Calculation By: M. Adamowski
Checked By:
Project: LAPD
Date: 12/15/09
Revision: C

N2 Supply Heat and Mass Balance

N2 venting due to heat absorbed by N2 trailer and piping upto LAPD condenser.

Nitrogen Data

Nitrogen physical properties from NIST REPROP

Nitrogen boiling temperature

$T_{N2} := 77.3 \cdot K$

Nitrogen liquid thermal cond.

$k_{N2\_liq} := 144 \cdot \frac{mW}{m \cdot K}$

Nitrogen liquid density

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

Nitrogen Heat of Vaporization

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

Nitrogen Vapor Density

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

Nitrogen Liquid Viscosity

$\mu_{N2\_l} := .162 \cdot cP$

Nitrogen Liquid specific heat

$Cp_{N2\_l} := 0.77 \cdot \frac{kJ}{kg \cdot K}$

Nitrogen Vapor Density at standard conditions

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

Nitrogen Delivered Price - Fermi (2009 price per 100 SCF)

$N2_{price} := \frac{0.35}{100 \cdot SCF}$

Pipe Data

Pipe Length

$L := 300 \cdot ft$

Pipe OD 1" Copper K Pipe

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

Pipe Insulation Thickness

$Pipe_{insul} := 3.4 \cdot in$

$Pipe_{insul.OD} := Pipe_{OD} + Pipe_{insul} = 4.025 \cdot in$

Piping data is for Type K copper piping with polyurethane insulation like Rovanco or Tricon piping.

Pipe Insulation k-factor

$k_{pipe.insul} := 0.021 \cdot \frac{W}{m \cdot K}$

$k_{pipe.insul} = 0.1456 \cdot \frac{BTU \cdot in}{hr \cdot ft^2 \cdot R}$

The insulation k is slightly higher than Rovanco's and slightly lower than Tricon's.

Outside Temperature

$T_{out} := 300 \cdot K$

300 K is 80.3 F

Liquid N2 Temperature

$T_{N2} := 78 \cdot K$

Heat Load on N2 Supply piping

The N2 supply piping is assumed to pre-insulated copper piping. The supply piping size is larger than what would be needed to deliver just liquid to provide capacity to accomodate N2 vapor. There is a phase separator at the end of the pipe.

Copper Piping Surface Area

$$Area_{piping} := 2\pi \cdot \left(\frac{Pipe_{OD}}{2}\right) \cdot L \qquad Area_{piping} = 49.1 \cdot ft^2$$

Piping Heat Absorbed

$$Piping_Q := \frac{k_{pipe.insul} \cdot Area_{piping}}{Pipe_{insul}} \cdot \left(T_{out} - T_{N2}\right) \qquad Piping_Q = 246 \cdot W$$

Rate of N2 Vapor Generated by Piping Heat

$$V\_N2_{piping} := \frac{Piping_Q}{Hvap_{N2}} \qquad V\_N2_{piping} = 9.8 \cdot \frac{lb}{hr}$$

N2 Vapor From N2 Trailer Heat

The N2 Vapor generated by the N2 trailer is an evaporation rate based on the size of the tank. A 4000 gallon horizontal truck mounted N2 tank has an evaporation rate of 0.70% per day of net capacity.

ref: Oil Field Nitrogen Tanks Specification Sheet, Chart Inc, www.chart-ind.com.

N2 Trailer Tank Capacity (Trailer #22, 3000 gal max)

$$Tank_{V.N2} := 3000 \cdot gal$$

N2 Trailer Tank Evap Factor

$$N2\_evapV_{tank} := 0.70 \cdot \frac{\%}{day}$$

N2 Trailer Evap Rate

$$V\_N2_{tank} := Tank_{V.N2} \cdot N2\_evapV_{tank} \cdot \rho_{N2\_liq} \qquad V\_N2_{tank} = 5.9 \cdot \frac{lb}{hr}$$

Back Calc of Trailer Tank Heat

$$Tank_Q := V\_N2_{tank} \cdot Hvap_{N2} = 148 \cdot W$$

Rate of Nitrogen Use

Total N2 for Heat from Piping and Trailer Tank

$$V\_N2_{pip\_tk} := V\_N2_{piping} + V\_N2_{tank} = 15.7 \cdot \frac{lb}{hr}$$

N2 Needed for LAPD Condenser

$$V\_N2_{LAPD} := 240 \cdot \frac{lb}{hr}$$

70% Vapor Quality

Total N2 flow from N2 Trailer Tank

$$V\_N2_{total} := V\_N2_{pip\_tk} + V\_N2_{LAPD} = 255.7 \cdot \frac{lb}{hr}$$

Time to Consume Full N2 Trailer Tank

$$N2\_supply_{time} := \frac{Tank_{V.N2} \cdot \rho_{N2\_liq}}{V\_N2_{total}} = 3.3 \cdot days$$

$$N2\_cost := \frac{V\_N2_{total}}{Vdens_{N2.STD}} \cdot N2_{price}$$

$$N2\_cost = 12 \cdot hr^{-1}$$

$$N2\_cost = 291 \cdot day^{-1}$$

$$N2\_cost = 1454 \cdot week^{-1}$$

$$N2\_cost = 106246 \cdot yr^{-1}$$

Nitrogen Phase Separator Sizing

A standpipe will be used as the Nitrogen phase separator

Separator Inside Diameter (sched 10)

$Sep_{ID} := 12.390 \cdot in$

Vertical Disengagement

$Sep_{disengage.H} := 2 \cdot ft$

Desired Reservoir of N2 as minutes of capacity

$N2_{reserv.t} := 10 \cdot min$

N2 Reservoir Volume Required

$$N2_{reserv.V} := \frac{V\_N2_{LAPD}}{\rho_{N2\_liq}} \cdot N2_{reserv.t} = 5.9 \cdot gal$$

Desired Min cycle time for N2 fill valve

$N2_{oper.t} := 5 \cdot min$

N2 Volume Required between Low and High

$$N2_{oper.V} := \frac{V\_N2_{LAPD}}{\rho_{N2\_liq}} \cdot N2_{oper.t} = 3 \cdot gal$$

Separator Height Required

$$Sep_H := Sep_{disengage.H} + \frac{N2_{reserv.V} + N2_{oper.V}}{\pi \cdot \left(\frac{Sep_{ID}}{2}\right)^2}$$

$Sep_H = 3.4 \cdot ft$

Nitrogen Inventory that Coils can Hold

Tubing Inside Diameter

$Tube_{ID} := 0.495 \cdot in$

Tubing Length (all coils)

$Tube_L := 20 \cdot ft + 8 \cdot ft + 27 \cdot ft$

Tubing Volume

$$\pi \cdot \left(\frac{Tube_{ID}}{2}\right)^2 \cdot Tube_L = 0.55 \cdot gal$$