

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 $30 \text{ }^\circ\text{C}$ and 100 kPa , evaluate:

- A sketch of the equipment and the process in the T - s diagram.
- Inside temperature.
- Vapour mass-fraction just after throttling.
- Enthalpy changes at each stage.
- Relation between bled mass flow-rate and overall thermal conductance of the vessel.

Para mantener una presión de $0,6 \text{ MPa}$ 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 $30 \text{ }^\circ\text{C}$ y 100 kPa . Se pide:

- Esquema de la instalación y representación del proceso en un diagrama T - s .
- Temperatura dentro del tanque.
- Fracción másica de vapor después de la válvula.
- Variación de entalpía del propano desde el tanque al exterior.
- 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.

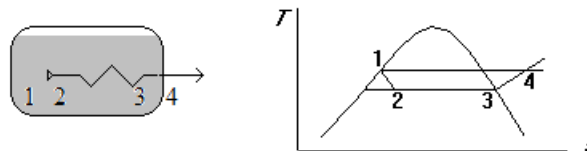


Fig. 1. Sketch of the equipment and the process.

- b) Inside temperature.

Using Antoine equation:

$$\ln \frac{p}{p_0} = A - \frac{B}{T} + C$$

with $A=13.71$, $B=1873$ and $C=-25.10$ with $T_0=1 \text{ K}$ and $p_0=1 \text{ kPa}$, one gets the two-phase temperature of propane at 0.6 MPa , which is 281 K ($8 \text{ }^\circ\text{C}$). 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 ($-42 \text{ }^\circ\text{C}$) 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 $h_3-h_2=(1-x)h_{LV}=(1-0.25)\cdot 430=320$ 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, $\Delta E=Q+W+\sum h_{te}dm_e$, becomes (at quasi-steady state):

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

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).

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