# SELF-REFRIGERATION IN A PROPANE VESSEL

**Statement**

Internal pressure in a propane vessel of 100 m$^3$ is kept at 0.6 MPa by bleeding a small amount of liquid, throttling it inside the vessel to atmospheric pressure, passing it through a heat exchanger, and finally venting it out. For atmospheric conditions at 30 °C and 100 kPa, evaluate:

a)      A sketch of the equipment and the process in the *T-s* diagram.

b)      Inside temperature.

c)      Vapour mass-fraction just after throttling.

d)      Enthalpy changes at each stage.

e)      Relation between bled mass flow-rate and overall thermal conductance of the vessel.

🟥Para mantener una presión de 0,6 MPa en un tanque de propano de 100 m$^3$ se toma un pequeño flujo de propano del interior, se expande en una válvula hasta la presión atmosférica, se pasa por un cambiador de calor (todo ello dentro del tanque) y finalmente se expulsa al exterior, que está a 30 °C y 100 kPa. Se pide:

a)      Esquema de la instalación y representación del proceso en un diagrama *T-s*.

b)      Temperatura dentro del tanque.

c)      Fracción másica de vapor después de la válvula.

d)      Variación de entalpía del propano desde el tanque al exterior.

e)      Relación entre el gasto de propano y la transmitancia térmica del tanque.

**Solution**.      a) A sketch of the equipment and the process in the *T-s* diagram.
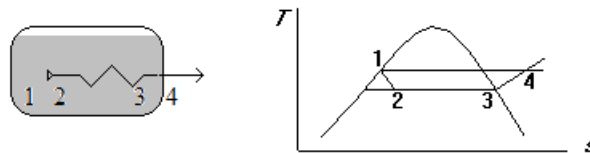


Fig. 1. Sketch of the equipment and the process.

b)      Inside temperature.
        Using Antoine equation:

$$\ln\left(\frac{p}{p_0}\right) = A - \frac{B}{\dfrac{T}{T_0} + C}$$

with *A*=13.71, *B*=1873 and *C*=−25.10 with $T_0$=1 K and $p_0$=1 kPa, one gets the two-phase temperature of propane at 0.6 MPa, which is 281 K (8 °C). This is the temperature inside the tank, i.e. at point 1.

c)      Vapour mass-fraction just after throttling.
        After throttling, Antoine equation gives 231 K (-42 °C) for the two-phase temperature at 100 kPa atmospheric pressure (its boiling point). The energy balance from 1 to 2 is

$h_1=h_2=h_{2L}+xh_{2LV}$, and, using the perfect substance model one gets $x=(h_1-h_{2L})/h_{2LV}=c_L(T_1-T_2)/h_{2LV}=2140\cdot(281-231)/430000=0.25$, where values for $c_L$ and $h_{2LV}$ are obtained from [tabulations](#).

d)  Enthalpy changes at each stage.

At the valve $h_2-h_1=0$; during vaporization $h_3-h_2=(1-x)h_{LV}=(1-0.25)\cdot430=320$ kJ/kg; during gas reheating $h_4-h_3=c_p\Delta T=1570\cdot(281-231)=78$ kJ/kg. However, it is not practical to take advantage of this last cooling term, because it would require a long heat exchanger (infinite, indeed, to reach a zero temperature approach); a more practical design is to neglect that term and rely only on the vaporization cooling, letting the gas to escape at state 3 instead of at state 4 (Fig. 1).

e)  Relation between bled mass flow-rate and overall thermal conductance of the vessel.

The cooling is intended to compensate the heat input through the tank wall, $\dot{Q}=KA\Delta T=KA(T_0-T_1)$, where $K$ is the global thermal conductance, accounting for the thermal conductivity through the wall material, and the thermal convection through the two boundary layers: the outside air, and the inside propane). The energy balance for the whole tank (including the cooling device) as an open system with one opening, $\Delta E=Q+W+\sum\int h_{te}dm_e$, becomes (at quasi-steady state):

$$\dot{Q}=\dot{m}\Delta h=KA\Delta T \quad \rightarrow \quad \dot{m}=KA\frac{T_0-T_1}{h_3-h_1},$$

with the meaning that, for a given global heat conductance with the ambient, $K$, and given external tank area $A$, the boil-off flow-rate required, $\dot{m}$, is proportional to the temperature jump wanted (dictated by the maximum pressure jump allowed).

[Back](#)