CALC. TO DETERMINE NEED
FOR A
N2 PHASE SEPARATOR

D-ZERO ENGINEERING NOTE # 3823.115 -EN- 422
April 7, 1995

Russ Rucinski
RD/DØ Mech.

Approved:
Summary
A nitrogen phase separator is recommended on the liquid supply line at the helium refrigerator plant. This engineering note documents the calculations done to reach that conclusion.

Method
The steady state liquid nitrogen consumption rate for the refrigerator, VLPC and solenoid systems is about 30 gal/hr. The estimated heat leak for the piping run to the refrigerator location is 50 watts.

The calculated quality at the refrigerator was 0.032. Given this quality, a two phase flow model based on Lockhart-Martinelli and also incorporating Baker diagram nomenclature was run on TK solver.¹ The result of this program was that without the use of a phase separator we could expect a slug flow pattern with a volume fraction of gas of 65%. Based on this, I recommend that we use a phase separator to siphon off the gas before the nitrogen is sent to a standard saver type subcooler. Including the phase separator will help ensure proper operation of the subcooler. The subcooler will help us attempt to deliver single phase liquid to the nitrogen control valves.

The raw calculations follow.

¹This TK solver program was developed a few years ago and was verified during the solenoid design report era. See D-Zero engineering note 3823.111-EN-338.
LOOK AT THE NEED FOR A LN\textsubscript{2} PHASE SEPARATOR. WOULD IT DO ANY GOOD?

\textbf{HEAT LOADS:}

\begin{itemize}
  \item 400 ft from Dewar to Refrig. \times \frac{1}{3} W/F = 40 W
  \item 4 Valves \times 1.5 W\times 4 = 6 W
  \item 50 Watts
\end{itemize}

\textbf{EXPECTED FLOW RATE:}

\begin{itemize}
  \item Refrig. = 10 \text{ gpm}
  \item V LPC = 18 \text{ gpm}
  \item Solenoide = 2 \text{ gpm}
\end{itemize}

\textbf{STATE 1}

\begin{align*}
P &= 50 \text{ psia} \approx 3.5 \text{ atm} \\
\text{Sat. Liquid:} & \quad h_f = -98.938 \frac{\text{J}}{\text{g}} \\
\text{Volume} &= 1.339 \text{ cm}^3/\text{g} \\
\dot{m} &= 30 \text{ gpm} \times \frac{2785.4345 \text{ cm}^3}{1 \text{ g}} \times \frac{1 \text{ hr}}{3600 \text{ s}} \times \frac{1}{1.339 \text{ cm}^3/\text{g}} = 23.56 \frac{\text{g}}{\text{s}}
\end{align*}

\begin{align*}
Q_{12} &= \dot{m} (h_2 - h_1) \\
h_2 &= \frac{Q_{12}}{\dot{m}} + h_1 = \frac{50 \frac{\text{J}}{\text{g}}}{23.56 \frac{\text{g}}{\text{s}}} + \frac{-95.175 \frac{\text{J}}{\text{g}}}{\text{s}} = -93.053 \frac{\text{J}}{\text{g}}
\end{align*}
**LN₂ PHASE SEPARATION**

\[ \chi = \frac{h_2 - h_f}{h_g - h_f} = \frac{-93.05 \pm 98.938}{84.167 \pm 98.938} = 0.03214 \]

\[ \gamma = \frac{1}{1.323 \gamma} = 0.75986 \times \frac{3}{cm^3} \times \frac{1}{kg} \times \frac{1000 L}{m^3} \times \frac{1000 cm^3}{m^3} \]

\[ = 755.86 kg/m^3 \]

\[ \delta = \frac{1}{78.013 \gamma} = 0.01282 \times \frac{kg}{m^3} = 12.82 \frac{kg}{m^3} \]

 Plug numbers into Tk 2 phase flow model.

Per: Baker diagram we are in slug flow regime.

Per: Loch Hart Martinell volume fractions are:

\[ V_L = 34.8\% \]

\[ V_g = 65.2\% \]

\[ \Delta P_{100 K} = 0.24 \text{ psi} \]

\[ \frac{1}{2} \text{" Silicon 10 pipe} \]

I conclude we should put a phase separator before the subcooler.
St | Input | Name | Output | Unit | Comment
--- | --- | --- | --- | --- | ---
| | Lockhart Martinelli correlation for two phase pressure drop through an adiabatic horizontal pipe
| | NITROGEN FOR REFRIG. UPGRADE
| | Russ Rucinski 4/7/95
| | Steady state flow conditions
| | Demonstrates need for phase separator

| valid | 'accurate | model validity
| | flow | 'turbulen | flow type
| | f | .01692739 | friction factor ; Must enter a guess
| | epsilon | ft | pipe roughness
| | D | in | Pipe inside diameter, 1/2" sch. 10 pip
| | L | ft | Length of pipe
| | A | m² | cross sectional area
| | mdot | g/s | Total mass flow rate
| | rhoL | kg/m³ | Liquid density
| | rhog | kg/m³ | density of the gas
| | muL | μPa-s | Liquid viscosity
| | muG | μPa-s | Gas viscosity
| | sigmaL | N/m | Surface tension of liquid
| | ReL | 161500 | Reynold's # for liquid
| | mdotG | kg/s | Mass flow rate for liquid
| | ReG | 9277 | Reynold's # for gas
| | mdotG | kg/s | Mass flow rate for gas
| | dpdLL | Pa/m | ΔP/ΔL for the liquid
| | dpdLTP | Pa/m | ΔP/ΔL for the two phase
| | deltaP | psig | Total pressure drop for the pipe
| | phiL | 2.8746626 | Lockhart-Martinelli parameter
| | X | 2.8025469 | Lockhart-Martinelli parameter
| | m | L-M constant; Look up in Table 7.19
| | n | L-M constant; Look up in Table 7.19
| | CG | L-M constant; Look up in Table 7.19
| | CL | L-M constant; Look up in Table 7.19
| | C | L-M constant; Look up in Table 7.19
| | lambda | 2.8445187 | Baker diagram dimensionless parameter
| | rhoair | kg/m³ | density of air
| | rhoH2O | kg/m³ | density of water
| | sigh | 3.1030377 | Baker diagram dimensionless parameter
| | sigmaH2 | N/m | Surface tension of water
| | muH2O | μPa-s | viscosity of water
| | BakerXa | 264 | X - axis value for Baker plot
| | BakerYa | 860 | Y - axis value for Baker plot
| | c | 1 | Volume fraction of liquid phase
| | M | 1 | Volume fraction of gas phase
| | RsubL | .34786691 | Gas velocity
| | RsubG | .65213309 | Gas velocity
| | GasVel | .39666047 | m/s | Liquid velocity
| | LiqVel | .37665137 | m/s |
The friction factor is calculated from eqn. (3.59) for laminar flow, or from eqn. (3.60) or eqn. (3.61) for turbulent flow, using the Reynolds number Re.

For diabatic flow (flow with heat transfer to or from the system), the pressure gradient at each point within the tube is given by a modification of eqn. (7.56) (Martinelli and Nelson 1948):

\[
\left(\frac{dp}{dL}\right)_{TP} = (1 - x)^{2-n}\phi_i (\frac{dp}{dL})_0
\]

(7.61)

where \( x \) is the local value of the fluid quality and \( (dp/dL)_0 \) is the pressure drop per unit length that would exist if the liquid were flowing alone at the total mass flow rate \( (\dot{m}_L + \dot{m}_0) \).

Because the addition of heat causes a change in the fluid quality along the length of the tube, the total frictional pressure drop must be determined by numerical integration of eqn. (7.61), or

\[
\Delta p_f = \int_0^L \left(\frac{dp}{dL}\right)_{TP} dL = \int_0^L (1 - x)^{2-n}\phi_i dL
\]

If the axial heat flux is constant (as is frequently the case for cryogenic-fluid transfer lines), we may write

\[
\frac{dx}{dL} = (x_2 - x_1)/L
\]

Example 7.8. Determine phase hydrogen in a 150-m mass flow rate of 4.00 kg/s hydrogen is flowing at an average velocity of 160 m (525 ft). For hydrogen at 354.6 kPa, find the following fluid properties:

\( \mu_L = 0.1034 \mu Pa \)
\( \mu_g = 1.367 \mu Pa \)
\( \alpha_L = 1.120 \mu m K \)

The cross-sectional area for

\( A = \frac{\pi}{4}A \)

The total mass flow rate per

\( \dot{m}/A = \frac{m}{\sqrt{\frac{A}{\pi}}} \)

The Reynolds numbers for

\( Re_L = (0.1627)(19) \)
\( Re_g = (0.1627)(19) \)

Table 7.19. Lockhart-Martinelli correlation constants

<table>
<thead>
<tr>
<th>Constant</th>
<th>Laminar</th>
<th>Turbulent</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m ) (vapor)</td>
<td>1</td>
<td>0.25</td>
</tr>
<tr>
<td>( n ) (liquid)</td>
<td>64</td>
<td>0.316</td>
</tr>
<tr>
<td>( C_L ) (vapor)</td>
<td>64</td>
<td>0.316</td>
</tr>
<tr>
<td>( C_L ) (liquid)</td>
<td>64</td>
<td>0.316</td>
</tr>
</tbody>
</table>

The four possible combinations are:

- \( \nu \) = laminar liquid, laminar vapor
- \( \nu \) = laminar liquid, turbulent vapor
- \( \nu \) = turbulent liquid, laminar vapor
- \( \nu \) = turbulent liquid, turbulent vapor

\[ Re_{GHS} = 9277 \]
\[ Re_{LIN} = 1615 \]
disintegrates into a mist or spray dispersed within the vapor phase; thus, mist flow results.

For low-quality flow, vapor bubbles are formed within the liquid phase, and bubble flow is achieved. For horizontal flow, the bubbles are usually concentrated in the upper portion of the tube; however, in vertical flow, the bubbles may be dispersed throughout the liquid. Increasing the vapor content of the flowing stream causes the bubbles to collect together into plugs of vapor that flow at intervals along the top of the pipe; hence, the name plug flow is applied to this flow pattern.