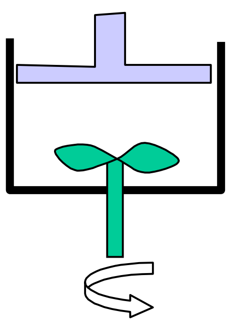
Example

- The internal energy of a closed system can be increased by adding heat or doing work. In the following example, 1 kg of saturated liquid water at 100°C is contained inside a piston-cylinder assembly. Instead of adding heat, a paddle wheel is doing work on the system and the water is undergoing a transition into 100% saturated vapor. During the process the piston moves "**freely**" inside the cylinder. **Question: Does this make a difference in our calculation?** Assume no heat transfer, determine the work done and the amount of entropy production.



$\Delta U = Q - W = 0 - W = -W$

$m(u_g - u_f) = -W$, u_g: saturated vapor, u_f: saturated liquid

$W = -(u_g - u_f) = -(2506.5 - 418.9) = -2087.6$ (kJ/kg) from Table A-4

$$\text{Entropy change}: \Delta s = \int \frac{\delta Q}{T} + (\Delta s)_{generation}, \quad \Delta s = (\Delta s)_{generation}$$

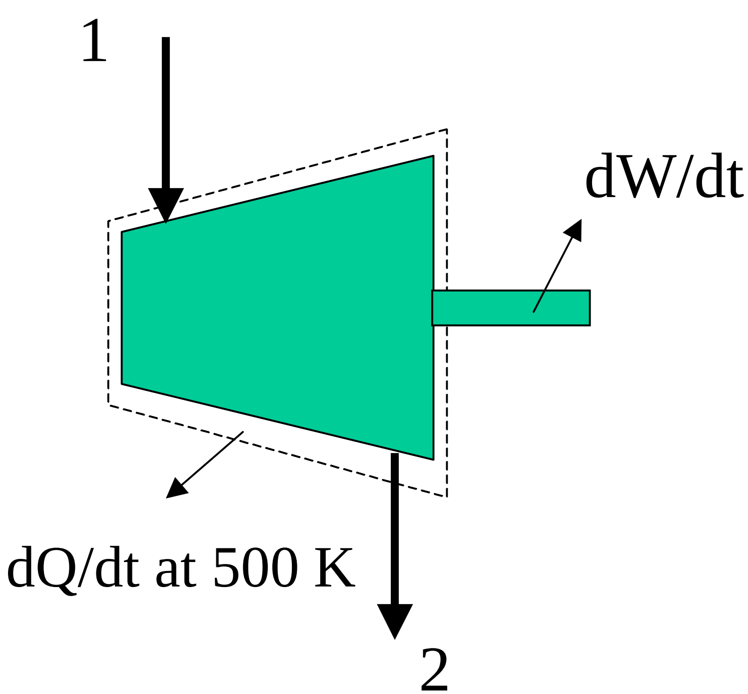
since there is no heat transfer

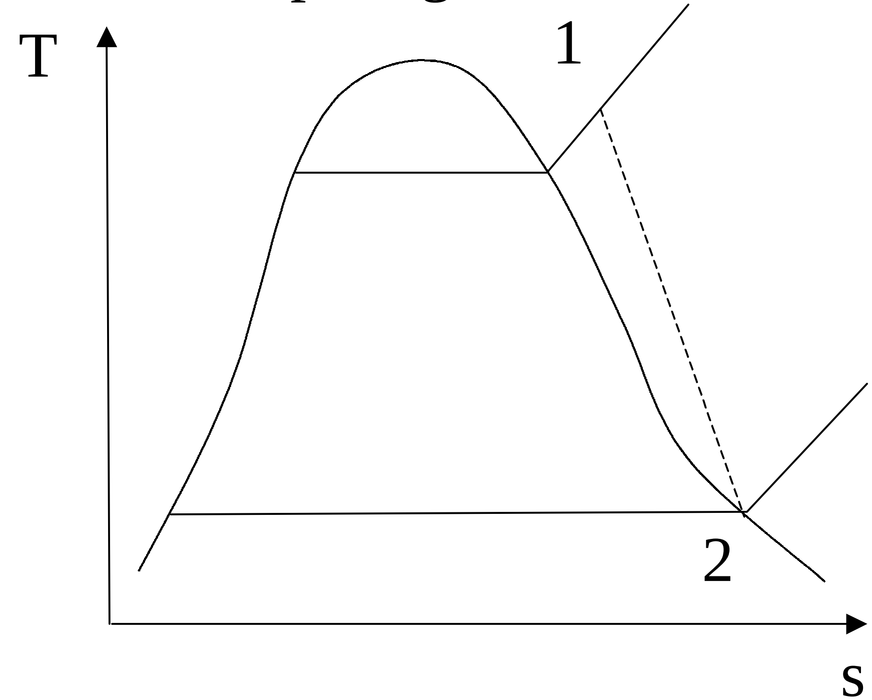
$(\Delta s)_{gen} = s_g - s_f = 7.356 - 1.307 = 6.049$ (kJ/kg K), from Table A-4

Answer to the question: yes, if the piston is fixed, the pressure inside the cylinder will increase as liquid evaporates into vapor. Accordingly, the saturation state will change.

Example

- Steam enters a turbine with a pressure of 3 MPa, a temp. of 400°C, and a velocity of 150 m/s. 100% saturated vapor exits at 100°C with velocity of 50 m/s. At steady state, the turbine develops work of 500 kJ per kg of steam. There is heat transfer between the turbine and its surroundings at an averaged surface temperature of 500 K. Determine the rate at which entropy is produced within the turbine per kg of steam.





Solution

$$\text{Mass conservation}: \frac{dm}{dt} = 0 = \dot{m}_1 - \dot{m}_2, \quad \dot{m} = \dot{m}_1 = \dot{m}_2$$

$$\text{Entropy balance analysis}: \frac{ds}{dt} = \int \frac{\dot{Q}}{T} + \dot{m}_1 s_1 - \dot{m}_2 s_2 + \dot{s}_{generation}$$

$$\text{Steady state}: 0 = \frac{ds}{dt} = \frac{\dot{Q}}{T} + \dot{m}_1 s_1 - \dot{m}_2 s_2 + \dot{s}_{gen}$$

$$\left(\frac{1}{\dot{m}}\right)\dot{s}_{gen} = -\left(\frac{1}{\dot{m}}\right)\frac{\dot{Q}}{T_b} + (s_2 - s_1), \text{ Need to determine } \dot{\text{Q}}, \text{s}_2, \text{and s}_1$$

$$\text{From table A-4, saturated table, s}_2 = s_g = 7.356(kJ/kgK)$$

$$\text{From table A-6, superheated table, s}_1 = 6.922(kJ/kgK)$$

$$\text{Question: How do we determine } \dot{\text{Q}}?$$

Solution

Use Energy balance equation of course :

$$\frac{\mathrm{dE}}{\mathrm{dt}} = \frac{\mathrm{dE_g}}{\mathrm{dt}} + \dot{Q} + \dot{E}_1 - \dot{E}_2 - \frac{dW}{dt}, \quad \frac{\mathrm{dE}}{\mathrm{dt}} = \frac{\mathrm{dE_g}}{\mathrm{dt}} = 0$$

$$-\dot{Q} = \dot{m}_1 (h_1 + \frac{V_1^2}{2}) - \dot{m}_2 (h_2 + \frac{V_2^2}{2}) - \frac{dW}{dt}$$

$$\frac{-\dot{Q}}{\dot{m}} = (h_1 - h_2) + \frac{1}{2}(V_1^2 - V_2^2) - \frac{1}{\dot{m}}\frac{dW}{dt}$$

Table A - 6, superheated vapor, $\mathrm{h_1} = 3230.8(kJ/kg)$

Table A - 4, saturated table, $\mathrm{h_2} = h_g = 2676(kJ/kg)$

$$\frac{-\dot{Q}}{\dot{m}} = (3230.8 - 2676) + \frac{1}{2}(150^2 - 50^2)(1/1000) - 500 = 64.8(kJ/kg)$$

From previous page : $\left(\frac{1}{\dot{m}}\right)\dot{s}_{gen} = -\left(\frac{1}{\dot{m}}\right)\frac{\dot{Q}}{T_b} + (s_2 - s_1)$

$$= \frac{64.8}{500} + (7.356 - 6.922) = 0.564(kJ/kg\,K)$$