Oxygen Concentration in Ventilated Spaces

The oxygen concentration in a confined volume during and after a release of an inert gas may be approximated for three different cases:

A. Ventilation fan(s) blowing into the confined volume.
B. Ventilation fan(s) drawing from the confined volume with the ventilation rate greater than the spill rate.
C. Ventilation fan(s) drawing from the confined volume with the ventilation rate less than or equal to the spill rate.

For each case, the differential equation and its solution is given, based on an oxygen mass balance for the confined volume. The following definitions and assumptions are common for each case.

Definitions

C = oxygen concentration
C_r = oxygen concentration during the release
C_e = oxygen concentration after the release has ended
Q = ventilation rate of fan(s), (cfm or m^3/s)
R = spill rate into confined volume, (scfm or m^3/s)
t = time (minutes or seconds), beginning of release is at t=0
t_e = time when release has ended, (minutes or seconds)
V = confined volume, (ft^3 or m^3)

Assumptions

- Complete and instantaneous mixing takes place in the confined volume.
- Q, R, and V remain constant
- Pressure in the confined volume remains constant and very near atmospheric pressure through the use of louvers or natural leakage.
- Gas entering from outside the confined volume is air with an oxygen concentration of 0.21 (21% by volume).

Case A: Ventilation fan(s) blowing into the confined volume.

The differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = 0.21Q - (R+Q)C$$

The solution for the boundary condition of C=0.21 at t=0 is

$$C_r(t) = \left[\frac{0.21}{Q+R}\right]\left[Q + \mathrm{Re}^{[-(Q+R)t/V]}\right]$$

Case B: Ventilation fans(s) drawing from the confined volume with the ventilation rate greater than the spill rate (Q>R).

The differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = 0.21(Q - R) - QC$$

The solution with the boundary condition of C=0.21 at t=0 is

$$C_r(t) = 0.21\left\{1 - \frac{R}{Q}\left[1 - e^{(-Qt/V)}\right]\right\}$$

Case C Ventilation fan(s) drawing from the confined volume with the ventilation rate less than or equal to the spill rate.

Differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = -RC$$

The solution with the boundary condition of C=0.21 at t=0 is

$$C_r(t) = 0.21e^{[-Rt/V]}$$

Case D After Release has ended

The oxygen concentration in the confined volume after the release has ended, Ce (t), can be approximated by one equation for all three cases.

The differential equation for the oxygen mass balance is

$$V\frac{dC}{dt} = 0.21Q - QC$$

The solution with the boundary condition of C=Cr (te) at t=te , where (t-te) is the time duration since the release ended is

$$C_e(t) = 0.21 - \left[0.21 - C_r(t_e)\right]e^{[-Q(t-t_e)/V]}$$