ALMA Memo 554

Effect of Vacuum Pressure on the Thermal Loading of the ALMA Cryostat

G. A. Ediss
National Radio Astronomy Observatory

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Introduction

Following a discussion of memo #547 [1], a comment was made that the thermal conductivity of the remaining gas in the cryostat would cause the cryostat hold time to be significantly less than predicted in the memo. This memo shows that this is not the case.

Theory and Calculations

Convection will be ignored, as the mean free path of the air molecules is > 10 mm for pressures < 10^{-2} mbar. This means that most of the heat transfer at lower pressures (< 10^{-3} mbar) will be due to the molecules traveling, unimpeded from one surface to the other, a distance of only 15 mm.

The thermal conductivity of air, K_{air}, between two plates is given by [2]

$$K_{air} = K_{air,o} \cdot \frac{1}{1 + \dfrac{7.6 \cdot 10^{-5}}{P \cdot \dfrac{d}{T}}}$$

where $K_{air,o}$ is the thermal conductivity of air at room temperature and pressure (0.0284 W/m/K), P is the pressure (Pa), d is the distance between the plates (m), and T is the average temperature of the plates (K).

Figure 1 gives the predicted thermal conductivity of air in the pressure range of 1 mbar to 10^{-6} mbar, assuming 15 mm between the plates and an average temperature of 200 K (the temperature of the outer vacuum container is taken as 300 K and the first shield as 100 K). Above 1 mbar, the curve is flat.

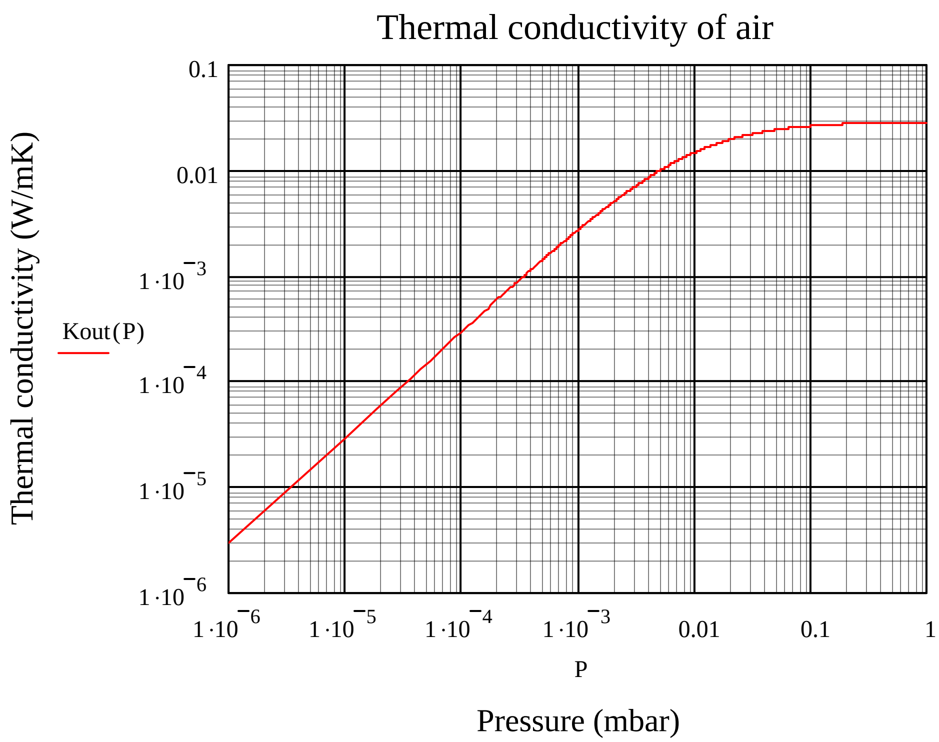

Figure 1

In normal operation, the OVC has a pressure of 10^{-8} mbar or less (when cryo-pumping). This gives a total load on the 25 m^2 shield at 90 K of 10 mW or less, and proportionately less (due to the difference in temperature of the shield being considered and the previous shield) on the 15 K (3.5 mW) and 4 K (0.5 mW) stages. This can be compared with the radiative and wiring loads on the various stages (6.15 W on 90 K, 0.95 W on 15 K and 40 mW on 4 K [3]) and the conductive loads can be ignored when considering the performance of the cryostat.

When there is a leak, however, the pressure in the OVC will rise. From the above curve, one can calculate that a pressure of 10^{-6} mbar will be required to raise the thermal load on the 90 K stage to 1 W; this will also give 350 mW on the 15 K and 50 mW on the 4 K stage. This will be seen as a rise in the operating temperature of the stages.

The difficulty is in determining the size of leak (and diffusion) which would be required to raise the OVC pressure by this much during cryo-pumping (not during normal pumping of the cryostat). Experience during the accelerated leak tests at the FEIC showed that as soon as a volume of gas was inserted into the cryostat the pressure rose to ~ 10^{-6} mbar, but then rapidly (less than a second) fell to below 10^{-8} mbar (the limit of the vacuum gauge), approximately three orders of magnitude. This indicated that a leak of > 10^{-3} mbar would be needed to raise the OVC pressure to > 10^{-6} mbar.

During pump-down of the cryostat, an end pressure will be achieved which is dependant on the end pressure of the turbo-pump and the leak rate. As soon as the cryostat starts cryo-pumping, the pressure will drop significantly as the gas is deposited on the cold surfaces.

Conclusion

As long as cryo-pumping is occurring and the cryostat pressure remains below 10^{-6} mbar, the conclusions in [1] on the cryostat hold time are unaffected. To obtain such high pressures, a catastrophic failure is required. Even large leaks and diffusion, as discussed in this memo and memo #547, will only increase the cold stage temperatures, but not enough to affect the performance of the receiver. Note that it was determined in memo #547 that the main "contaminant" was water vapor, which freezes out at much higher temperatures than the "dry air" components. Thus, the pressure in most cryostats falls by several orders of magnitude when the cold head is turned on and the head temperature drops below 0 C.

References

[1] G. A. Ediss, "Estimate of the ALMA cryostat hold time," ALMA Memo #547, 2006-02-27, http://www.alma.nrao.edu/memos/html-memos/alma547/memo547.pdf

[2] J. A. Potkay, G. R. Lambertus, R. D. Sacks, and K. D.Wise "A low pressure- and temperature- programmable mGC column," *Solid-State Sensor, Actuator and Microsystems Workshop*, Hilton Head Island, SC, USA, June 2006, pp. TBD.

[3] K. Saini, "Cryostat thermal budget spreadsheet," 2005-04-06. http://edm.alma.cl/forums/alma/dispatch.cgi/iptfedocs/showFolder/101322/