_v*(T_2 - T_1)$ $W = (R/n-1) *(T_1 - T_2)$ or $W = (P_1V_1 - P_2V_2)/(n-1)$	5. Polytropic process $Q - W = U_2-U_1$

Assigned problems

4-7
4-8
4-13
4-18
4-23
4-30
4-32
4-36
4-37
4-40
4-41

4–7 **A piston–cylinder device** initially contains 0.07 m^3 of **nitrogen gas** at 130 kPa and 120°C. The nitrogen is now **expanded** to a pressure of 100 kPa **polytropically** with a polytropic exponent whose value is equal to the specific heat ratio (called *isentropic expansion*). Determine the final temperature and the boundary work done during this process.

W.F. = nitrogen gas (diatomic), ideal gas
System = closed, a piston–cylinder device
Process = polytropically expansion

The properties of nitrogen are R = 0.297 kJ/kg.K , $\Upsilon = c_p/c_v = 1.4 = n$

Normally, n = ϒ we call the process as adiabatic, but problem states that the process is polytropic and use ϒ as a polytropic exponent.

The mass and the final volume of nitrogen are

$$m = \frac{P_1 V_1}{RT_1} = \frac{(130\text{ kPa})(0.07\text{ m}^3)}{(0.2968\text{ kJ/kg.K})(120+273\text{ K})} = 0.07802\text{ kg}$$

$$P_1 V_1^n = P_2 V_2^n \longrightarrow (130\text{ kPa})(0.07\text{ m}^3)^{1.4} = (100\text{ kPa})V_2^{1.4} \longrightarrow V_2 = 0.08443\text{ m}^3$$

The final temperature and the boundary work are determined as

$$T_2 = \frac{P_2 V_2}{mR} = \frac{(100\text{ kPa})(0.08443\text{ m}^3)}{(0.07802\text{ kg})(0.2968\text{ kPa.m}^3/\text{kg.K})} = \mathbf{364.6\text{ K}}$$

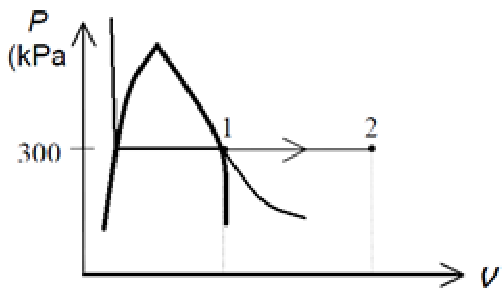
$$W_b = \frac{P_2 V_2 - P_1 V_1}{1-n} = \frac{(100\text{ kPa})(0.08443\text{ m}^3) - (130\text{ kPa})(0.07\text{ m}^3)}{1-1.4} = \mathbf{1.64\text{ kJ}}$$

4–8 A mass of 5 kg of **saturated water vapor** at 300 kPa is **heated at constant pressure** until the temperature reaches 200°C. Calculate the work done by the steam during this process.

W.F. = water, initially saturated water vapor
System = closed, a piston–cylinder device
Process = constant pressure expansion

$$\left.\begin{array}{l} P_1 = 300\text{ kPa} \\ \text{Sat. vapor} \end{array}\right\} v_1 = v_{g\,@\,300\text{ kPa}} = 0.60582\text{ m}^3/\text{kg}$$

$$\left.\begin{array}{l} P_2 = 300\text{ kPa} \\ T_2 = 200°\text{C} \end{array}\right\} v_2 = 0.71643\text{ m}^3/\text{kg}$$



The boundary work

$$W_b = \int_1^2 P\,dV = P(V_2 - V_1) = mP(v_2 - v_1)$$
$$= (5\text{ kg})(300\text{ kPa})(0.71643 - 0.60582)\text{ m}^3/\text{kg}\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right)$$
$$= \mathbf{165.9\text{ kJ}}$$

4–13 Nitrogen at an initial state of 300 K, 150 kPa, and 0.2 m^3 is **compressed slowly in an isothermal** process to a final pressure of 800 kPa. Determine the work done during this process.

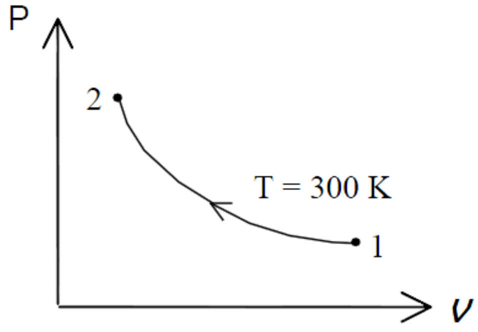
W.F. = nitrogen gas (diatomic), ideal gas
System = closed, a piston–cylinder device
Process = constant temperature (isothermal) compression

The boundary work

$$W_b = \int_1^2 P\,dV = \mathbf{RT}\ln\frac{V_2}{V_1} = \mathbf{RT}\ \ln\frac{P_1}{P_2}$$

$$= \mathbf{0.297 \times 573} \left(\ln\frac{150\text{ kPa}}{800\text{ kPa}}\right)$$

$$= -\mathbf{50.2\ kJ}$$



4–18 A frictionless piston–cylinder device contains 2 kg of nitrogen at 100 kPa and 300 K. Nitrogen is now compressed slowly according to the relation $PV^{1.4}$ = constant until it reaches a final temperature of 360 K. Calculate the work input during this process.

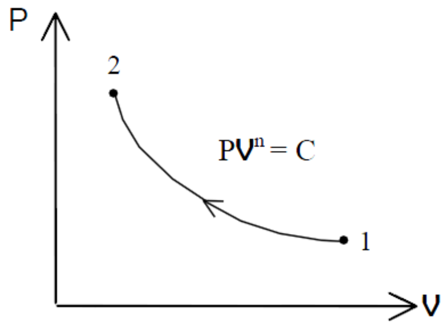
W.F. = nitrogen gas (diatomic), ideal gas
System = closed, a piston–cylinder device
Process = $PV^{1.4}$ = constant (adiabatic) compression

The boundary work

$$W_b = \int_1^2 P\,dV = \frac{P_2V_2 - P_1V_1}{1-\gamma} = \frac{mR(T_2 - T_1)}{1-\gamma}$$

$$= \frac{(2\text{ kg})(0.2968\text{ kJ/kg}\cdot\text{K})(360-300)\text{K}}{1-1.4}$$

$$= -\mathbf{89.0\ kJ}$$



4–23 A piston–cylinder device contains 50 kg of **water at 250 kPa and 25°C**. The cross-sectional area of the piston is 0.1 m^2. Heat is now transferred to the water, causing part of it to evaporate and expand. When the volume reaches 0.2 m^3, the piston reaches a linear spring whose spring constant is 100 kN/m. More heat is transferred to the water until the piston rises 20 cm more. Determine
(a) the final pressure and temperature and
(b) the work done during this process.
Also, show the process on a P-V diagram.

W.F. = water, initially compressed liquid water at 25°C (under 250 kPa piston pressure)
System = closed, a piston–cylinder device
Processes = 1-2 constant pressure (when the piston reaches a linear spring)
2-3 linear law from 250 kPa to 450 kPa (due to compression of the spring)

$$P_3 = P_2 + \frac{F_s}{A} = P_2 + \frac{kx}{A} = (250\text{ kPa}) + \frac{(100\text{ kN/m})(0.2\text{ m})}{0.1\text{ m}^2}\left(\frac{1\text{ kPa}}{1\text{ kN/m}^2}\right) = \mathbf{450\ kPa}$$

The specific and total volumes at the three states are

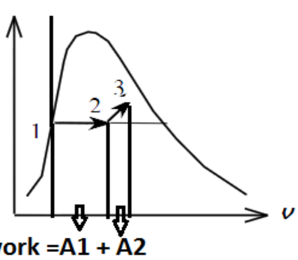
$$\left.\begin{array}{l} T_1 = 25°\text{C} \\ P_1 = 250\text{ kPa} \end{array}\right\} v_1 \cong v_{f@25°\text{C}} = 0.001003\text{ m}^3/\text{kg}$$

$$V_1 = m v_1 = (50\text{ kg})(0.001003\text{ m}^3/\text{kg}) = 0.05\text{ m}^3$$

$$V_2 = 0.2\text{ m}^3$$

$$V_3 = V_2 + x_{23}A_p = (0.2\text{ m}^3) + (0.2\text{ m})(0.1\text{ m}^2) = 0.22\text{ m}^3$$

$$v_3 = \frac{V_3}{m} = \frac{0.22\text{ m}^3}{50\text{ kg}} = 0.0044\text{ m}^3/\text{kg}$$



Boundary work =A1 + A2

At 450 kPa, $v_f = 0.001088\text{ m}^3/\text{kg}$ and $v_g = 0.41392\text{ m}^3/\text{kg}$. Noting that $v_f < v_3 < v_g$, the final state is a saturated mixture and thus the final temperature is

$$T_3 = T_{\text{sat@450 kPa}} = \mathbf{147.9°C}$$

(*b*) The pressure remains constant during process 1-2 and changes linearly (a straight line) during process 2-3. Then the boundary work during this process is simply the total area under the process curve,

$$W_b = \text{Area} = P_1(V_2 - V_1) + \frac{P_2 + P_3}{2}(V_3 - V_2)$$

$$= \left((250\text{ kPa})(0.2-0.05)\text{m}^3 + \frac{(250+450)\text{ kPa}}{2}(0.22-0.2)\text{m}^3\right)\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right)$$

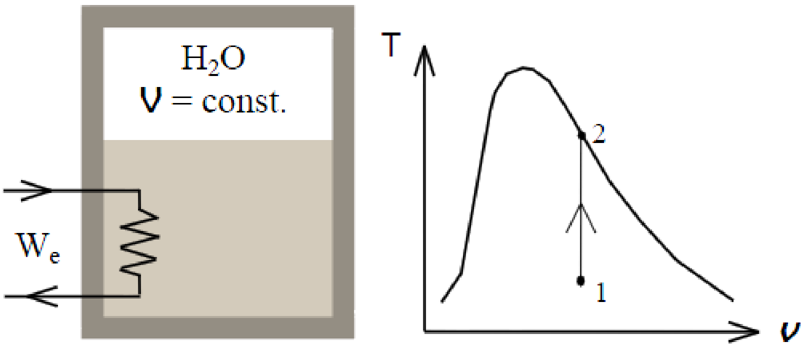
$$= \mathbf{44.5\ kJ}$$

4–30 **A well-insulated rigid tank** contains 5 kg of a **saturated liquid–vapor mixture** of water at l00 kPa. Initially, three-quarters of the mass is in the liquid phase. An electric resistor placed in the tank is connected to a 110-V source, and a current of 8 A flows through the resistor when the switch is turned on. Determine how long it will take to vaporize all the liquid in the tank. Also, show the process on a *T-v* diagram with respect to saturation lines.

W.F. = water, initially saturated liquid- saturated water vapor
System = closed, insulated rigid tank
Process = constant volume

A well-insulated rigid tank ⟶ no heat transfer and no boundary work

$Q - (W_b + W_m + W_e) = U_2 - U_1$
$0 - (0 + 0 + W_e) = U_2 - U_1$



$$VI\Delta t = m(u_2 - u_1)$$

The properties of water

$$\left.\begin{array}{l} P_1 = 100\text{kPa} \\ x_1 = 0.25 \end{array}\right\} \begin{array}{ll} v_f = 0.001043, & v_g = 1.6941 \text{ m}^3/\text{kg} \\ u_f = 417.40, & u_{fg} = 2088.2 \text{ kJ/kg} \end{array}$$

$$v_1 = v_f + x_1 v_{fg} = 0.001043 + [0.25 \times (1.6941 - 0.001043)] = 0.42431 \text{ m}^3/\text{kg}$$

$$u_1 = u_f + x_1 u_{fg} = 417.40 + (0.25 \times 2088.2) = 939.4 \text{ kJ/kg}$$

$$\left.\begin{array}{l} v_2 = v_1 = 0.42431 \text{ m}^3/\text{kg} \\ \text{sat.vapor} \end{array}\right\} u_2 = u_{g@0.42431\text{m}^3/\text{kg}} = 2556.2 \text{ kJ/kg}$$

Substituting,

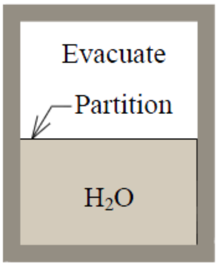
$$(110 \text{ V})(8 \text{ A})\Delta t = (5 \text{ kg})(2556.2 - 939.4)\text{kJ/kg}\left(\frac{1000 \text{ VA}}{1 \text{ kJ/s}}\right)$$

$$\Delta t = 9186 \text{ s} \cong \mathbf{153.1 \text{ min}}$$

4–32 **An insulated tank** is divided into two parts by a partition. One part of the tank contains 2.5 kg of **compressed liquid water** at 60°C and 600 kPa while the other part is evacuated. The partition is now removed, and the **water expands to fill the entire tank**. Determine the final temperature of the water and the volume of the tank for a final pressure of 10 kPa.

W.F. = water, initially compressed liquid water at 60°C
System = closed, insulated rigid tank
Process = free expansion of water

Q = 0 and W_b = 0



$$0 = \Delta U = m(u_2 - u_1)$$

$$u_1 = u_2$$

The properties of water

$$\left.\begin{array}{l} P_1 = 600 \text{ kPa} \\ T_1 = 60°\text{C} \end{array}\right\} \begin{array}{l} v_1 \cong v_{f@60°\text{C}} = 0.001017 \text{ m}^3/\text{kg} \\ u_1 \cong u_{f@60°\text{C}} = 251.16 \text{ kJ/kg} \end{array}$$

We now assume the final state in the tank is saturated liquid-vapor mixture and determine quality. This assumption will be verified if we get a quality between 0 and 1.

$$\left.\begin{array}{l} P_2 = 10 \text{ kPa} \\ (u_2 = u_1) \end{array}\right\} \begin{array}{ll} v_f = 0.001010, & v_g = 14.670 \text{ m}^3/\text{kg} \\ u_f = 191.79, & u_{fg} = 2245.4 \text{ kJ/kg} \end{array}$$

$$x_2 = \frac{u_2 - u_f}{u_{fg}} = \frac{251.16 - 191.79}{2245.4} = 0.02644$$

Thus,

$$T_2 = = T_{\text{sat @ 10 kPa}} = \mathbf{45.81\ °C}$$

4–36 **An insulated piston–cylinder** device contains 5 L of **saturated liquid water** at a **constant pressure** of 175 kPa. Water is stirred by a paddle wheel while a current of 8 A flows for 45 min through a resistor placed in the water. If one-half of the liquid is evaporated during this constantpressure process and the paddle-wheel work amounts to 400 kJ, determine the voltage of the source. Also, show the process on a *P-v* diagram with respect to saturation lines.

W.F. = water, initially saturated liquid water
System = closed, insulated piston-cylinder
Process = constant pressure

Q = 0
$Q - W = U_2 - U_1$
$Q - (W_b + W_e + W_m) = U_2 - U_1$
$0 - (W_b + W_e + W_m) = U_2 - U_1$
$W_b = P*(V2 - V1)$
h = u + PV

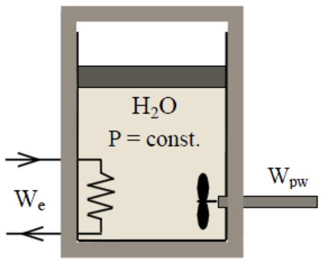
$0 - (W_e + W_m) = (U_2 - PV_2) - (U_1 - PV_1)$
$0 - (W_e + W_m) = h_2 - h_1$

The properties of water

$$\left.\begin{array}{l} P_1 = 175 \text{ kPa} \\ \text{sat.liquid} \end{array}\right\} \begin{array}{l} h_1 = h_{f@175 \text{ kPa}} = 487.01 \text{ kJ/kg} \\ v_1 = v_{f@175 \text{ kPa}} = 0.001057 \text{ m}^3\text{/kg} \end{array}$$

$$\left.\begin{array}{l} P_2 = 175 \text{ kPa} \\ x_2 = 0.5 \end{array}\right\} h_2 = h_f + x_2 h_{fg} = 487.01 + (0.5 \times 2213.1) = 1593.6 \text{ kJ/kg}$$

$$m = \frac{V_1}{v_1} = \frac{0.005 \text{ m}^3}{0.001057 \text{ m}^3\text{/kg}} = 4.731 \text{ kg}$$

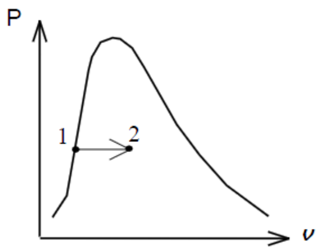


Substituting,

$$VI\Delta t + (400\text{kJ}) = (4.731 \text{ kg})(1593.6 - 487.01)\text{kJ/kg}$$

$$VI\Delta t = 4835 \text{ kJ}$$

$$V = \frac{4835 \text{ kJ}}{(8 \text{ A})(45 \times 60 \text{ s})}\left(\frac{1000 \text{ VA}}{1 \text{ kJ/s}}\right) = \mathbf{223.9 \text{ V}}$$



4–37 A **piston–cylinder** device contains **steam** initially at 1 MPa, 450°C, and 2.5 m^3. Steam is allowed to cool at constant pressure until it first starts condensing. Show the process on a T-v diagram with respect to saturation lines and determine (a) the mass of the steam, (b) the final temperature, and (c) the amount of heat transfer.

W.F. = water, initially superheat steam
System = closed, piston-cylinder
Process = constant pressure

$Q - W = U_2 - U_1$
$W_b = P*(V2 - V1)$
$Q = h_2 - h_1$

The properties of water

$$\left.\begin{aligned} P_1 &= 1\text{ MPa} \\ T_2 &= 450°\text{C} \end{aligned}\right\} \begin{aligned} v_1 &= 0.33045\text{ m}^3/\text{kg} \\ h_1 &= 3371.3\text{ kJ/kg} \end{aligned}$$

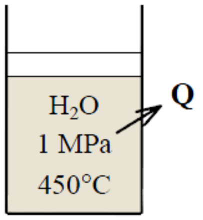
$$m = \frac{V_1}{v_1} = \frac{2.5\text{ m}^3}{0.33045\text{ m}^3/\text{kg}} = \mathbf{7.565\ kg}$$

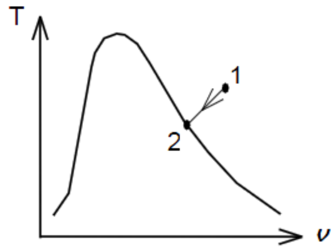
(*b*) The final temperature is determined from

$$\left.\begin{aligned} P_2 &= 1\text{ MPa} \\ &\text{sat. vapor} \end{aligned}\right\} \begin{aligned} T_2 &= T_{sat@1\text{ MPa}} = \mathbf{179.9°C} \\ h_2 &= h_{g@1\text{ MPa}} = 2777.1\text{ kJ/kg} \end{aligned}$$

(*c*) Substituting, the energy balance gives

$$Q_{out} = -\ (7.565\text{ kg})(2777.1 - 3371.3)\text{ kJ/kg} = \mathbf{4495\ kJ}$$





4–40 A **piston–cylinder** device initially contains 0.8 m^3 of **saturated water vapor** at 250 kPa. At this state, the piston is resting on a set of stops, and the mass of the piston is such that a pressure of 300 kPa is required to move it. Heat is now slowly transferred to the steam until the volume doubles. Show the process on a P-v diagram with respect to saturation lines and determine (a) the final temperature, (b) the work done during this process, and (c) the total heat transfer.

W.F. = water, initially superheat steam
System = closed, piston-cylinder
Processes = 1-2 constant volume (pressure of the saturated water vapor < Piston pressure)
2-3 constant pressure

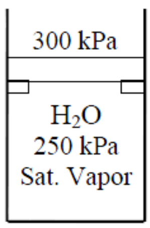
The properties of steam

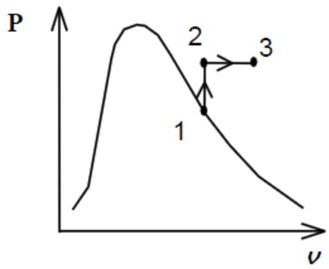
$$\left.\begin{aligned} P_1 &= 250\text{ kPa} \\ &sat.vapor \end{aligned}\right\} \begin{aligned} v_1 &= v_{g@250\text{ kPa}} = 0.71873\text{ m}^3/\text{kg} \\ u_1 &= u_{g@250\text{ kPa}} = 2536.8\text{ kJ/kg} \end{aligned}$$

$$m = \frac{V_1}{v_1} = \frac{0.8\text{ m}^3}{0.71873\text{ m}^3/\text{kg}} = 1.113\text{ kg}$$

$$v_3 = \frac{V_3}{m} = \frac{1.6\text{ m}^3}{1.113\text{ kg}} = 1.4375\text{ m}^3/\text{kg}$$

$$\left.\begin{aligned} P_3 &= 300\text{ kPa} \\ v_3 &= 1.4375\text{ m}^3/\text{kg} \end{aligned}\right\} \begin{aligned} T_3 &= \mathbf{662°C} \\ u_3 &= 3411.4\text{ kJ/kg} \end{aligned}$$





(*b*) The work done during process 1-2 is zero (since V= const) and the work done during the constant pressure process 2-3 is

$$W_{b,} = \int_2^3 P\,dV = P(V_3 - V_2) = (300\text{ kPa})(1.6 - 0.8)\text{m}^3\left(\frac{1\text{ kJ}}{1\text{ kPa}\cdot\text{m}^3}\right) = \mathbf{240\ \ kJ}$$

(*c*) Heat transfer is determined from the energy balance,

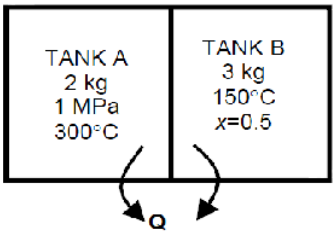
$$Q_{in} = m(u_3 - u_1) + W_{b,}$$

$$= (1.113\text{ kg})(3411.4 - 2536.8)\text{ kJ/kg} + 240\text{ kJ} = \mathbf{1213\ \ kJ}$$

4–41 Two tanks (Tank A and Tank B) are separated by a partition. Initially Tank A contains 2-kg steam at 1 MPa and 300°C while Tank B contains 3-kg saturated liquid–vapor mixture with a vapor mass fraction of 50 percent. Now the partition is removed and the two sides are allowed to mix until the mechanical and thermal equilibrium are established. If the pressure at the final state is 300 kPa, determine (a) the temperature and quality of the steam (if mixture) at the final state and (b) the amount of heat lost from the tanks.

W.F. = water
System = closed, rigid tank
Process = mixing

The properties of steam in both tanks at the initial state



$$\left.\begin{array}{l} P_{1,A} = 1000 \text{ kPa} \\ T_{1,A} = 300°\text{C} \end{array}\right\} \begin{array}{l} v_{1,A} = 0.25799 \text{ m}^3/\text{kg} \\ u_{1,A} = 2793.7 \text{ kJ/kg} \end{array}$$

$$\left.\begin{array}{l} T_{1,B} = 150°\text{C} \\ x_1 = 0.50 \end{array}\right\} \begin{array}{ll} v_f = 0.001091, & v_g = 0.39248 \text{ m}^3/\text{kg} \\ u_f = 631.66, & u_{fg} = 1927.4 \text{ kJ/kg} \end{array}$$

$$v_{1,B} = v_f + x_1 v_{fg} = 0.001091 + [0.50 \times (0.39248 - 0.001091)] = 0.19679 \text{ m}^3/\text{kg}$$

$$u_{1,B} = u_f + x_1 u_{fg} = 631.66 + (0.50 \times 1927.4) = 1595.4 \text{ kJ/kg}$$

The total volume and total mass of the system are

$$V = V_A + V_B = m_A v_{1,A} + m_B v_{1,B} = (2 \text{ kg})(0.25799 \text{ m}^3/\text{kg}) + (3 \text{ kg})(0.19679 \text{ m}^3/\text{kg}) = 1.106 \text{ m}^3$$

$$m = m_A + m_B = 3 + 2 = 5 \text{ kg}$$

Now, the specific volume at the final state may be determined

$$v_2 = \frac{V}{m} = \frac{1.106 \text{ m}^3}{5 \text{ kg}} = 0.22127 \text{ m}^3/\text{kg}$$

which fixes the final state and we can determine other properties

$$\left.\begin{array}{l} P_2 = 300 \text{ kPa} \\ v_2 = 0.22127 \text{ m}^3/\text{kg} \end{array}\right\} \begin{array}{l} T_2 = T_{\text{sat @ 300 kPa}} = \mathbf{133.5°C} \\ x_2 = \dfrac{v_2 - v_f}{v_g - v_f} = \dfrac{0.22127 - 0.001073}{0.60582 - 0.001073} = \mathbf{0.3641} \\ u_2 = u_f + x_2 u_{fg} = 561.11 + (0.3641 \times 1982.1) = 1282.8 \text{ kJ/kg} \end{array}$$

(*b*) Substituting,

$$-Q_{\text{out}} = \Delta U_A + \Delta U_B = [m(u_2 - u_1)]_A + [m(u_2 - u_1)]_B$$
$$= (2 \text{ kg})(1282.8 - 2793.7)\text{kJ/kg} + (3 \text{ kg})(1282.8 - 1595.4)\text{kJ/kg} = -3959 \text{ kJ}$$

or $\quad Q_{\text{out}} = \mathbf{3959\ kJ}$