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ENGINEERING NOTE

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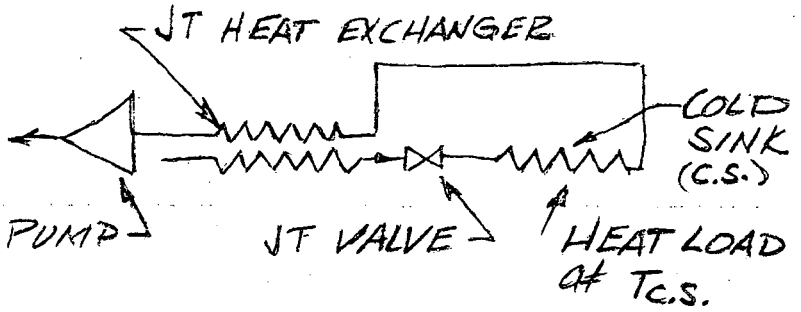
PROGRAM — PROJECT — JOB
HIGH FIELD MAGNET DEVELOPMENT
CRYOGENIC SYSTEMS

TITLE
THE EFFECT OF PRESSURE DROP IN HeII REFRIGERATION SYSTEMS

SUMMARY

The capacity of a HeII refrigeration system is shown to be reduced in proportion to the pressure drop in the low pressure circuit and further that this effect is amplified as the temperature is reduced.

ANALYSIS



For the system sketched the refrigeration power is $\dot{m}\Delta h_{c.s.}$, where $\dot{m}$ is the mass flow in the circuit and $\Delta h_{c.s.}$ is the enthalpy gain in the cold sink and which is very nearly independent of temperature. The mass flow can also be written in terms of the vacuum pump speed, $\dot{V}_{V.P.}$, so that the refrigeration power $\mathcal{R}$ is

$$\mathcal{R} = \dot{m}\Delta h_{c.s.} = \frac{(P_{c.s.} - \Delta P)\dot{V}_{V.P.}\,\Delta h_{c.s.}}{R T_{V.P.}} \qquad (1)$$

where the subscripts V.P. refer to the vacuum pump, C.S. to the cold sink and ΔP is the pressure loss between the two. Because of the pressure range, the flow is most likely laminar and the pressure loss can therefore be written as

$$\Delta P = \frac{128\mu L \dot{m} R T_e}{\pi d_e^4 P_{c.s.}} \qquad (2)$$

where T_e is an average temperature over the segment

where the pressure drop occurs and d_e is an effective diameter which accounts for the various flow geometries involved. Substituting for ΔP in eq(1) using equation (2) we get

$$\mathcal{R} = \frac{\dfrac{P_{c.s.}\dot{V}_{vp}\,\Delta h_{c.s.}}{R\,T_{v.p.}}}{1 + \dfrac{128\,\mu L\,\dot{V}_{vp}\,T_e}{\pi d_e^4\,P_{c.s.}\,T_{v.p.}}} \qquad (3)$$

The effect of a restrictive geometry (as reflected by d_e) is apparent from eq (3). When the second term in the denominator of (3) becomes appreciable as compared to unity $\mathcal{R}$ becomes quite sensitive to d_e.

EFFECT OF COLD SINK TEMPERATURE

In the range of interest the vapor pressure can be well approximated by

$$\frac{P}{P_0} = \left(\frac{T}{T_0}\right)^{6.6} \qquad (4)$$

Using (4) for $P_{c.s.}$ in (3) yields

$$\mathcal{R} = \frac{\dfrac{P_0\,\dot{V}_{vp}\,\Delta h_{c.s.}}{R\,T_{v.p.}}\left(\dfrac{T_{c.s.}}{T_0}\right)^{6.6}}{1 + \dfrac{128\,\mu L\,\dot{V}_{v.p.}\,T_e}{\pi d_e^4\,T_{v.p.}\,P_0\left(\dfrac{T_{c.s.}}{T_0}\right)^{6.6}}} \qquad (5)$$

It can be seen now that the second term in the denominator of (5) will change rapidly with small changes in cold sink temperature. A flow impedance which is acceptable at 1.9 K may not be so at 1.7 K

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