Estimation of Maximum Temperature for Argon Gas Exiting Ullage Space in Micro-Boone

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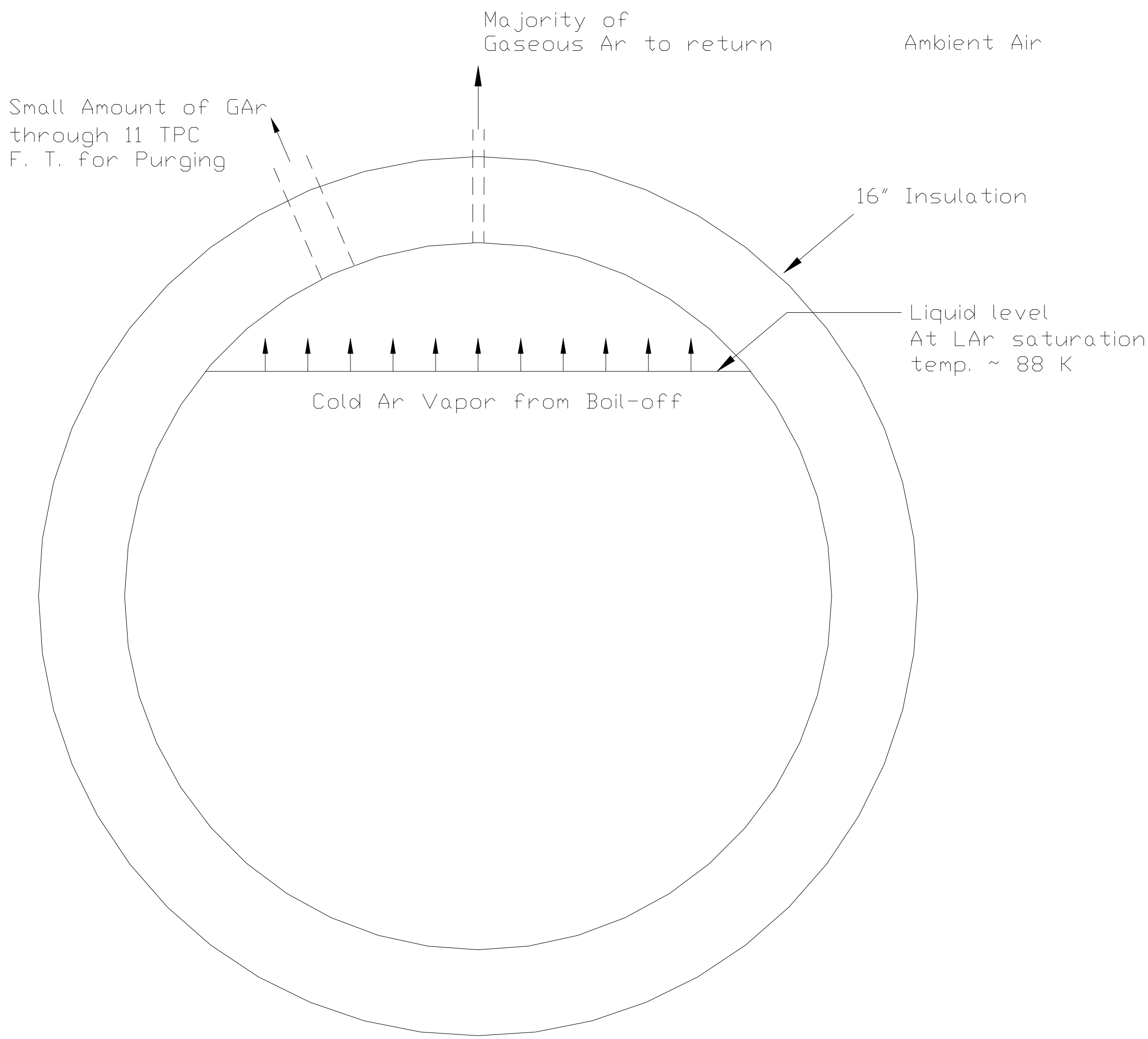
Purpose and Assumptions of the Study

- The purpose of this study is to estimate the maximum temperature (as the upper limit) of argon at the top of the ullage space for out gassing study.
- Note: this study is not applicable to the volume inside nozzles and feedthrough on top of the vessel where temperatures are much higher since the top of the nozzle is at ambient temperature. Temperature profile inside nozzles will be given in another study.
- It is assumed that boil-off gas is created by heat input below liquid level Q_{below}, and boil-off gas is heated by 100% of the heat input above liquid surface Q_{above} (instead of a portion of Q_{above}).
- Note: if a portion of Q_{above} is transferred to the liquid region, amount of boil-off will increase and gas temperature will be lower due to more flow and less heat input. Since it is difficult to model heat convection from Ullage space to liquid region involving evaporating process, 100% of Q_{above} is assumed to deposit into the gas.

Sketch – Boil-off Argon flows through Ullage Space

Assumptions:
Boil-off vapor is assumed to flow upward with constant velocity from liquid surface. Argon gas is heated in the Ullage on the way to vent line.



Energy Balance

- Boil-off flow equals heat input below liquid level divided by latent heat
  - $mdot = Q_{below} / h_{fg}$ or $Q_{below} \sim mdot \times h_{fg}$
- In ullage space, argon gas is heated by heat comes in above liquid level as it flows from liquid level to exit
  - $Q_{above} \sim mdot \times C_p \times dT$, where dT is the temperature increase of argon
- Eliminating mdot from above equations,
  - $dT \sim h_{fg}/C_p \times Q_{above}/Q_{below}$
- The gas temperature exiting Ullage space becomes
  - $Tgas)_{exit} \sim T)_{sat} + dT$
- For argon,
  - $h_{fg} \sim 160$ j/g and $C_p \sim 0.52$ j/g- K, => $h_{fg}/C_p \sim 308$ K

Heat Inputs, Q_{below} and Q_{above}

- Heat input to Micro-Boone vessel mainly comes from conduction through insulation, electronics and wires.
- Heat Conduction through insulation depends on area and temperature difference between outer and inner surfaces.
  - ~ Area x Integral[K(T)] from T_i to T_o.
- Assuming temperature at outer surface, T_o = 300 K.
- Below liquid level, temperature at inner surface is at saturation temperature $T_i)_{below} = T)_{sat}$ or 88 K.
- All heat from electronics and wire are deposited to liquid region (and is treated as % of heat conduction through insulation as for case 3)
- In Ullage space, temperature at inner surface $T_i)_{above})_{ave}$ is solved through iteration.
- For Micro-Boone, ratio of surface area in Ullage space to that of liquid region equals ~ 0.33. (105" wide liquid level in 150" diameter vessel)

Average Temperature on Inner Surface of Ullage Space

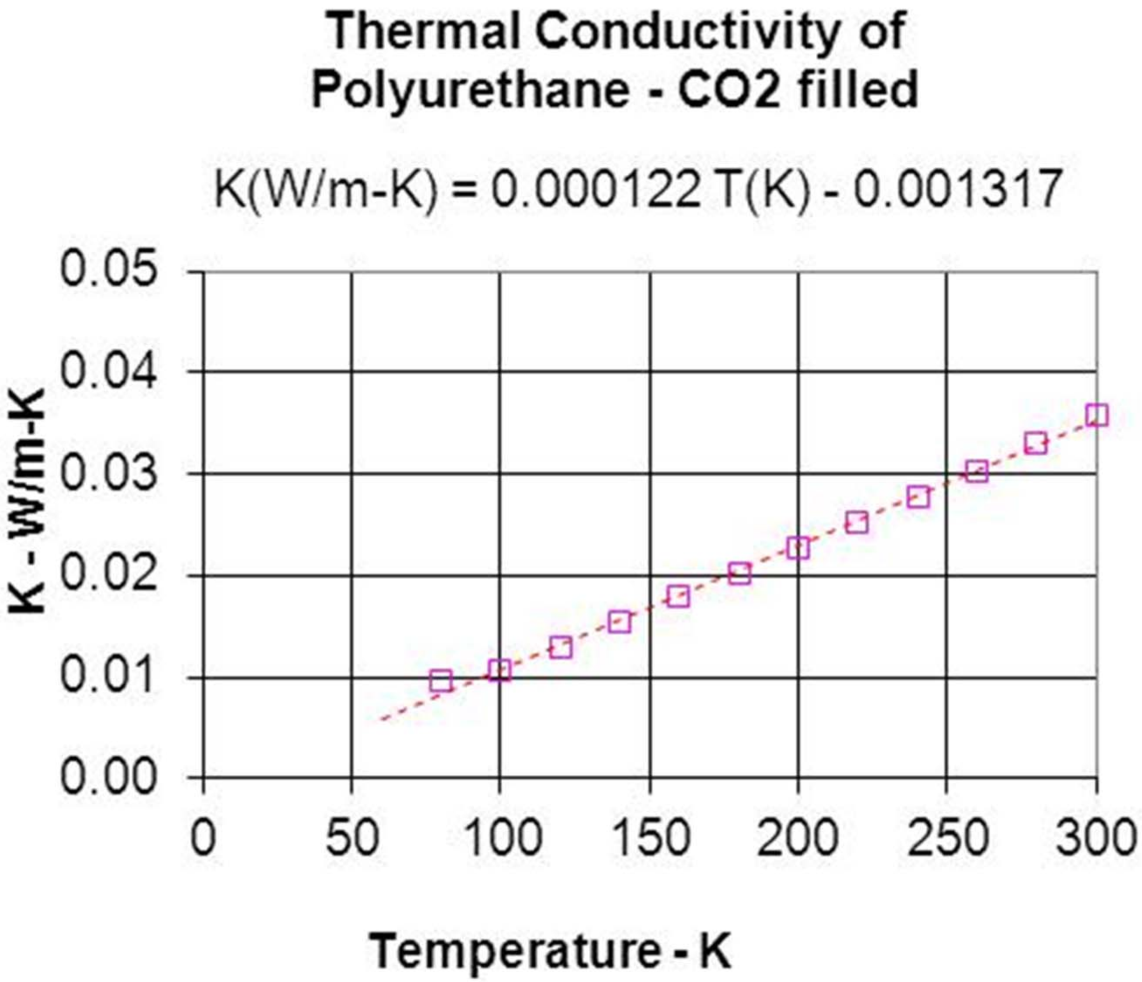
- From previous slide, $dT \sim h_{fg}/C_p \times Q_{above}/Q_{below}$
- Temperatures of inner surface in Ullage Space have been calculated for the following 2 cases
  - Case 1) argon gas and inner vessel surface are at the same temperature
    - $Tgas)_{exit} \sim T)_{sat} + dT$
    - $T_i)_{above})_{ave} \sim [T)_{sat} + Tgas)_{exit}]/2 \sim T)_{sat} + dT/2$
  - Case 2) argon at exit is 10 K below vessel temperature to account for convective heat transfer between argon and cryostat, $Tx = T_i - Tgas)_{exit} = 10$ K, or $T_i = Tgas)_{exit} + Tx$
    - $Tgas)_{exit} \sim T)_{sat} + dT$
    - $T_i)_{above})_{ave} \sim [T)_{sat} + Tgas)_{exit} + dTx]/2 \sim T)_{sat} + dT/2 + dTx/2$

Results for 3 Cases

- For the present study, results with no electronic heat (case 1 and 2) and with 50% of insulation heat (case 3) are calculated for cryostat with polyurethane insulation
  - Case 1: No electronic heat and argon and vessel at same temperature
  - Case 2: No electronic heat and argon at exit is 10 K below vessel
  - Case 3: Heat from electronics equals 50% that of insulation and argon at exit is 10 K below vessel
- Would be interest to calculate latest values for Micro-Boone.

Thermal Conductivity of Polyurethane

(Linear with Temperature 80 - 300 K)



Case 1 – Heat conduction from insulation (only), no heat from electronics, temperature of argon is the same as cryostat

$T_{gas})_{exit} \sim 178$ K

For K(T) = a T + b						
Qbelow ~ Int[K dT]Ti to To			4.738			
Qabove ~ Int[K dT]Tiav to To						
Use ratio of surface area and temperature to solve Tout iteratively						
Iteration	To	Ti)ave-1	Int[KdT]a-o	dT	Tgas)exit	Ti)ave-2
1	300	88	4.738	101.5	189.5	138.7
2	300	138.7	4.103	87.9	175.9	131.9
3	300	131.9	4.207	90.1	178.1	133.0
4	300	133.0	4.190	89.7	177.7	132.9
5	300	132.9	4.193	89.8	177.8	132.9

Case 2 – Heat conduction from insulation, no heat from electronics, temperature at exit for argon is 10 K below cryostat

$Tgas)_{exit}$ ~ 176 K

Corrected with convection between vessel to argon

For K(T) = a T + b	dt]vessel-argon 10 K
Qbelow ~ Int[K dT]Ti to To	Tvessel = Tout + dt]vessel-argon
Qabove ~ Int[K dT]Tiav to To	**Tave ~ Tsat + dT/2 + dt]/2**

Use ratio of surface area and temperature to solve Tout iteratively

Iteration	To	Ti)ave-1	Int[KdT]a-o	dT	Tgas)exit	Ti)ave-2
1	300	88	4.738	101.5	189.5	143.7
2	300	143.7	4.024	86.2	174.2	136.1
3	300	136.1	4.144	88.8	176.8	137.4
4	300	137.4	4.125	88.3	176.3	137.2
5	300	137.2	4.128	88.4	176.4	137.2

Case 3 – Total heat equals 150% conduction from insulation (50% is from electronics), temperature of argon at exit is 10 K below cryostat - $Tgas)_{exit}$ ~ 150 K

(Temperature decreases by ~ 26 K compared with heat solely from insulation)

Corrected with convection between vessel to argon			
With 50% from cold electronics and saddels to Qbelow			
For K(T) = a T + b	dt]vessel-argon	10	K
Qbelow ~ 1.5 x Int[K dT]Ti to To	Tvessel = Tout + dt]vessel-argon		
Qabove ~ Int[K dT]Tav to To	**Tave ~ Tsat + dT/2 + dt]/2**		
factor ~ 1.5			

Use ratio of surface area and temperature to solve Tout iteratively

Iteration	To	Ti)ave-1	Int[KdT]a-o	dT	Tgas)exit	Ti)ave-2
1	300	88	4.738	67.7	155.7	126.8
2	300	126.8	4.281	61.1	149.1	123.6
3	300	123.6	4.326	61.8	149.8	123.9
4	300	123.9	4.322	61.7	149.7	123.9
5	300	123.9	4.322	61.7	149.7	123.9

Summary

- Temperatures of argon exiting ullage space have been estimated using energy balance and basic heat transfer calculation.
- For the 3 cases calculated, $Tgas)_{exit}$ are 178 K, 176 K and 150 K.
- It appears the maximum temperature of argon at the top of Ullage space will be in the range between 150 to ~ 178 K.
- As stated earlier, this study is NOT applicable to nozzles and feedthrough on top of the vessel since the top of the nozzle is at ambient temperature. Temperature will be much higher there and further study will be carried out to provide quantitative results.