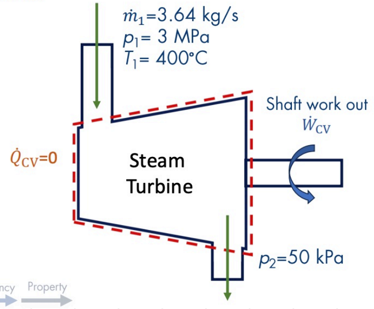
Example (Part 1 of 2)

Steam enters a steady, adiabatic turbine at 3 MPa and 400°C and leaves at 50 kPa. If the mass flow rate of the water is 3.64 kg/s, what is maximum possible power output of an idealized, reversible turbine.



$$\overset{\text{steady-state}}{\frac{d\cancel{S_{cv}}}{dt}} = \overset{\text{adiabatic}}{\sum \frac{\cancel{\dot{Q}_k}}{T_k}} + \dot{m}(s_{in} - s_{out}) + \overset{\text{reversible}}{\cancel{\dot{S}_{gen}}}$$

"Isentropic" (adiabatic, reversible)

State 1: $P_1 = 3\text{ MPa}$, $T_1 = 400°C$ → Table A-6 Superheated vapor → $s_1 = 6.9235\ [kJ/kg\cdot K]$, $h_1 = 3231.7\ [kJ/kg]$

State 2: $P_2 = 50\text{ kPa}$, $s_2 = s_1$ → Table A-5 2-phase mixture →

"ideal" = isentropic

$$x_2 = \frac{s_2 - s_f}{s_{fg}} = \frac{6.9235 - 1.0912\ [kJ/kg\cdot K]}{6.5019\ [kJ/kg\cdot K]}$$

$$= 0.897$$

$$h_2 = h_f + x h_{fg}$$

$$= 340.54\ [kJ/kg] + 0.897 \times 2304.7\ [kJ/kg]$$

$$= 2407.9\ [kJ/kg]$$

First law:

$$\overset{\text{steady}}{\frac{d\cancel{E}}{\cancel{dt}}} = \overset{\text{adiabatic}}{\cancel{\dot{Q}_{cv}}} - \dot{W}_{cv} + \dot{m}\left(h + \overset{\text{negligible}}{\cancel{\tfrac{1}{2}V^2}} + \cancel{gz}\right)_1 - \dot{m}\left(h + \cancel{\tfrac{1}{2}V^2} + \cancel{gz}\right)_2$$

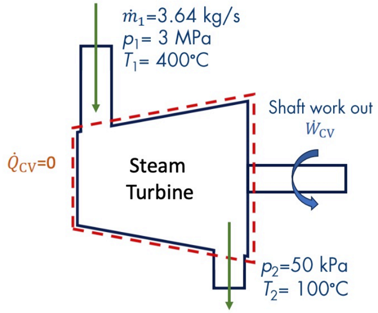
$$\dot{W}_{cv} = \dot{m}(h_1 - h_2)$$

$$= 3.64\ [kg/s] \times (3231.7\ [kJ/kg] - 2407.9\ [kJ/kg]) = \boxed{3.00\ \text{MW}}$$

Ideal, reversible power output of turbine

Example (Part 2 of 2)

The actual steam turbine from Part 1 is not ideal. The water exits the turbine at 100°C. What is the isentropic efficiency of the real turbine.



The previous State 2 was idealized.

State 2a (actual) : $P_{2a} = 50$ kPa, $T_{2a} = 100°C$ → Table A-6 → $h_{2a} = 2682.4$ [kJ/kg]

$$\eta = \frac{w_a}{w_s} = \frac{h_1 - h_{2a}}{h_1 - h_{2s}} = \frac{3237.7 - 2682.4 \text{ [kJ/kg]}}{3237.7 - 2407.9 \text{ [kJ/kg]}} = \boxed{66.7\%}$$