

## Outgassing Rate Determination

For the Panametrics -Thermal Vacuum & Thermal Bakeout Chambers

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On: May 22, 2000  
Re: Tech Memo PAN000522

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### Vacuum Physics

The general formula for the **conductance** through an aperture at high vacuum is given as:

$$1) \quad C = \frac{\bar{v}}{4} A_0 \quad cm^3 / S,$$

where  $A_0$  is the area of the aperture in  $cm^2$ , and  $\bar{v}$  is the RMS velocity of the gas in the chamber, which is equal to:

$$\bar{v} = \sqrt{\frac{8k_B T}{m\pi}} \quad cm / S, \quad \text{with } m = M / N_a.$$

$T$  is the temperature in Kelvin, and  $m$  is the mass of the gas-species in grams.  $M$  is the molar mass in gm/mole,  $N_a$  is Avogadro's Number ( $6.023 \times 10^{23}$  molecules/mole). Keeping with cgs units, the Boltzmann constant,  $k_B = 1.38 \times 10^{-16}$  gm  $cm^2$   $S^{-2}$   $K^{-1}$ , giving:

$$\bar{v}_{T,M} = 1.455 \times 10^4 \sqrt{T/M} \quad cm / S.$$

For a gas of molar mass  $M$ , at temperature  $T$ , the conductance is:

$$C_{T,M} = 3,638 \sqrt{T/M} A_0 \quad cm^3 / S,$$

Conductance apertures in parallel add in series, so  $A_0$  is the summed area of all apertures in a shroud or bake-out box. For outgassing calculations it is important that the total conductance is small compared to the pumping speed of the vacuum system. For  $T = 313$  K ( $40^\circ C$ ), and  $M = 100$  gm/mole:

$$C = 6,436 A_0 \quad cm^3 / S.$$

In the ultra-high vacuum region, the number of particles incident upon unit surface area per unit time is known as the **impingement rate**,  $Z_A$ , given as:

$$2) \quad Z_A = \frac{n \bar{v}}{4} \text{ cm}^{-2} \text{S}^{-1},$$

where  $n$  is the **number density** of particles (per  $\text{cm}^3$ ), and  $\bar{v}$  is the RMS velocity.

Now, the mass flux,  $\dot{m}$ , at the TQCM, is given as:

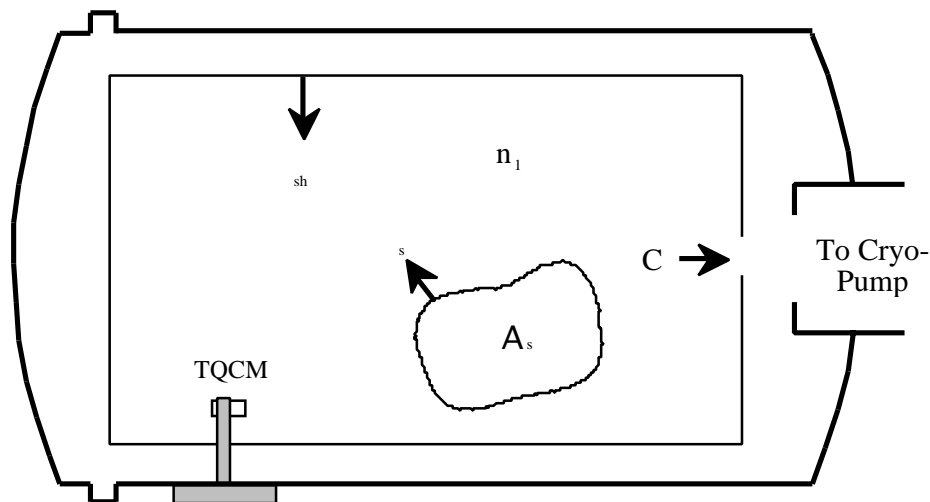
$$\dot{m} = Z_A A_{TQCM} m = S_T A_{TQCM} \frac{df}{dt} \text{ gm/S}$$

where  $A_{TQCM}$  is the sensitive area of the TQCM in  $\text{cm}^2$ ,  $S_T$  is the sensitivity of the TQCM in  $\text{gm/cm}^2/\text{Hz}$ , and  $\frac{df}{dt}$  is the TQCM frequency change in  $\text{Hz/S}$  (rate change during an hour).

Therefore, substituting for  $Z_A$  from Equation 2), and solving for  $n$ :

$$3) \quad n = \frac{4S_T}{m\bar{v}} \frac{df}{dt}.$$

A typical vacuum chamber setup for measuring mean outgassing rates of parts or subassemblies is shown in Figure 1) below. The TQCM must be mounted on a temperature-controlled plate to dissipate the heat (~4-6 watts) generated by the thermoelectric cooler, and should generally view the item under test. During the high temperature bakeout of the parts, the TQCM crystal is held at an elevated temperature, around  $+90^\circ\text{C}$ , to keep the accumulated mass at a low level. The



TQCM must be removed from the chamber if the bakeout temperature is above  $100^\circ\text{C}$ .

### Figure 1) Thermal Vacuum/Thermal Bake-out Chamber

After the parts have been baked at a specified temperature for a specified time, the shroud or bakeout-box temperature is reduced to the measurement value, typically +40°C (or the maximum on-orbit operating temperature plus 10°C). The TQCM crystal temperature is kept hot while the shroud is cooling down in order to desorb any deposits that have condensed on the crystal during the bakeout. The TQCM crystal temperature is then lowered to the measurement value, typically -20°C, and the rate is measured by logging the frequency increase during a given time interval (typically every hour for 8 hours).

Considering the chamber to be a cylindrical container with an exit aperture and with the item under test and the TQCM inside the container, the relationship between the measured TQCM rate and the mean outgassing rate of the parts is described below. When steady-state conditions have been reached, there is a balance between the molecular fluxes such that, from Figure 1):

$$4) \quad v_{sh} A_{sh} + v_s A_s = C n_1$$

where  $v_{sh}$  and  $v_s$  are the flux density from the shroud and sample (item under test), respectively, and  $A_{sh}$  is the (inside) area of shroud,  $A_s$  is the exposed area of the sample,  $C$  is the net conductance of the exit aperture, and  $n_1$  is the total number density from the shroud and the sample. (Actually  $n_1$  is the number density of the condensable fraction of the total number density that will condense on the TQCM at the measurement temperature.) The assumptions in Equation 4) are that the net conductance is small in comparison to the pumping speed of the system, and/or that there is minimal back-streaming from outside the shroud. Back-streaming can be minimized by placing a cold-plate outside of the exit aperture. If these assumptions cannot be realized, the back-streaming must be accounted for by adding another term to the right-side of Equation 4).

For an empty chamber  $v_s A_s = 0$ , so with Equation 3) for  $n$ :

$$5) \quad v_{sh} A_{sh} = C n_0 \quad v_{sh} = \frac{n_0 C}{A_{sh}} = \frac{4SrC}{mA_{sh}V} \frac{df_0}{dt}$$

where  $\frac{df_0}{dt}$  indicates the chamber background frequency change (in Hz/S). This is just the impingement rate (ref. Equation 2) on the shroud. For a system in equilibrium, the mean outgassing rate (OGR) is equal to the impingement rate times the mass, so the outgassing rate of the shroud is:

$$OGR_{sh} = Z_A m = v_{sh} m = \frac{4S\tau C}{A_{sh} v} \frac{df_0}{dt} \quad gm/cm^2/S.$$

Using Equation 1) for the conductance, and simplifying, we get a general equation for the empty chamber:

$$6) \quad OGR_{sh} = \frac{A_0}{A_{sh}} S_T \frac{df_0}{dt} \quad gm/cm^2/S.$$

Plugging the QCM-Research TQCM sensitivity ( $1.96 \times 10^{-9}$  gm/cm<sup>2</sup>/Hz) into Equation 6), then converting the TQCM frequency-change to Hz/hr,

$$OGR_{sh} = 5.44 \times 10^{-13} \frac{A_0}{A_{sh}} \frac{df_0}{dt} \text{ (in Hz/hr)} \quad gm/cm^2/S.$$

To find the outgassing rate of an instrument or item(s) under test:

Starting over with Equation 4) above, inserting Equation 5), and given that the outgassing rate of the sample is equal to  $v_s m$ :

$$OGR_s = v_s m = \frac{mC}{A_s} (n_1 - n_0) = \frac{4S\tau C}{vA_s} \left( \frac{df_1}{dt} - \frac{df_0}{dt} \right).$$

Again, simplifying by using Equation 1), and dividing by 3600 to allow us to enter the TQCM rate changes in Hz/hr, the mean outgassing rate of a sample is:

$$7) \quad OGR_s = 5.44 \times 10^{-13} \frac{A_0}{A_s} \left( \frac{df_1}{dt} - \frac{df_0}{dt} \right) \quad gm/cm^2/S, \quad \left( \frac{df}{dt} \text{ in Hz/hr} \right).$$

Where  $A_0$  is the total (limiting) aperture area of the shroud,  $A_s$  is the exposed area of the sample (both in cm<sup>2</sup>), and  $\frac{df_1}{dt}$  and  $\frac{df_0}{dt}$  are the TQCM rate changes for the sample and the empty chamber. The chamber background is typically low compared to the sample, so that  $\frac{df_0}{dt}$  can be ignored. Otherwise, the background measurement must be taken with the empty chamber in the same configuration as when the item(s) under test are installed. The TQCM measurements must be made over an 8-hour period, with readings taken at least every hour. The TQCM crystal temperature must remain stable during the measurement interval, or the data is not valid.