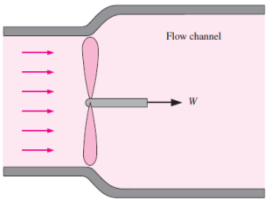
Question 2

Windmills slow down the air and cause it to fill a larger channel as it passes through the blades. Consider a circular windmill with a 7-m diameter rotor in a 10 m/s wind on a day with an atmospheric pressure of 100 kPa and a temperature of 20 Celsius. The wind speed behind the windmill is measured at 9 m/s. Determine the diameter of the channel downstream from the rotor and the power produced by this windmill, presuming that the air is incompressible.



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Answer 2

The flow of air through a flow channel is considered. The diameter of the wind channel downstream from the rotor and the power produced by the windmill are to be determined.

Analysis The specific volume of the air is

$$v = \frac{RT}{P} = \frac{(0.287 \text{ kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(293 \text{ K})}{100 \text{ kPa}} = 0.8409 \text{ m}^3/\text{kg}$$

The diameter of the wind channel downstream from the rotor is

$$A_1V_1 = A_2V_2 \longrightarrow (\pi D_1^2/4)V_1 = (\pi D_2^2/4)V_2$$

$$\longrightarrow D_2 = D_1\sqrt{\frac{V_1}{V_2}} = (7 \text{ m})\sqrt{\frac{10 \text{ m/s}}{9 \text{ m/s}}} = \mathbf{7.38 m}$$

The mass flow rate through the wind mill is

$$\dot{m} = \frac{A_1V_1}{v} = \frac{\pi(7 \text{ m})^2(10 \text{ m/s})}{4(0.8409 \text{ m}^3/\text{kg})} = 457.7 \text{ kg/s}$$

The power produced is then

$$\dot{W} = \dot{m}\frac{V_1^2 - V_2^2}{2} = (457.7 \text{ kg/s})\frac{(10 \text{ m/s})^2 - (9 \text{ m/s})^2}{2}\left(\frac{1 \text{ kJ/kg}}{1000 \text{ m}^2/\text{s}^2}\right) = \mathbf{4.35 kW}$$

Question 3 :

A 0.2 m^3 fully insulated rigid container is divided into two equal volumes by ony a thin membrane. Initially, one of these chambers is filled with air at a pressure of 700 kPa and 37 ^{0}C while the other chamber is evacuated.

C_p = 1.005 kJ/kg.K C_v = 0.721 kJ/kg.K

a) Determine the change in internal energy of the air when the membrane is ruptured.
b) Determine the final air pressure in the container

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Answer 3

a) The total internal energy does not change. Therefore, the temperature does not change
b) Given that the ideal gas law applies, the pressure is halved and becomes 350 kPa

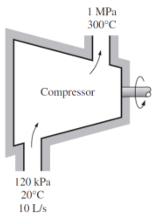
Question 4:

An adiabatic air compressor compresses 10 liter/s of air as 120 kPa and 20^0 C to 1000 kPa and 300^0 C.

At room temperature: C_p = 1.005 kJ/kg.K $\quad$ C_v = 0.721 kJ/kg.K. At 300 ^{0}C : C_p = 1.031 kJ/kg.K
C_v = 0.753 kJ/kg.K; R_{air} = 0.287 kPa·m^3/kg·K

Determine

a) The amount of work required by the compressor in kJ/kg and
b) The power required to drive the air compressor in kW



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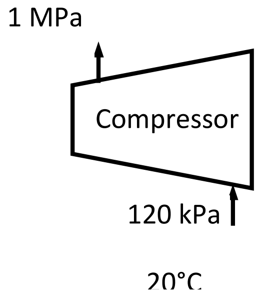
Analysis (*a*) There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the compressor as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta\dot{E}_{system}^{\nearrow 0\ (steady)}}_{\substack{\text{Rate of change in internal, kinetic,}\\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{W}_{in} + \dot{m}h_1 = \dot{m}h_2 \quad (\text{since } \Delta ke \cong \Delta pe \cong 0)$$

$$\dot{W}_{in} = \dot{m}(h_2 - h_1) = \dot{m}c_p(T_2 - T_1)$$



Thus,

$$w_{in} = c_p(T_2 - T_1) = (1.018\ \text{kJ/kg}\cdot\text{K})(300 - 20)\text{K} = \mathbf{285.0 kJ/kg}$$

(*b*) The specific volume of air at the inlet and the mass flow rate are

$$v_1 = \frac{RT_1}{P_1} = \frac{(0.287\ \text{kPa}\cdot\text{m}^3/\text{kg}\cdot\text{K})(20 + 273\ \text{K})}{120\ \text{kPa}} = 0.7008\ \text{m}^3/\text{kg}$$

$$\dot{m} = \frac{\dot{V}_1}{v_1} = \frac{0.010\ \text{m}^3/\text{s}}{0.7008\ \text{m}^3/\text{kg}} = 0.01427\ \text{kg/s}$$

Then the power input is determined from the energy balance equation to be

$$\dot{W}_{in} = \dot{m}c_p(T_2 - T_1) = (0.01427\ \text{kg/s})(1.018\ \text{kJ/kg}\cdot\text{K})(300 - 20)\text{K} = \mathbf{4.068 kW}$$

Question 5:

A geothermal plant uses geothermal water extracted at 160^0 C at a rate of 440 kg/s as the heat The actual rate of heat rejection from this plant source and produces 22 MW of net power. If the environmental temperature is 25^0 C, determine

a) The actual thermal efficiency
b) The maximum possible thermal efficiency

The water is to be regarded as a saturated liquid at all times

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6-88 A geothermal power plant uses geothermal liquid water at 160ºC at a specified rate as the heat source. The actual and maximum possible thermal efficiencies and the rate of heat rejected from this power plant are to be determined.

Assumptions **1** The power plant operates steadily. **2** The kinetic and potential energy changes are zero. **3** Steam properties are used for geothermal water.

Properties Using saturated liquid properties, the source and the sink state enthalpies of geothermal water are (Table A-4)

$$\left.\begin{array}{l} T_{\text{source}} = 160°\text{C} \\ x_{\text{source}} = 0 \end{array}\right\} h_{\text{source}} = 675.47 \text{ kJ/kg}$$

$$\left.\begin{array}{l} T_{\text{sink}} = 25°\text{C} \\ x_{\text{sink}} = 0 \end{array}\right\} h_{\text{sink}} = 104.83 \text{ kJ/kg}$$

Analysis (*a*) The rate of heat input to the plant may be taken as the enthalpy difference between the source and the sink for the power plant

$$\dot{Q}_{\text{in}} = \dot{m}_{\text{geo}}(h_{\text{source}} - h_{\text{sink}}) = (440 \text{ kg/s})(675.47 - 104.83) \text{ kJ/kg} = 251{,}083 \text{ kW}$$

The actual thermal efficiency is

$$\eta_{\text{th}} = \frac{\dot{W}_{\text{net,out}}}{\dot{Q}_{\text{in}}} = \frac{22 \text{ MW}}{251.083 \text{ MW}} = \mathbf{0.0876} = \mathbf{8.8\%}$$

(*b*) The maximum thermal efficiency is the thermal efficiency of a reversible heat engine operating between the source and sink temperatures

$$\eta_{\text{th,max}} = 1 - \frac{T_L}{T_H} = 1 - \frac{(25+273) \text{ K}}{(160+273) \text{ K}} = \mathbf{0.312} = \mathbf{31.2\%}$$

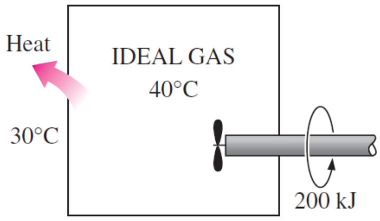
(*c*) Finally, the rate of heat rejection is

$$\dot{Q}_{\text{out}} = \dot{Q}_{\text{in}} - \dot{W}_{\text{net,out}} = 251.1 - 22 = \mathbf{229.1 MW}$$

Question 6:

A rigid tank contains an ideal gas at 40^0 C that is being stirred by a paddle wheel. The paddle wheel does 200 kJ of work on the ideal gas. It is observed that the temperature of the ideal gas remains constant during the stirring as a result of the heat transfer between the system and the surroundings which is at 30^0 C.

Determine the entropy change of the ideal gas



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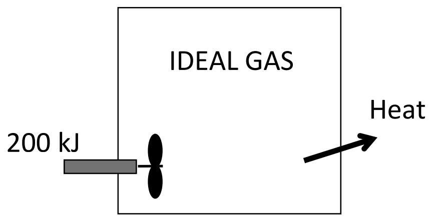
Answer 6

7-23 A rigid tank contains an ideal gas that is being stirred by a paddle wheel. The temperature of the gas remains constant as a result of heat transfer out. The entropy change of the gas is to be determined.

Assumptions The gas in the tank is given to be an ideal gas.

Analysis The temperature and the specific volume of the gas remain constant during this process. Therefore, the initial and the final states of the gas are the same. Then $s_2 = s_1$ since entropy is a property. Therefore,



$$\Delta S_{sys} = \mathbf{0}$$

Question 7 :

Air is being used as the working fluid in a simple ideal Brayton cycle that has a pressure ratio of 12, a compressor inlet temperature of 300 K and a turbine inlet temperature of 1000K.

a) Determine the required mass flow rate of air for a net power output of 70 MW, assuming that both the compressor and the turbine have an isentropic efficiency of 100 %
b) Determine the required mass flow rate of air for a net power output of 70 MW, assuming that both the compressor and the turbine have an isentropic efficiency of 85 %

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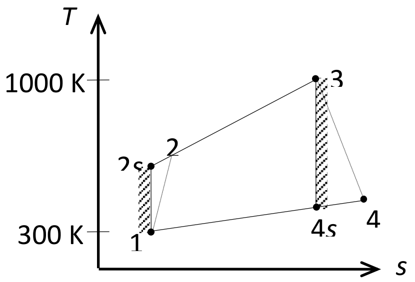
Answer 7:

9-98 A gas turbine power plant that operates on the simple Brayton cycle with air as the working fluid has a specified pressure ratio. The required mass flow rate of air is to be determined for two cases.

Assumptions **1** Steady operating conditions exist. **2** The air-standard assumptions are applicable. **3** Kinetic and potential energy changes are negligible. **4** Air is an ideal gas with constant specific heats.

Properties The properties of air at room temperature are c_p = 1.005 kJ/kg·K and k = 1.4 (Table A-2).



Analysis (*a*) Using the isentropic relations,

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (300\text{ K})(12)^{0.4/1.4} = 610.2\text{ K}$$

$$T_{4s} = T_3\left(\frac{P_4}{P_3}\right)^{(k-1)/k} = (1000\text{ K})\left(\frac{1}{12}\right)^{0.4/1.4} = 491.7\text{ K}$$

$$w_{\text{s,C,in}} = h_{2s} - h_1 = c_p(T_{2s} - T_1) = (1.005\text{ kJ/kg}\cdot\text{K})(610.2 - 300)\text{K} = 311.75\text{ kJ/kg}$$

$$w_{\text{s,T,out}} = h_3 - h_{4s} = c_p(T_3 - T_{4s}) = (1.005\text{ kJ/kg}\cdot\text{K})(1000 - 491.7)\text{K} = 510.84\text{ kJ/kg}$$

$$w_{\text{s,net,out}} = w_{\text{s,T,out}} - w_{\text{s,C,in}} = 510.84 - 311.75 = 199.1\text{ kJ/kg}$$

$$\dot{m}_s = \frac{\dot{W}_{\text{net,out}}}{w_{\text{s,net,out}}} = \frac{70{,}000\text{ kJ/s}}{199.1\text{ kJ/kg}} = \mathbf{352\ \ kg/s}$$

(*b*) The net work output is determined to be

$$w_{\text{a,net,out}} = w_{\text{a,T,out}} - w_{\text{a,C,in}} = \eta_T w_{\text{s,T,out}} - w_{\text{s,C,in}} / \eta_C$$
$$= (0.85)(510.84) - 311.75/0.85 = 67.5\text{ kJ/kg}$$

$$\dot{m}_a = \frac{\dot{W}_{\text{net,out}}}{w_{\text{a,net,out}}} = \frac{70{,}000\text{ kJ/s}}{67.5\text{ kJ/kg}} = \mathbf{1037\ \ kg/s}$$