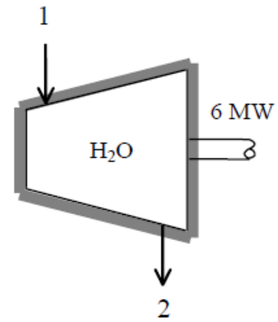
<u>Ex:</u> Steam enters an adiabatic turbine at 7 MPa, 600°C, and 80 m/s and leaves at 50 kPa, 150°C, and 140 m/s. If the power output of the turbine is 6 MW, determine (a) the mass flow rate of the steam flowing through the turbine (b) the isentropic efficiency of the turbine and(c) the increase in entropy.



<u>Sol:</u>

P_1=7 MPa, T_1=600°C, Ve_1=80 m/s

P_2=50 kPa, T_2=150°C, Ve_2=140 m/s

$\dot{W}_a = 6\,MW$, $\dot{m} = ?$, $\eta_T = ?$

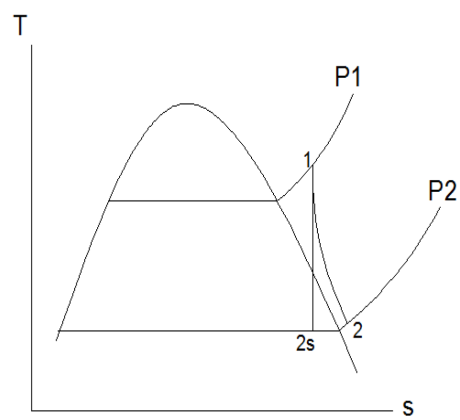
$$\dot{Q} - \dot{W}_a = \dot{m}\left((h_2 - h_1) + \frac{1}{2}(Ve_2^{\,2} - Ve_1^{\,2}) + g(z_2 - z_1) \right)$$

For adiabatic turbine, and negligible the change in potential energy

$$-\dot{W}_a = \dot{m}\left((h_2 - h_1) + \frac{1}{2}(Ve_2^{\,2} - Ve_1^{\,2}) \right)$$

$$\eta_T = \frac{\dot{W}_a}{\dot{W}_s}$$

<u>State 1:</u>



P_1=7 MPa=7000 kPa, T_1=600°C, Ve_1=80 m/s

At P_{sat}= P_1=7000 kPa, T_{sat}=285.83 °C

Since T_1> T_{sat}, the steam is superheated

h_1=3650.6 kJ/kg, s_1=7.091 kJ/kg.K

<u>State 2:</u>

P_2=50 kPa, T_2=150°C, Ve_2=140 m/s

At P_{sat}= P_2=50 kPa=0.05 MPa, T_{sat}=81.32 °C

Since T_2> T_{sat}, the steam is superheated

h_2=2780.2 kJ/kg, s_2=7.9413 kJ/kg.K

<u>State 2s:</u>

P_2=50 kPa, s_{2s}=s_1=7.091 kJ/kg.K

At P_{sat}= P_2=50 kPa=0.05 MPa, s_g=7.5931 kJ/kg.K, s_f=1.0912 kJ/kg.K

Since $s_f < s_{2s} < s_g$, the steam is wet (liquid-vapor mixture)

$s_{2s} = s_f + x_{2s}(s_{fg})$

7.091 = 1.0912 + x_{2s} (6.5019), x_{2s} =0.9227

h_{2s} =h_f+x_{2s} (h_{fg})=340.54+0.9227(2304.7)=2467.08 kJ/kg

$$-\dot{W}_a = \dot{m}\left((h_2 - h_1) + \frac{1}{2}(Ve_2^{\,2} - Ve_1^{\,2}) \right)$$

$$-6 * 1000 = \dot{m}\left((2780.2 - 3650.6) + \frac{1}{2000}(140^2 - 80^2) \right)$$

$$\dot{m} = 6.946 \ \ kg/s$$

$$-\dot{W}_s = \dot{m}\left((h_{2s} - h_1) + \frac{1}{2}(Ve_2^{\,2} - Ve_1^{\,2}) \right)$$

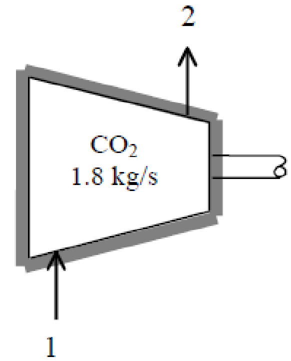
$$\dot{W}_s = - \dot{m}\left((h_{2s} - h_1) + \frac{1}{2}(Ve_2^{\,2} - Ve_1^{\,2}) \right)$$

$$= -6.946\left(2467.08 - 3650.6 + \frac{1}{2000}(140^2 - 80^2) \right) = 8174.88\ kW$$

$$\eta_T = \frac{\dot{W}_a}{\dot{W}_s} = \frac{6000}{8174.88} = 0.734$$

$$\Delta s = s_2 - s_1 = 7.9413 - 7.091 = 0.8503\ \ kJ/kg.K$$

Ex: Carbon dioxide enters an adiabatic compressor at 100 kPa and 300 K at a rate of 1.8 kg/s and exits at 600 kPa and 450 K. Neglecting the kinetic energy changes, determine the isentropic efficiency of the compressor, the power required and the change in entropy. Take k = 1.260 and C_p = 0.917 kJ/kg.K.



Sol:

P_1=100 kPa, T_1=300 K, $\dot{m} = 1.8\ kg/s$

P_2=600 kPa, T_2=450 K

$\eta_c = ?,\ \Delta s = s_2 - s_1 = ?$

$$\eta_C = \frac{\text{Isentropic compressor work}}{\text{Actual compressor work}} = \frac{w_s}{w_a}$$

$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1}$$

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1}$$

$$\dot{Q} - \dot{W}_a = \dot{m}\left((h_2 - h_1) + \frac{1}{2}(Ve_2^{\,2} - Ve_1^{\,2}) + g(z_2 - z_1)\right)$$

For adiabatic compressor and neglecting the change in potential and kinetic energies, we get:

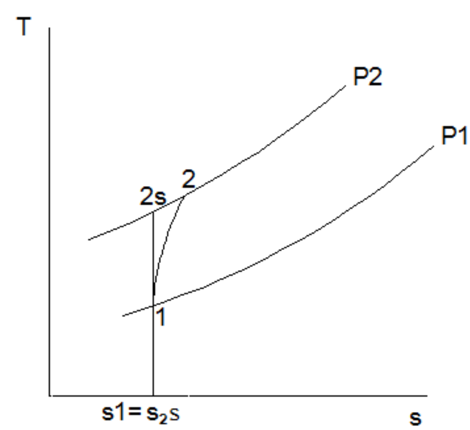
$$\dot{W}_a = \dot{m}(h_1 - h_2)$$

$$\Delta s = s_2 - s_1 = s_2 - s_{2s} = C_p \ln\left(\frac{T_2}{T_{2s}}\right)$$

$$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

$$\frac{T_{2s}}{300} = \left(\frac{600}{100}\right)^{\frac{1.26-1}{1.26}}$$, T_{2s}=434.202 K

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1} = \frac{434.202 - 300}{450 - 300} = 0.895$$



$$\dot{W}_a = \dot{m}(h_1 - h_2) = \dot{m}\,C_p(T_1 - T_2) = 1.8 * 0.917(300 - 450) = -247.59\,kW$$

$$\Delta s = s_2 - s_1 = s_2 - s_{2s} = C_p \ln\left(\frac{T_2}{T_{2s}}\right) = 0.917\ \ln\left(\frac{450}{434.202}\right) = 0.0327 kJ/kg.K$$