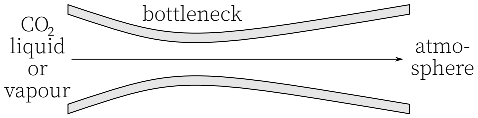
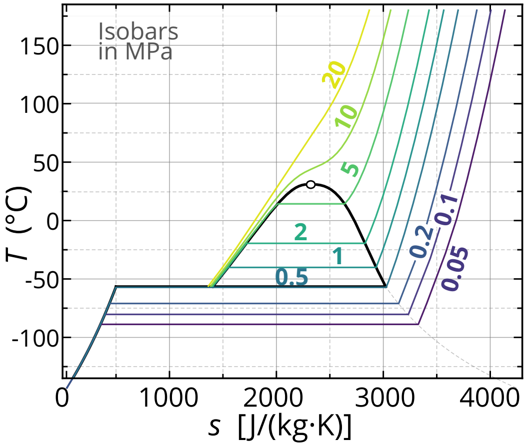
9. CO₂ FIRE EXTINGUISHER (8 points) — *Jaan Kalda.* A fire extinguisher contains liquid CO_2 in equilibrium with its saturated vapour at room temperature $T_0 = 298\,\mathrm{K}$. Consider two scenarios: **(a)** the container is held upside-down so that the liquid phase flows to the nozzle; **(b)** it is held upright so that the saturated vapour flows to the nozzle. The nozzle has the shape of a converging–diverging channel (see figure), and the flow through it can be modelled as reversible and adiabatic. Atmospheric pressure is $p_{\mathrm{atm}} = 1.0 \times 10^5\,\mathrm{Pa}$; the CO_2 triple point is at $(T_\mathrm{t}, p_\mathrm{t}) = (216.6\,\mathrm{K}, 0.518\,\mathrm{MPa})$.



The temperature–entropy diagram of CO_2 with isobars is provided below.



i) *(1.5 points)* Identify the phase or phases present and their temperature in the stream emerging from the nozzle.

ii) *(3.5 points)* Find the mass fraction x of solid CO_2 in the stream for both scenarios.

iii) *(3 points)* Now consider an arbitrary pure substance in equilibrium with its saturated vapour at temperature T, and suppose that only the vapour (not the liquid) escapes through a nozzle, undergoing reversible adiabatic expansion. Under what condition on the vaporisation latent heat L (per unit mass), the isobaric specific heat of the vapour c_p, and the temperature T does a fraction of the escaping vapour condense into droplets, even for a vanishingly small pressure drop? Does condensation occur for water vapour at $T = 373\,\mathrm{K}$ ($L \approx 2260\,\mathrm{kJ \cdot kg^{-1}}$, $c_p \approx 2.0\,\mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$)?