End Calorimeter Pressure Buildup In the Event of a Loss of Cooling

D-Zero Engineering Note #3740.222-EN-146

Keith Primdahl
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Approved Tom Peterson

Introduction

The temperature of the two-phase argon within the cryostats of D-zero is to be maintained by liquid nitrogen cooling loops located in argon vapor at the top of each cryostat. Should a loss of liquid nitrogen supply occur, the steady-state heat load on each cryostat will vaporize liquid argon; hence, increase the cryostat pressure. At 13 psig, relief valves will open, resulting in the venting of argon vapor.

The concern of this analysis is to determine the time required for such a pressure build up to occur. The analysis was performed on the geometry of the end calorimeter; however, similar results can be expected for the central calorimeter.

Approach

The heat input on the cryostat is primarily through the signal wire ports. Other sources include pipe connections through the top of the cryostat and the cryostat supports. The supports are equipped with thermal siphons which deliver heat directly to the top of the vessel.

I have postulated that should a loss of cooling occur, the heat build up would be contained in the argon (liquid and vapor) above the signal ports, located in a region bounded by the cryostat wall and the outer radius of the outer hadronic modules. Since the remainder of the argon can be considered an incompressible fluid, the first law of thermodynamics can be used to find the heat input required for pressure build up within a constant volume. The first law shows that the heat input will contribute to an increase of internal energy of the contained argon.

First Law: $Q = m_2 u_2 - m_1 u_1$

Continuity: $m_2 = m_1 = m$

Internal Energy: $u = h - Pv$

Combining the above:

$$Q = [\ (h_2 - P_2 v_2) - (h_1 - P_1 v_1)\ ]\ m$$

Where: Q = required heat input
P = pressure
u = specific internal energy
h = specific enthalpy
v = specific volume
m = mass
subscripts: 1 = initial state, normal operation
2 = final state, relief valve open

From knowledge of the quality (ratio of vapor mass to total mass) at state one, the thermodynamic properties can be found. Pressure at state two is equal to the relief pressure of the cryostat, while total volume and total mass are identical to state one. The quality at state two is calculated from the specific volumes of the argon vapor, liquid, and mixture. Accordingly, the enthalpy at state two can be determined, and the first law applied to find the required heat input.

Results

	State 1	State 2
Mass (g)	965325	965325
Volume (cm^3)	1022860	1022860
Pressure (bar)	1.2	1.9
Saturation temperature (K)	88.9	93.7
Specific volume (cm^3/g)	1.0596	1.0596
Specific enthalpy (J/g)	76.3283	82.2762

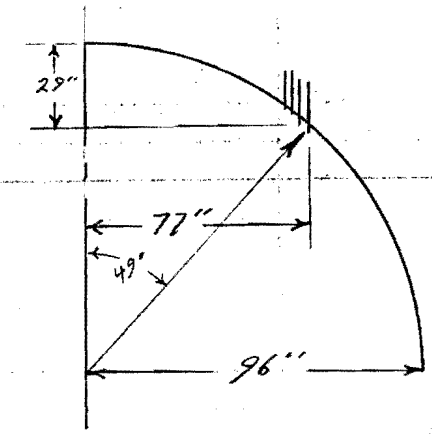
Required heat input, $Q = 5.67 \times 10^6$ Joules

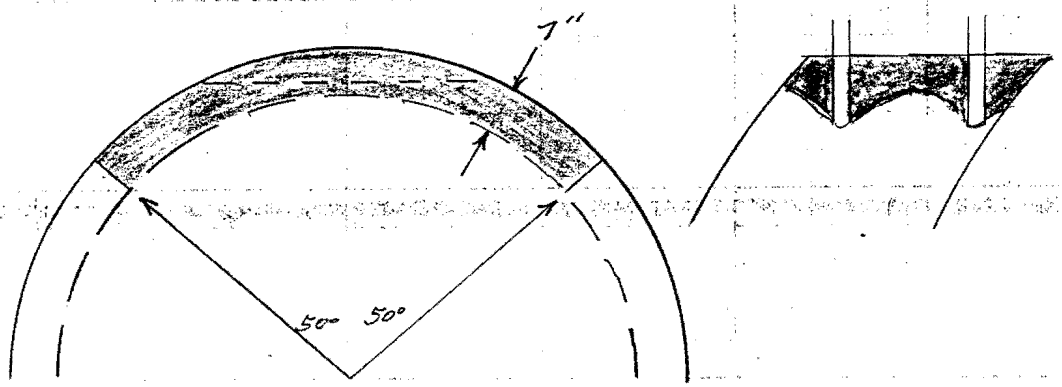
Assumed rate of heat input = 1500 watts*

Time until 1.9 bar is reached:

$$t = \frac{5.67 \times 10^6 \text{ Joules}}{1500 \text{ Watts}} = \underline{63 \text{ minutes}}$$

* *Cryogenic Design of the D-Zero Liquid Argon Calorimeter* 3740.214-EN120





$$A = \left(\frac{100}{360}\right)\left[(96'')^2 - (89'')^2\right]\pi = 1130\ in^2$$

$$V_{TOT} = (1130\ in^2)(70'') = 79107\ in^3$$

$V_{VAPOR} = 18394\ in^3 = 301424\ cm^3$ (FROM "EC LIQUID LEVEL" BY KAP)

$V_{LIQUID} = 60713\ in^3 = 994908\ cm^3$

ADD 25,000 cm^3 OF VAPOR IN FEED THICKNESS (APPROXIMATELY 1/2 ACTUAL VOLUME)

REDUCE V_{LIQUID} BY 30% TO ACCOUNT FOR "CORNERS" WHERE THERE IS NO HEAT INPUT

$$\left.\begin{aligned} V_{VAPOR} &= 326424\ cm^3 \\ V_{LIQUID} &= 696436\ cm^3 \end{aligned}\right\} V_{TOT} = 1{,}022{,}860\ cm^3$$

FIRST LAW:

$$Q = m_2(u_2) - m_1(u_1)$$

CONTINUITY:

$m_2 = m_1 = m$

$$\frac{Q}{m} = u_2 - u_1 \qquad u = h - Pv$$

$$Q = \left[(h_2 - P_2 v_2) - (h_1 - P_1 v_1)\right] m$$

h_1, P_1, v_1, & P_2 ARE KNOWN

h_2 AND v_2 ARE NOT KNOWN, BUT BOTH ARE A FUNCTION OF X. X CAN BE VERIFIED BY $v_2 m = V$ = CONSTANT

FIND Q REQUIRED TO REACH STATE 2, $P = 1.9$ BAR

NOTE 13 psi $\cong$ 0.9 BAR (RELIEF VALVE IS SET AT 13 psig).

INITIAL CONDITIONS, STATE 1:

$P_1 = 1.2 \text{ BAR} = 1.2 \times 10^6 \frac{\text{DYNE}}{\text{cm}^2} = 1.2 \times 10^6 \text{ g/cm s}^2$

$T_1 = 88.91 \text{ BAR}$

$v_f = 0.7231 \text{ cm}^3/\text{g}$

$v_g = 148.3850 \text{ cm}^3/\text{g}$

$h_f = 75.9622 \text{ J/g}$

$h_g = 236.5147 \text{ J/g}$

$m_f = (696,436 \text{ cm}^3)/(0.7231 \text{ cm}^3/\text{g}) = 963125 \text{ g}$

$m_g = (326,424 \text{ cm}^3)/(148.350 \text{ cm}^3/\text{g}) = 2200 \text{ g}$

$m_1 = 965325 \text{ g}$

$x_1 = \frac{2200 \text{ g}}{965325 \text{ g}} = 0.00228$

$h_1 = (1 - .00228)(75.9622 \text{ J/g}) + (.00228)(236.5147 \text{ J/g}) = 76.3283 \text{ J/g}$

$v_1 = \frac{1022860 \text{ cm}^3}{965325 \text{ g}} = 1.0596 \text{ cm}^3/\text{g}$

STATE 2 CONDITIONS:

$P_2 = 1.9 \text{ BAR} = 1.9 \times 10^6 \frac{\text{DYNE}}{\text{cm}^2} = 1.9 \times 10^6 \text{ g/cm s}^2$

$T_2 = 93.68 \text{ K}$

$v_f = 0.7391 \text{ cm}^3/\text{g}$

$v_g = 97.2893 \text{ cm}^3/\text{g}$

$h_f = 81.7620 \text{ J/g}$

$h_g = 238.0570 \text{ J/g}$

$m_2 = m_1 = 965325$

$v_2 = v_1 = 1.0596 \text{ cm}^3/\text{g}$

$$x_2 = \frac{v_2 - v_{f2}}{v_{g2} - v_{f2}} = \frac{1.0569 \text{ cm}^3/\text{g} - 0.7391 \text{ cm}^3/\text{g}}{97.2893 \text{ cm}^3/\text{g} - 0.7391 \text{ cm}^3/\text{g}} = 0.00329$$

$$h_2 = (1-x)h_{f2} + x h_{g2} = (1 - .00329)(81.7620 \text{ J/g}) + (.00329)(238.057 \text{ J/g})$$

$h_2 = 82.2762$

$$Q = \left[(h_2 - P_2 v_2) - (h_1 - P_1 v_1) \right]$$

$$Q = \left\{ \left[(82.2762\ J/g) - (1.9 \times 10^6\ g/m\,s^2)(1.0596\ m^3/g)\left(\frac{J}{10^7 g\,m^2/s^2}\right) \right] - \left[(76.3283\ J/g) - (1.2 \times 10^6\ g/m\,s^2)(1.0596\ m^3/g)\left(\frac{J}{10^7 g\,m^2/s^2}\right) \right] \right\}$$

$$\left\{ 965325\ g \right\} = 5.670 \times 10^6 \text{ JOULES}$$

ASSUMING 1500 WATT INPUT:

$$t = \left(\frac{5.670 \times 10^6 \text{ JOULES}}{1500 \text{ WATTS}} \right)\left(\frac{1 \text{ MIN}}{60 \text{ S}} \right) = \underline{63 \text{ MINUTES}}$$