How to calculate purge gas volumes

Simple equations estimate sweep gas quantities and cycles to remove vapor-space contaminants

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Preparation for startup or shutdown involves purging contaminants from the process unit. Another important aspect of purging is the thorough removal of contaminants or hydrocarbons on equipment items taken out of service for maintenance. Several presented methods quickly estimate the sweep gas quantity and cycles that can perform an efficient purge.

Clean vapor space. Usually, a clean gas or vapor is used to flush vapor-space contaminants in routine plant operations. This purge/preparation step occurs frequently during startup, shutdown and maintenance activities. Commonly used gases include nitrogen, natural gas, steam or process gas. Equipment or system size vastly affect the efficiency and purge type used. Three different purge methods estimate the quantity of sweep gas and required cycles for efficient contaminant removal.

Plug flow. The simplest purging method is plug flow. The cleansing gas moves uniformly within the equipment and sweeps contaminants from the system. In practice, plug flow is difficult to achieve. If

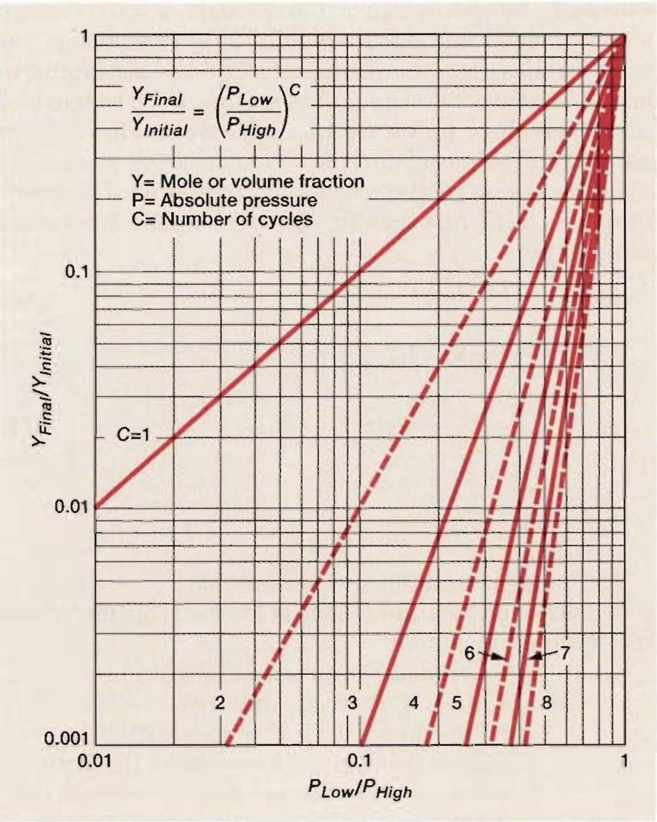

Fig. 2. Number of cycles needed to purge contaminants.

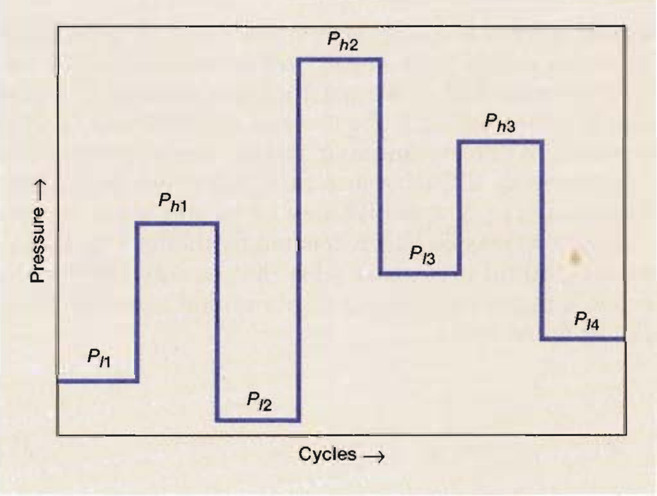

Fig. 1. Pressure cycles for contaminant removal.

the equipment diameter is small, plug-flow sweeping may be adequate. Otherwise, another approach is warranted. On a cost-effective basis, plug-flow purging requires the smallest clean gas volume:

$$M_{plug} = P\, V_E\, MW/RT \tag{1}$$

Assume:
1. Ideal gas
2. Isothermal
3. Clean gas contains no contaminant.

where M_{plug} = Mass of clean gas required
MW = Clean gas molecular weight
P = Final pressure (absolute)
R = Gas constant
T = Final temperature (absolute)
V_E = Equipment volume to be purged.

Perfectly mixed. Another contaminant removal method is encouraged mixing. Instead of plug flow, purge gas mixes well within the equipment and the contaminant levels decrease over time. This method is often used for small vessels or pump maintenance work. However, as equipment size and complexity increases, purge gas maldistribution inhibits adequate contaminant removal. Standard back-mix reactor equations approximate this purge type:

$$dY/dt = -(F/V_E)Y \tag{2}$$

$$t = (V_E/F)(\ln Y_0 - \ln Y_t) \tag{3}$$

$$M_{mix} = \frac{P\, V_E\, MW}{RT}(\ln Y_0 - \ln Y_t) \tag{4}$$

Assume:
1. Ideal gas
2. Isothermal
3. Clean gas contains no contaminant
4. Perfect and instantaneous mixing of clean gas within the equipment volume.

where F = Clean gas volumetric flowrate
M_{mix} = Mass of clean gas required
t = Time to reach final concentration
Y = Contaminant mole or volume fraction
Y_0 = Initial contaminant mole or volume fraction
Y_t = Final contaminant mole or volume fraction

Cyclic purge. For large or complex systems, cyclic purging is frequently used. The system is pressurized to a calculated value with clean gas, then depressured. The process is repeated until the desired contaminant level is achieved. While pressurizing, the gas is mixed within the equipment by diffusion and turbulence. While the unit depressurizes, low points, dead legs and other system connections may be blown down individually. Fig. 1 illustrates general pressure cycles that equipment may be exposed to during purging. Contaminant concentrations can be found by:

$$Y_1 = \frac{\left(\frac{P_{l1} V_E}{RT}\right) Y_0}{\left(\frac{P_{h1} V_E}{RT}\right)} = \left(\frac{P_{l1}}{P_{h1}}\right) Y_0 \tag{5}$$

$$Y_2 = \frac{\left(\frac{P_{l2} V_E}{RT}\right) Y_1}{\left(\frac{P_{h2} V_E}{RT}\right)} = \left(\frac{P_{l2}}{P_{h2}}\right) Y_1 = \frac{P_{l1}\, P_{l2}}{P_{h1}\, P_{h2}} Y_0 \tag{6}$$

$$Y_3 = \frac{\left(\frac{P_{l3} V_E}{RT}\right) Y_2}{\left(\frac{P_{h3} V_E}{RT}\right)} = \left(\frac{P_{l3}}{P_{h3}}\right) Y_2$$

$$= \left(\frac{P_{l1}\, P_{l2}\, P_{l3}}{P_{h1}\, P_{h2}\, P_{h3}}\right) Y_0 \tag{7}$$

$$Y_c = \frac{\left(\frac{P_{lc} V_E}{RT}\right) Y_{c-1}}{\left(\frac{P_{hc} V_E}{RT}\right)} = \left(\frac{P_{lc}}{P_{hc}}\right) Y_{c-1} = \left(\frac{\prod_{i=1}^{c} P_{li}}{\prod_{i=1}^{c} P_{hi}}\right) Y_0 \tag{8}$$

Assume:
1. Ideal gas
2. Isothermal
3. Clean gas contains no contaminant.

where c = Number of purging cycles
P = Absolute pressure
l = Low pressure part of cycle
h = High pressure part of cycle
Y_i = Contaminant mole or volume fraction at cycle i

For the special case where the equipment is pressured to the same value and depressured to the same initial value each cycle:

$$\frac{Y_c}{Y_0} = \left(\frac{P_l}{P_h}\right)^c \tag{9}$$

$$M_{cycle} = \frac{c\, V_E\, MW}{RT}(P_h - P_l) \tag{10}$$

where M_{cycle} = Mass of clean gas required
Y_i = Contaminant mole or volume fraction at cycle i

Fig. 2 graphically represents Eq. 9. This figure can quickly assess the number of cycles required to purge an equipment item. Common practice adds one more cycle than would be predicted by theory to account for poor mixing and other real world effects. Always measure the purge gas contaminant concentration during depressuring to ensure adequate cleansing. ■

The author

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