4.g If you throttle a saturated liquid what happens to the fluid state? What if this is done to an ideal gas?

The throttle process is approximated as a constant enthalpy process. Changing the state from saturated liquid to a lower pressure with the same h gives a two-phase state so some of the liquid will vaporize and it becomes colder.

If the same process happens in an ideal gas then same h gives the same temperature (h a function of T only) at the lower pressure.

4.6 A windmill takes a fraction of the wind kinetic energy out as power on a shaft. In what manner does the temperature and wind velocity influence the power? Hint: write the power as mass flow rate times specific work.

The work as a fraction \( f \) of the flow of kinetic energy becomes

\[
\dot{W} = \dot{m}w = \dot{m} f \frac{1}{2} V^2 = \rho A V_{in} f \frac{1}{2} V^2
\]

so the power is proportional to the velocity cubed. The temperature enters through the density, so assuming air is ideal gas

\[
\rho = \frac{1}{\nu} = \frac{P}{RT}
\]

and the power is inversely proportional to temperature.

A windmill farm west of Denmark in the North Sea.
A 0.6 m diameter household fan takes air in at 98 kPa, 20°C and delivers it at 105 kPa, 21°C with a velocity of 1.5 m/s. What are the mass flow rate (kg/s), the inlet velocity and the outgoing volume flow rate in m³/s?

Solution:

Continuity Eq. \[ \dot{m}_i = \dot{m}_e = AV/v \]

Ideal gas \[ v = RT/P \]

Area: \[ A = \frac{\pi}{4} D^2 = \frac{\pi}{4} \times 0.6^2 = 0.2827 \text{ m}^2 \]

\[ \dot{V}_e = AV_e = 0.2827 \times 1.5 = 0.4241 \text{ m}^3/\text{s} \]

\[ v_e = \frac{RT_e}{P_e} = \frac{0.287 \times (21 + 273)}{105} = 0.8036 \text{ m}^3/\text{kg} \]

\[ \dot{m}_i = \dot{V}_e/v_e = 0.4241/0.8036 = 0.528 \text{ kg/s} \]

\[ AV_i/v_i = \dot{m}_i = AV_e/v_e \]

\[ V_i = V_e \times (v_i/v_e) = V_e \times \frac{RT_i}{P_i v_e} = 1.5 \times \frac{0.287 \text{ kJ/kg-K} \times (20 + 273) \text{ K}}{98 \text{ kPa} \times 0.8036 \text{ m}^3/\text{kg}} = 1.6 \text{ m/s} \]
Superheated vapor ammonia enters an insulated nozzle at 30°C, 1000 kPa, shown in Fig. P4.25, with a low velocity and at the steady rate of 0.01 kg/s. The ammonia exits at 300 kPa with a velocity of 450 m/s. Determine the temperature (or quality, if saturated) and the exit area of the nozzle.

Solution:

C.V. Nozzle, steady state, 1 inlet and 1 exit flow, insulated so no heat transfer.

Energy Eq.4.13: \[ q + h_i + \frac{V_i^2}{2} = h_e + \frac{V_e^2}{2}, \]

Process: \[ q = 0, \quad V_i = 0 \]

Table B.2.2: \[ h_i = 1479.1 = h_e + \frac{450^2}{2 \times 1000} \quad \Rightarrow \quad h_e = 1377.85 \text{ kJ/kg} \]

Table B.2.1: \[ P_e = 300 \text{ kPa} \quad \text{Sat. state at } -9.24^\circ\text{C} : \]
\[ h_e = 1377.85 = 137.89 + x_e \times 1293.82, \]
\[ \Rightarrow x_e = 0.9584, \quad v_e = 0.001536 + x_e \times 0.40566 = 0.3903 \text{ m}^3/\text{kg} \]

\[ A_e = \dot{m}_e v_e / V_e = 0.01 \times 0.3903 / 450 = 8.67 \times 10^{-6} \text{ m}^2 \]
Saturated liquid R-134a at 25°C is throttled to 300 kPa in a refrigerator. What is the exit temperature? Find the percent increase in the volume flow rate.

Solution:
Steady throttle flow. Assume no heat transfer and no change in kinetic or potential energy.

\[ h_e = h_i = h_{fg C} = 234.59 \text{ kJ/kg} = h_{fe} + x_e h_{fg e} \quad \text{at 300 kPa} \]

From table B.5.1 we get \( T_e = T_{sat} \text{ (300 kPa)} = 0.56^o \text{C} \)

Let’s use 0°C for the following (we could interpolate to get at 0.56°C)

\[ x_e = \frac{h_e - h_{fe}}{h_{fg e}} = \frac{234.59 - 200}{198.36} = 0.1744 \]

\[ \nu_e = \nu_f + x_e \nu_{fg} = 0.000773 + 0.06842 = 0.0127 \text{ m}^3/\text{kg} \]

\[ \nu_i = \nu_{fg C} = 0.000829 \text{ m}^3/\text{kg} \]

\[ \dot{V} = m\nu \text{ so the ratio becomes} \]

\[ \frac{\dot{V}_e}{\dot{V}_i} = \frac{m\nu_e}{m\nu_i} = \frac{\nu_e}{\nu_i} = \frac{0.0127}{0.000829} = 15.32 \]

So the increase is 14.32 times or 1432%
A steam turbine has an inlet of 3 kg/s water at 1200 kPa, 350°C and velocity of 15 m/s. The exit is at 100 kPa, 150°C and very low velocity. Find the specific work and the power produced.

Solution:

Energy Eq. 4.13: \[ h_1 + \frac{1}{2} V_1^2 + gZ_1 = h_2 + \frac{1}{2} V_2^2 + gZ_2 + w_T \]

Process: \[ Z_1 = Z_2 \quad \text{and} \quad V_2 = 0 \]

Table B.1.3: \[ h_1 = 3153.59 \text{ kJ/kg}, \quad h_2 = 2776.38 \text{ kJ/kg} \]

\[ w_T = h_1 + \frac{1}{2} V_1^2 - h_2 = 3153.59 + \frac{15^2}{2000} - 2776.38 = 377.3 \text{ kJ/kg} \]

(remember to convert m^2/s^2 = J/kg to kJ/kg by dividing with 1000)

\[ \dot{W}_T = \dot{m} \times w_T = 3 \text{ kg/s} \times 377.3 \text{ kJ/kg} \]

\[ = 1132 \text{ kW} \]

Air at 20 m/s, 1500 K, 875 kPa with 5 kg/s flows into a turbine and it flows out at 25 m/s, 850 K, 105 kPa. Find the power output using constant specific heats.

Solution:

Energy Eq. 4.13: \[ h_1 + \frac{1}{2} V_1^2 + gZ_1 = h_2 + \frac{1}{2} V_2^2 + gZ_2 + w_T \]

Process: \[ Z_1 = Z_2 \quad \text{and} \quad V_2 = 0 \]

Table A.5: \[ C_p = 1.004 \text{ kJ/kg-K} \]

\[ w_T = h_1 + \frac{1}{2} V_1^2 - h_2 - \frac{1}{2} V_2^2 = C_p(T_1 - T_2) + \frac{1}{2} V_1^2 - \frac{1}{2} V_2^2 \]

\[ = 1.004 \text{ kJ/kg-K} \times (1500 - 850) \text{ K} + \frac{20^2 - 25^2}{2000} \text{ (m}^2/\text{s}^2) \times (\text{kJ/J}) \]

\[ = 652.5 \text{ kJ/kg} \]

(remember to convert m^2/s^2 = J/kg to kJ/kg by dividing with 1000)

\[ \dot{W}_T = \dot{m} \times w_T = 5 \text{ kg/s} \times 652.5 \text{ kJ/kg} \]

\[ = 3263 \text{ kW} \]
A windmill with rotor diameter of 20 m takes 40% of the kinetic energy out as shaft work on a day with 20°C and wind speed of 35 km/h. What power is produced?

Solution:

Continuity Eq. \[ \dot{m}_i = \dot{m}_c = \dot{m} \]

Energy \[ \dot{m} (h_i + \frac{1}{2} V_i^2 + gZ_i) = \dot{m}(h_c + \frac{1}{2} V_c^2 + gZ_c) + \dot{W} \]

Process information: \[ \dot{W} = \dot{m} \frac{1}{2} V_i^2 \times 0.4 \]

\[ \dot{m} = \rho A V = A V_i / v_i \]

\[ A = \frac{\pi}{4} D^2 = \frac{\pi}{4} 20^2 = 314.16 \text{ m}^2 \]

\[ v_i = \frac{RT_i}{P_i} = \frac{0.287 \times 293}{101.3} = 0.8301 \text{ m}^3/\text{kg} \]

\[ V_i = 35 \text{ km/h} = \frac{35 \times 1000}{3600} = 9.7222 \text{ m/s} \]

\[ \dot{m} = A V_i / v_i = \frac{314.16 \times 9.7222}{0.8301} = 3679.5 \text{ kg/s} \]

\[ \frac{1}{2} V_i^2 = \frac{1}{2} 9.7222^2 = 47.26 \text{ J/kg} \]

\[ \dot{W} = 0.4 \dot{m} \frac{1}{2} V_i^2 = 0.4 \times 3679.5 \text{ kg/s} \times 47.26 \text{ J/kg} = 69557 \text{ W} \]

\[ = 69.56 \text{ kW} \]
A boiler section boils 3 kg/s saturated liquid water at 2000 kPa to saturated vapor in a reversible constant-pressure process. Find the specific heat transfer in the process.

C.V. Boiler. Steady state single inlet and exit flow. Neglect potential energy and since velocities are low we neglect kinetic energies.

Energy Eq. 4.13: \( q + h_i = h_e \)

From Table B.1.2: \( h_i = 908.77 \) kJ/kg
Table B.1.3: \( h_e = 2799.51 \) kJ/kg

\[ q = h_e - h_i = 2799.51 - 908.77 = 1890.74 \text{ kJ/kg} \]
A condenser (heat exchanger) brings 1 kg/s water flow at 10 kPa quality 95% to saturated liquid at 10 kPa, as shown in Fig. P4.91. The cooling is done by lake water at 20°C that returns to the lake at 30°C. For an insulated condenser, find the flow rate of cooling water.

Solution:

C.V. Heat exchanger

![Diagram of heat exchanger]

Table B.1.1: \( h_{20} = 83.94 \text{ kJ/kg} \), \( h_{30} = 125.77 \text{ kJ/kg} \)

Table B.1.2: \( h_{95\%, 10\text{kPa}} = 191.81 + 0.95 \times 2392.82 = 2465 \text{ kJ/kg} \)

\( h_{f, 10\text{kPa}} = 191.81 \text{ kJ/kg} \)

Energy Eq.4.10: \( \dot{m}_{\text{cool}}h_{20} + \dot{m}_{\text{H2O}}h_{30} = \dot{m}_{\text{cool}}h_{30} + \dot{m}_{\text{H2O}}h_{f, 10\text{kPa}} \)

\[ \dot{m}_{\text{cool}} = \dot{m}_{\text{H2O}} \frac{h_{95\%} - h_{f, 10\text{kPa}}}{h_{30} - h_{20}} = 1 \text{ kg/s} \times \frac{2465 - 191.81}{125.77 - 83.94} = 54.3 \text{ kg/s} \]