Establishing Hardware Outgassing Certification Criteria

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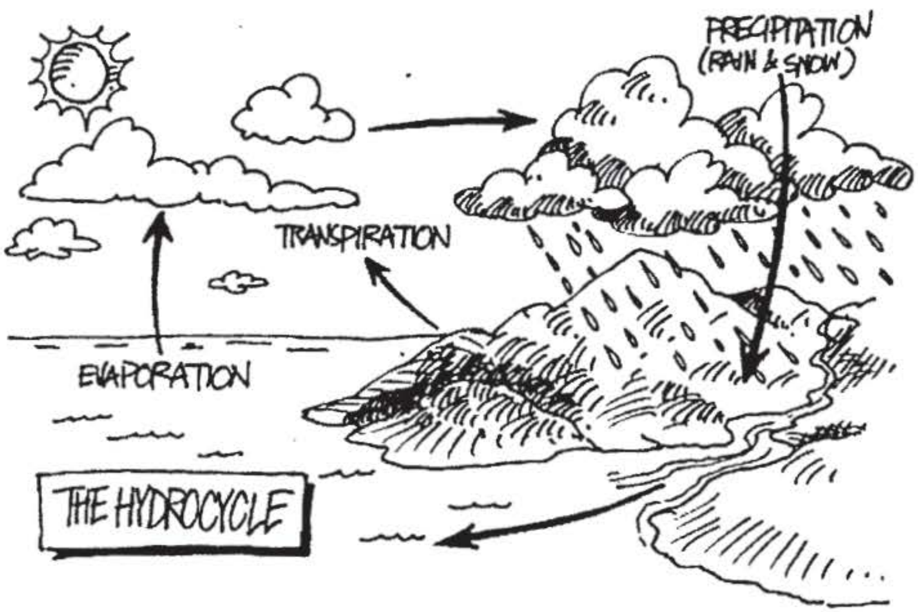
Code 546

Hardware Requirements

- The QCM measures deposition rate at a particular location in the chamber
  - Chamber modeling is used to determine the deposition rate that results from the desired outgassing rate
  - Specify hardware and QCM temperatures
  - Specify QCM location and orientation



Just as measuring rainfall in Greenbelt does not tell you the how much water evaporated from the ocean, QCM deposition alone does not tell us the outgassing rate of hardware.

Outgassing and Deposition

- Definition

- Outgassing rate (OGR) in $g/cm^2/s$ to Deposition Rate (DPR) in $g/cm^2/s$
  - A is area in cm^2
  - VF is viewfactor
  - Subscript HW for hardware

$$\frac{OGR_{HW} \cdot A_{HW} \cdot VF_{HW->QCM}}{A_{QCM}} = DPR_{QCM}$$

- Deposition rate ($g/cm^2/s$) to Delta (Hz/hr)
  - CF is conversion factor from QCM manufacturer ($g/cm^2/Hz$)

$$DPR_{QCM} \div CF \cdot (3600 \frac{s}{hr}) = Delta$$

Derivation

- Hardware Outgassing

- Outgassing requirement
  - Derived from the project performance specifications
  - Contaminant effects are used to deduce accretion limits
  - Molecular transport modeling of the spacecraft provides outgassing rate limits that result in acceptable accretions on sensitive surfaces
- Bakeout requirement (deposition on QCM)
  - Outgassing requirement
  - Chamber configuration
  - Transport modeling of the chamber provides the correspondence between outgassing and deposition

Background Levels

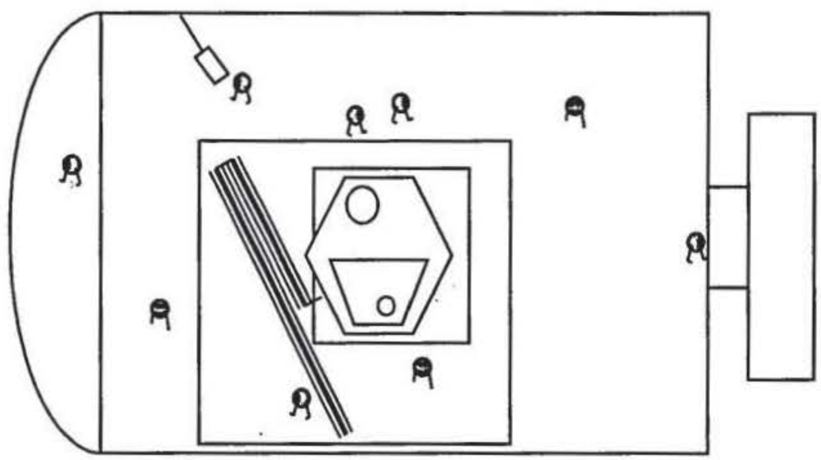
- Background Outgassing

If the background is high, it is likely to decrease over the course of the hardware test, making data interpretation difficult.

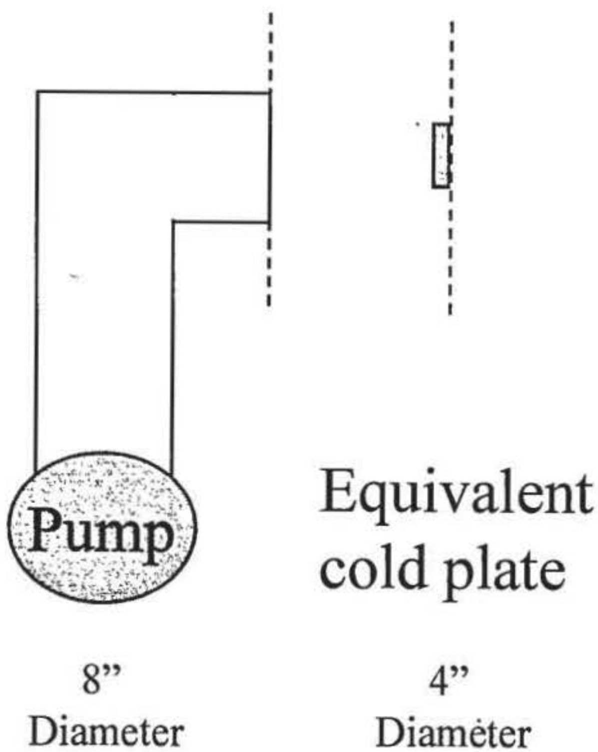
- Chamber history
  - Presence of undesirable species (eg, silicones)
  - High background outgassing rates
- Acceptable background rate
  - Rule of thumb (non-critical): half the hardware requirement
  - Rule of thumb (critical): 1/10th the hardware requirement
  - High backgrounds also mean that the coldfinger results are less representative of the hardware being tested
- Pre-test chamber bakeouts are used to reduce the background

Molecular Transport

- At low pressures, most collisions are with chamber or hardware surfaces, not other molecules
- Molecules do not bounce like balls; they stick to the surface momentarily and then re-emit in a random direction
- Molecules move randomly until they condense on a cold surface
- They do not know where the QCM and pump are located (cold surfaces act like fly paper, not like magnets)



Effective Pump Area



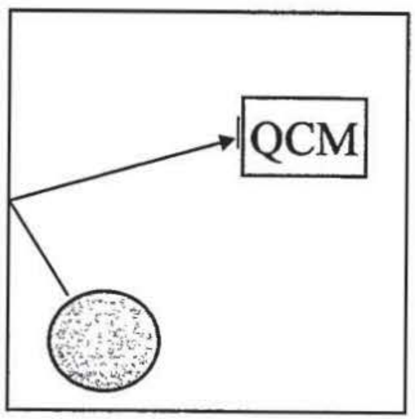
- The vacuum pump is located at the end of a tube, so does not have 100% efficiency
  - Molecules entering the tube can bounce back out
- The pump effective area is the area of a cold plate that would remove molecules at the same rate as the pump
  - Even for simple cases, the chamber pump efficiency must be known
  - The efficiency may be calculated by modeling the pump and chamber, or by running a characterization test

Viewfactors

- Complex test configurations
  - Multiple hardware elements in view of QCM
  - Non-isothermal environment
  - Numerical analysis is required
- Ideal chamber configurations
  - Viewfactor to the QCM is nearly independent of hardware geometry
- Simple test configurations
  - Isothermal environment
  - Single hardware element
  - Viewfactor may be found statistically

Geometry Independent

- Ideal "Hot Wall"



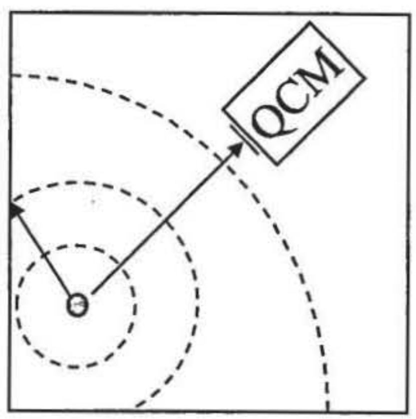
- The chamber is sealed
- Only the QCM crystal is cold enough to condense the outgassed species
- The hardware and chamber are the same temperature

$$VF_{HW->QCM} = 1$$

Configuration

- Ideal "Cold Wall"

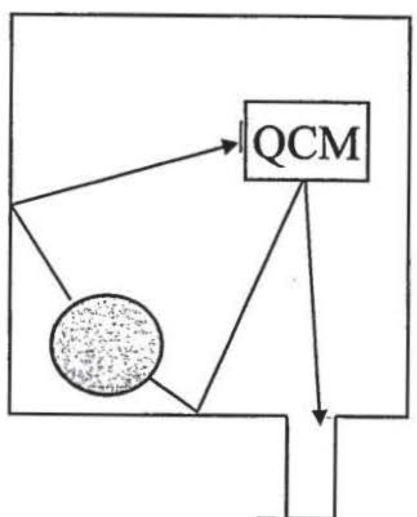
- The hardware is a point source
- All surfaces condense the outgassed species
- Molecules outgas as expanding sphere
- QCM crystal plane is tangent to the sphere



$$VF_{HW->QCM} = \frac{A_{QCM}}{4\pi \cdot d^2_{HW->QCM}}$$

Simple Configurations

- Hot Wall



- Chamber and hardware are isothermal
- Cold surfaces and pump effective area are small (or baffled)
  - When molecules are well mixed (many bounces) before reaching a cold surface, the ratio of areas gives the statistical viewfactor

$$VF_{HW->QCM} = \frac{A_{QCM}}{A_{QCM} + A_{Pump} + A_{Other}}$$

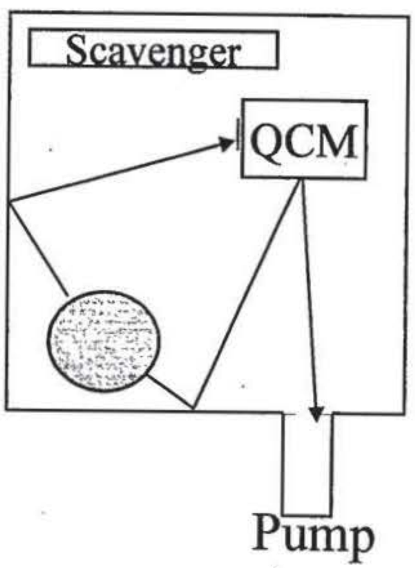
Effective Pump Area

- Hot Wall
  - Chamber Characterization

$$VF_{HW\to QCM} = \frac{A_{QCM}}{A_{QCM} + A_{Pump} + A_{Other}}$$

$$\frac{OGR_{HW} \cdot A_{HW} \cdot VF_{HW\to QCM}}{A_{QCM}} = DPR_{QCM}$$

- Solve for unknowns: $OGR_{chamber}$, A_{pump}
  - Two equations required
    - Achieve a stable QCM reading
    - Then activate the cold finger or scavenger plate
- Pump effective area is a function of the ratio of before and after rates

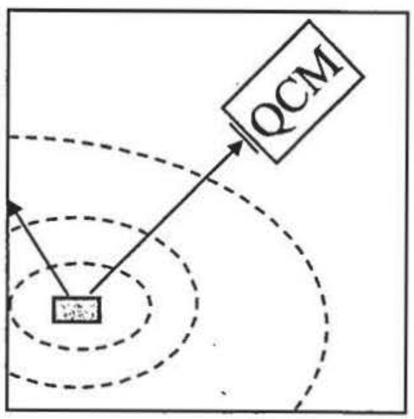


$$\frac{Rate_{NoScavenger}}{Rate_{WithScavenger}} = \frac{A_{QCM} + A_{Pump} + A_{Scavenger}}{A_{QCM} + A_{Pump}}$$

$$A_{Pump} \approx \frac{A_{Scavenger}}{Ratio - 1}$$

Simple Configurations

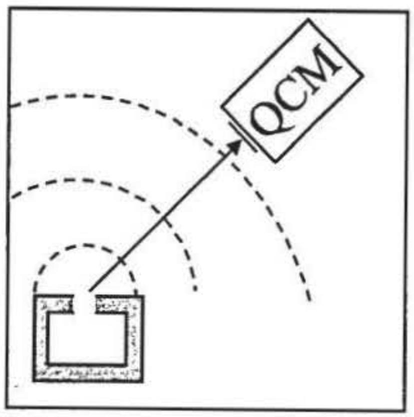
- Cold Wall



- Chamber wall is colder than the QCM
- The hardware item is relatively uniform
  - No vents, lubricated mechanisms, etc
- Item is either small (size < distance to QCM) or has a simple shape
  - Small items can use the ideal formula
  - Radiation viewfactor formulas have been tabulated for simple shapes (plate to plate, cylinder to plate, etc)

Simple Configurations

- Cold Wall, Vented Cavity



- Chamber wall is colder than the QCM
- Primary outgassing source is inside a cavity with one vent
- The QCM faces the vent
- Vent is small enough to treat as a point source
  - Diameter << distance to QCM
- Assume molecules exiting the vent are uniformly distributed over a hemisphere
  - Not the end of a tube

$$VF_{HW->QCM} = \frac{A_{QCM}}{2\pi \cdot d^2_{HW->QCM}}$$

Test Boxes

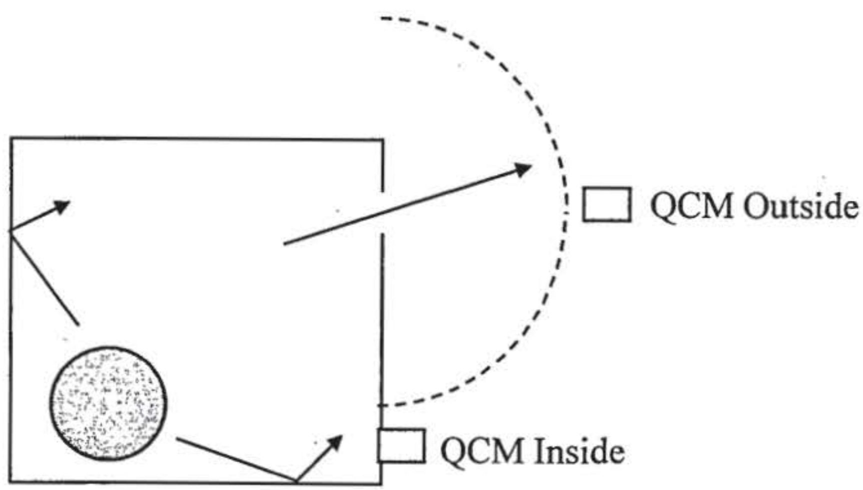
- Description

- We may create a near ideal situation by using an enclosure around the hardware
- Test box may be much cleaner than the chamber
- Specify that a test box is required in the test plan
  - Test phases may incorporate changing the vent area
  - Test box may have a coldfinger installed inside

Test Boxes

- Test Box w/ Cold Wall

- QCM inside the box
  - Hot Wall equation applies
  - Use the box vent area as the chamber pump area
- QCM outside the box
  - Vented Cavity equation applies

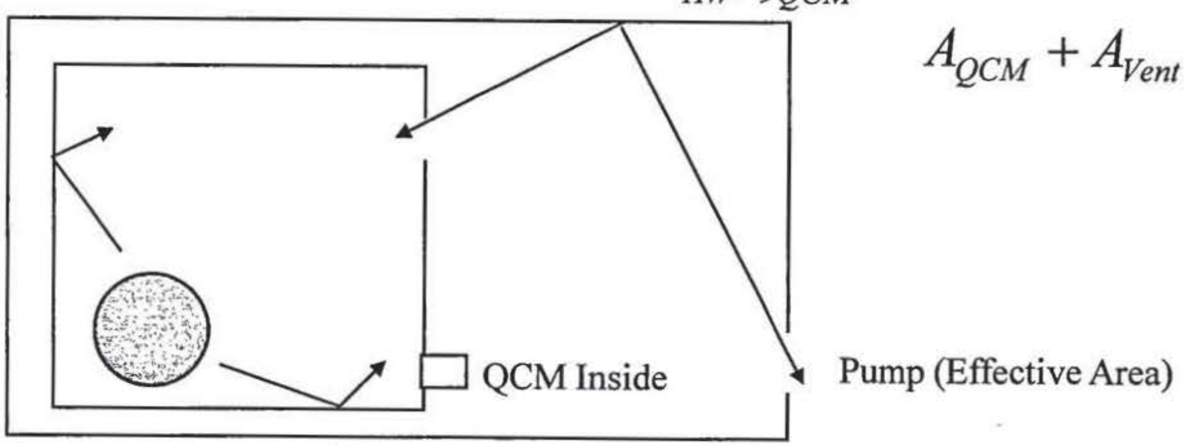


Test Boxes

- Test Box w/ Hot Wall

- QCM must be inside the box
  - Adjustment of Hot Wall equation
- Random walk causes some molecules to re-enter the box
  - The portion re-entering is A_vent/(A_pump+A_vent)
  - This fraction is used to reduce the effective area of the vent

$$VF_{HW->QCM} = \frac{A_{QCM}}{A_{QCM} + A_{Vent} \cdot \left[1 - {A_{Vent}}\big/{(A_{Vent} + A_{Pump})}\right]}$$



Viewfactor Summary

- Hot Wall $$VF_{HW->QCM} = \frac{A_{QCM}}{A_{QCM} + A_{Pump} + A_{Other}}$$

- Ideal Cold Wall $$VF_{HW->QCM} = \frac{A_{QCM}}{4\pi \cdot d^2_{HW->QCM}}$$

- Vented Cavity $$VF_{HW->QCM} = \frac{A_{QCM}}{2\pi \cdot d^2_{HW->QCM}}$$

- Test Box, Hot Wall $$VF_{HW->QCM} = \frac{A_{QCM}}{A_{QCM} + A_{Vent} \cdot \left[1 - A_{Vent} / (A_{Vent} + A_{Pump})\right]}$$

$$\frac{OGR_{HW} \cdot A_{HW} \cdot VF_{HW->QCM}}{A_{QCM}} = DPR_{QCM}$$