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Calc of Argon condensed and N2 vaporized for a given heat exchange:

This calculation takes a heat load and determines the Argon vaporization rate from that heat load and the flow of liquid Nitrogen required to condense back this vaporized Argon.

The heat load used is twice the estimated heat absorbed through the tank insulation.

Heat Absorbed by LAPD Tank (result of separate calc)

$Heat_{Absorbed} := 2103 \cdot W$

Q for condensing/vaporizing taken as twice the estimated tank heat absorbed

$Q_{cond} := 2 \cdot Heat_{Absorbed}$ $Q_{cond} = 4206 \cdot W$

Argon Data

Argon physical properties from NIST REFPROP

Argon Liquid Density

$Ldens_{Ar} := 1395 \cdot \frac{kg}{m^3}$

Argon Heat of Vaporization

$Hvap_{Ar} := 161 \cdot \frac{kJ}{kg}$

Nitrogen Data

Nitrogen physical properties from NIST REFPROP

Nitrogen Liquid Density

$Ldens_{N2} := 807 \cdot \frac{kg}{m^3}$

Nitrogen Vapor Density

$Vdens_{N2} := 4.5 \cdot \frac{kg}{m^3}$

Nitrogen Heat of Vaporization

$Hvap_{N2} := 199 \cdot \frac{kJ}{kg}$

Nitrogen Gas Viscosity

Nitrogen Vapor Density at standard conditions

@ 78 K

$\mu_{N2.v} := 0.0549 \cdot cpoise$

$Vdens_{N2.STD} := 0.073841 \cdot \frac{lb}{ft^3}$

Calc of Argon vaporized and then condensed

The vaporized Argon becomes the condensed Argon in the condenser. The mass rate of Argon is equal to Q divided by the heat of vaporization of Argon. The Argon liquid flow rate out of the condenser is calculated from the mass rate and Argon liquid density.

$mflow_{Ar} := \frac{Q_{cond}}{Hvap_{Ar}}$ $\qquad mflow_{Ar} = 207.339 \cdot \frac{lb}{hr}$

$Lflow_{Ar} := \frac{mflow_{Ar}}{Ldens_{Ar}}$ $\qquad Lflow_{Ar} = 2.381 \cdot \frac{ft^3}{hr}$ $\qquad Lflow_{Ar} = 0.297 \cdot gpm$

Calc of Nitrogen flow required

The Argon condenser uses liquid Nitrogen coolant. The mass rate of Nitrogen vaporized is calculated from Q and the heat of vaporization of Nitrogen. The mass rate of Nitrogen entering the condenser is the Nitrogen vaporized divided by an outlet vapor quality. The vapor quality is set to 70% to keep the Nitrogen side wet for better heat transfer. The Nitrogen liquid flow rate into the condenser is calculated from the mass rate of Nitrogen and Nitrogen liquid density.

$Qual_{vapor} := 70\%$

$mflow_{N2} := \frac{Q_{cond}}{Hvap_{N2}} \cdot \frac{1}{Qual_{vapor}}$ $\qquad mflow_{N2} = 239.638 \cdot \frac{lb}{hr}$

$Lflow_{N2} := \frac{mflow_{N2}}{Ldens_{N2}}$ $\qquad Lflow_{N2} = 0.593 \cdot gpm$

$$Vflow_{N2.STD} := \frac{mflow_{N2}}{Vdens_{N2.STD}} \qquad Vflow_{N2.STD} = 3245 \cdot \frac{ft^3}{hr}$$

Calc max Cv for N2 solenoid valve (volumetric flow units)

ref: Fischer Control Valve Handbook, 4th ed.

piping geometry factor

$F_p := 1$ assumed straight in / out piping with no reducer or expander

equation constant

$$N_1 := 1 \cdot \frac{gpm}{psi^{\frac{1}{2}}}$$

the equation constant makes the Cv unitless

upstream absolute static pressure

$P_1 := 30 \cdot psi + 14.69 \cdot psi$

$P_1 = 44.69 \cdot psi$

downstream absolute static pressure

$P_2 := 5 \cdot psi + 14.69 \cdot psi$

$P_2 = 19.69 \cdot psi$

$$G_f := \frac{Ldens_{N2}}{62.37 \cdot \frac{lb}{ft^3}} \qquad G_f = 0.808$$

liquid specific gravity (relative to water @ 60F)

$$Cv_{N2} := \frac{Lflow_{N2}}{N_1 \cdot F_p \cdot \sqrt{\frac{P_1 - P_2}{G_f}}} \qquad Cv_{N2} = 0.107$$

Pipe Data

Pipe Equivalent Length

$L := 300 \cdot ft$

Pipe Roughness

$\varepsilon := 0.0005 \cdot ft$

Pipe Outside diameter

$Pipe_{OD} := 0.625 \cdot in$

Pipe Wall Thickness

$Pipe_{wall} := 0.049 \cdot in$

$Pipe_{ID} := Pipe_{OD} - 2 \cdot Pipe_{wall} = 0.527 \cdot in$

Piping data is for Type K copper piping

Pipe Velocity

$$Vel_{pipe} := \frac{Lflow_{N2}}{\pi \cdot \left(\frac{Pipe_{ID}}{2}\right)^2} = 0.872 \cdot \frac{ft}{s}$$

Reynolds number

$$Re := \frac{Vel_{pipe} \cdot Pipe_{ID} \cdot Ldens_{N2}}{\mu_{N2.v}} = 52313$$

Friction factor calculation

Guess $f := 0.5$

$$\text{Given} \quad \frac{1}{\sqrt{f}} = -4.0 \cdot \log\left(\frac{\varepsilon}{3.7 \cdot Pipe_{ID}} + \frac{1.256}{Re \cdot \sqrt{f}}\right)$$

valid for Re>4000

$f := Find(f) \qquad f = 0.0102$

Pressure drop

$$\Delta P := \frac{2 \cdot L \cdot Ldens_{N2} \cdot \left[\frac{Lflow_{N2}}{\left(\frac{Pipe_{ID}}{2}\right)^2 \cdot \pi}\right]^2 \cdot f}{Pipe_{ID}}$$

$$\Delta P = 1.15 \cdot psi$$