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Turbine: (SSSF) Process

Example of a SSSF process: a steam turbine. The mass flow rate through a steam turbine is 1.5 kg/s, and the heat transfer rate from the boundaries of the turbine is 8.5 kW. Determine the power output of the turbine.
The following data are given for the steam entering and leaving the turbine.

	Inlet Conditions	Outlet Conditions
Pressure	2.0 MPa	0.1 MPa
Temperature	$350\,^0$C	
Quality		100 %
Velocity	50 m/s	200 m/s
Elevation above reference	6 m	3 m

Solution

- Sketch the turbine and define the control volume with control surface.
- The general continuity equation for a control volume becomes:

$$\dot{M}_{\rm in} - \dot{M}_{\rm out} = 0 \qquad \text{therefore} \qquad \dot{M}_{\rm in} = \dot{M}_{\rm out} = \dot{M}$$

- The general energy equation for a control volume becomes

$$\dot{Q} + \dot{W}_{\rm shaft} + \left[\dot{M}\left(h + ke + pe\right)\right]_{\rm in} - \left[\dot{M}\left(h + ke + pe\right)\right]_{\rm out} = 0$$

- Inlet conditions

$P_{\rm i} = 2\,MPa, T_{\rm i} = 350\,^0C$; From Table B-2, p. 628: $h_{\rm i} = 3137.0\,kJ/kg$,

$v_{\mathrm{i}} = 0.1386\, m^3/kg$; $\bar{V}_{\mathrm{i}} = 50\, m/s, z_{\mathrm{i}} = 6\, m.$

Therefore $ke_{\mathrm{i}} = \bar{V}/2 = (50)^2/2 = 1.25\, kJ/kg; pe_{\mathrm{i}} = gz_{\mathrm{i}} = (9.81) \times (6) = 0.059\, kJ/kg.$

• <u>Outlet conditions</u>

Saturated steam: $x = 1$, $P_{\mathrm{o}} = 0.1\, MPa$. From Table B1b, p. 624: $h_{\mathrm{o}} = 2675.5\, kJ/kg, v_{\mathrm{o}} = v_{\mathrm{g}} = 1.694\, m^3/kg, T_{\mathrm{o}} = 99.6\, ^0C, \bar{V}_{\mathrm{o}} = 200\, m/s, z_{\mathrm{o}} = 3\, m.$

Therefore $ke_{\mathrm{o}} = \bar{V}_{\mathrm{o}}^2/2 = (200)^2/2 = 20.0\, kJ/kg, pe_{\mathrm{o}} = gz_{\mathrm{o}} = (9.81) \times (3) = 0.029\, kJ/kg.$

• <u>Energy Equation: SSSF Process</u>

$$\dot{Q} + \dot{W}_{\mathrm{shaft}} + \dot{M}\left[(h_{\mathrm{i}} - h_{\mathrm{o}}) + (ke_{\mathrm{i}} - ke_{\mathrm{o}}) + (pe_{\mathrm{i}} - pe_{\mathrm{o}})\right] = 0$$

Substitution gives:

$$-8.5 + \dot{W}_{\mathrm{shaft}} + 1.5\left[(3137.0 - 2675.5) + (1.25 - 20.0) + (0.059 - 0.029)\right] = 0$$

and

$$-8.5 + \dot{W}_{\mathrm{shaft}} + 1.5\left[461.5 - 18.75 + 0.030\right] = 0$$

and

$$-8.5 + \dot{W}_{\mathrm{shaft}} + 1.5\left[442.78\right] = 0$$

Therefore

$$\dot{W}_{\mathrm{shaft}} = 8.5 - (1.5) \times (442.78) = -655.67 \qquad \left[\frac{kJ}{s}\right]$$

The power **out of** the turbine (CV) is

$$\dot{W}_{\mathrm{shaft}} = -0.656\, MW$$

Observe that the contribution of the potential energy is negligible. Also note that the kinetic energy of the steam exiting the turbine decreases the available work from the turbine.

Show the process on a $T - v$ diagram and a $h - s$ diagram which is called a Mollier diagram (see Fig. B.2, p. 603).