THE EFFECT OF BAROMETRIC PUMPING ON FIELD DETERMINED RESPIRATION RATE FOR BIOVENTING PROCESS

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Abstract: Field measured respiration rates are necessary to size the appropriate oxygen supply equipment and to determine the proper injection/extraction flow rate and operating mode in the design of a bioventing system. Respiration rates are also used to estimate the amount of contaminant metabolized during the bioventing process. Almost all respiration tests are conducted in an open system subject to air diffusion and interaction with the lower atmosphere. Oxygen supply to shallow surface soil by diffusion can be significant, as indicated by field collected data. Temporal variations in barometric pressure due to weather patterns may induce air intrusion into the subsurface. However, the effect of fluctuations in barometric pressure on soil gas pressures and soil gas composition is generally ignored/neglected in *in situ* respiration tests. In this paper, the effect of barometric pumping on oxygen intrusion from the atmosphere to the shallow vadose zone is investigated using computer simulation. A model is also presented to correct the impact of barometric pumping on field-determined respiration rates.

Bioventing is a process designed to provide indigenous organisms with adequate oxygen to aerobically degrade target contaminants. Bioventing has been used successfully to remediate soils contaminated with jet fuel, gasoline, and diesel fuel components.

Respiration rate in a bioventing process is used to measure how fast a target contaminant in vadose zone soils is biologically degraded. The quantification of microbial respiration rates under field conditions is generally carried out using *in situ* respiration tests described by Hinchee *et a1*. (1992). During an *in situ* respiration test, narrowly screened soil gas monitoring points are placed into both contaminated and uncontaminated vadose zone soils. The soils with the monitoring points are vented with air for a given period of time, i.e., for 8 hours or longer. Then, soil vapor samples are collected and analyzed over time for oxygen, along with other soil gases.

Almost all respiration tests are conducted in an open system subject to air diffusion and interaction with the lower atmosphere. Oxygen supply to shallow surface soil by diffusion can be significant, as indicated by data from FEW Air Force Base (Figure 1). Figure 2 illustrates the fluctuation of barometric pressure, also based on collected from FEW Air Force Base. Field data indicate that "fresh" air can migrate several meters into the subsurface with homogeneous soils in response to a typical barometric pressure cycle. This air intrusion can affect monitoring activities aimed at characterizing the composition and movement of gases in the vadose zone. It has been shown that relatively small gradients in total pressure can result in viscous gas fluxes larger than diffusive fluxes. However, the effect of air diffusion and fluctuations in barometric pressure on soil gas pressures and soil gas composition is generally ignored/neglected in *in situ* respiration tests. Therefore, the current method for field determination of respiration rate may underestimate the real microbial respiration rate, especially for shallow soil contamination.

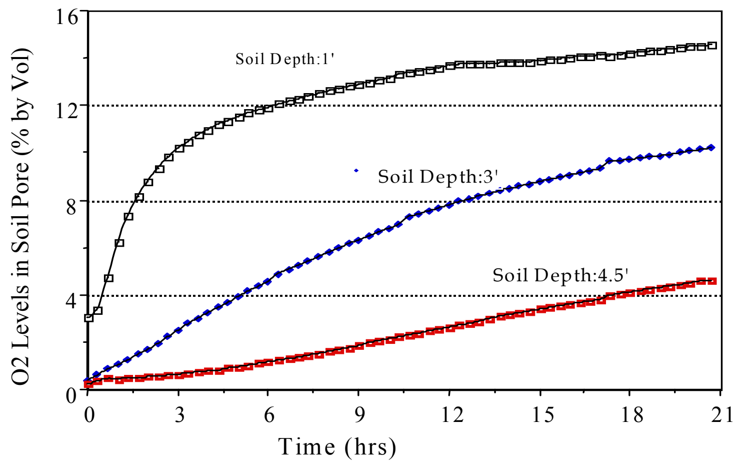

Figure 1. Oxygen Diffusion Over Time in Soil Pores at Various Depths Measured From a Field Site at F.E. Warren AFB, WY. (1994)

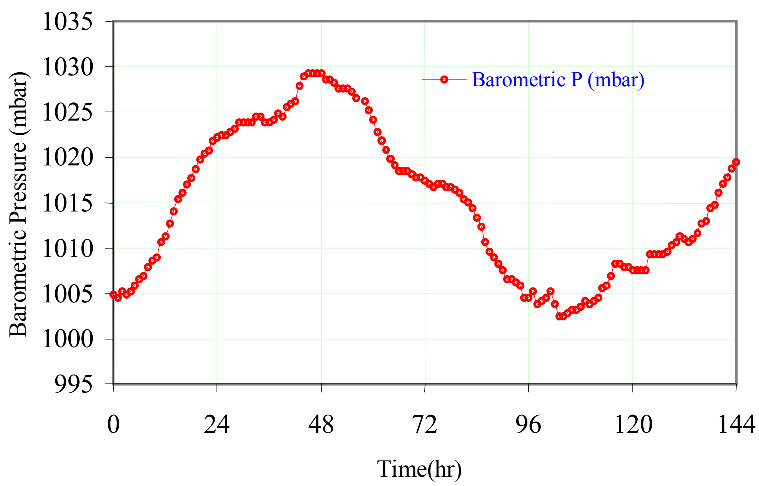

Figure 2. Plot of Barometric Pressure vs Time Using FEW AFB Data (1994)

The effect of barometric pumping and air diffusion on oxygen intrusion from the atmosphere to the shallow vadose zone can be described using the following equations.

1. Vadose Zone Air Pressure Equation:

$$\frac{\partial P^2}{\partial t} = \frac{k_z P_{atm}}{\theta_a \mu} \frac{\partial^2 P^2}{\partial Z^2} \qquad (1)$$

Boundary conditions:

$$P = P_{atm} \qquad Z = 0 \qquad \text{(upper boundary)} \tag{2}$$

$$\frac{\partial P}{\partial Z} = 0 \qquad Z = Z_t \qquad \text{(lower boundary)} \tag{3}$$

P_{atm} is atmospheric pressure, can often be fitted with sinusoidal curve. Thus,

$$P_{atm} = P_{av} + \left|(\Delta p)_{\max}\right| Sin(\frac{t - t_0}{\varpi}\pi) \tag{4}$$

2. Soil Gas Transport Equation:

$$(\theta_a + \theta_w k_{aw}^{ox})\frac{\partial C_a^{ox}}{\partial t} = -q_z \frac{\partial C_a^{ox}}{\partial z} + D_z^{ox} \frac{\partial^2 C_a^{ox}}{\partial z^2} + R_b \tag{5}$$

$$q_z = -\frac{k_z}{\mu}\frac{\partial P}{\partial z} \tag{6}$$

Boundary conditions:

$$C_a^{ox} = C_{a,atm}^{ox} \qquad Z = 0 \qquad \text{(upper boundary)} \tag{7}$$

$$\frac{\partial C_a^{ox}}{\partial Z} = 0 \qquad Z = Z_t \qquad \text{(lower boundary)} \tag{8}$$

Initial condition:

$$C_a^{ox} = C_{a,init}^{ox} \qquad t = 0 \tag{9}$$

where C_a^{ox} = the concentration of oxygen in soil gas (g/m^3); $C_{a,atm}^{ox}$ = the oxygen concentration in atmosphere (g/m^3); D_z^{ox} = diffusion coefficient of oxygen in air-phase (cm/s^2); $C_{a,init}^{ox}$ = the initial oxygen concentration in soil gas (g/m^3); k_{aw}^{ox} = the linear partition coefficient for air with respect to water (g/m^3-air)/(g/m^3-water); k_z = air-phase permeability tensor in the z-direction (cm^2); P = air pressure in vadose zone (cm H_2O); P_{atm} = atmospheric pressure (cm H_2O); P_{av} = the average atmospheric pressure in a barometric cycle (cm H_2O); $(\Delta P)_{\max}$ = the maximum variation of atmospheric pressure in a barometric cycle (cm H_2O); q_z = Darcy air flow velocity, (cm/s); R_b = the respiration rate due to biodegradation (g/m^3/day); t is time (s); Z = the vertical depth from soil surface (cm); θ_a = air-filled porosity, dimensionless; θ_w = the air-filled porosity, dimensionless; μ = dynamic viscosity of air (gm/cm/s); t_o and ω = barometric cycle coefficients (in hour).

Based on the above mathematical equations, a numerical model has been developed and used to simulate the effects of barometric pumping on the "intrusion" of oxygen into the shallow vadose zone. Figure 3 shows the oxygen concentration recovery at two different soil depths (40 cm and 80 cm) due to air diffusion or barometric pumping effect. It demonstrates that the oxygen recovery rate caused by barometric pumping is significantly faster that that caused by air diffusion only.

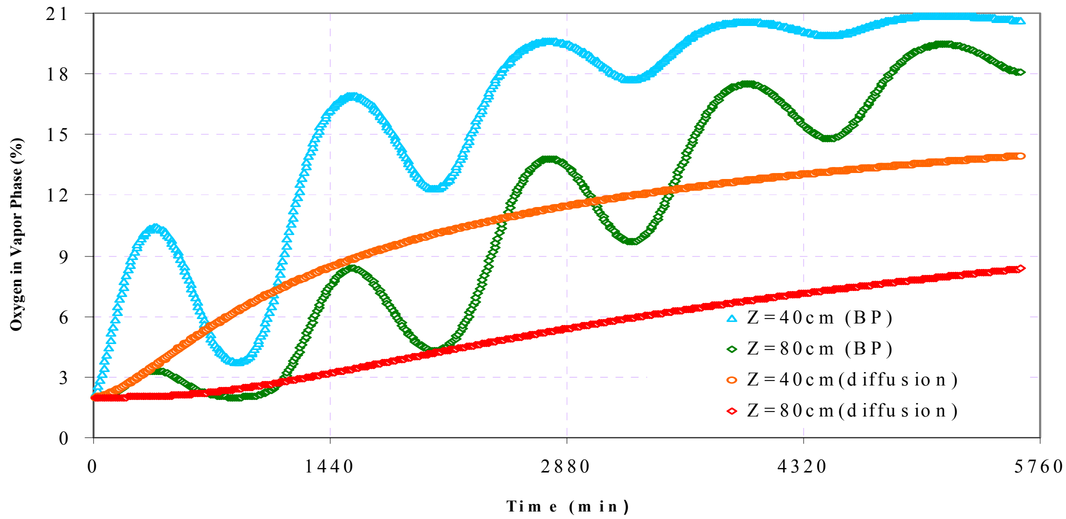

Figure 3. Comparison of Oxygen Induced by Barometric Pumping and Diffusion in Shallow Vadose Zone

Figure 4 depicts the simulated results of oxygen induced by both barometric pumping and diffusion in vadose zone soil at different depths up to 300 cm.

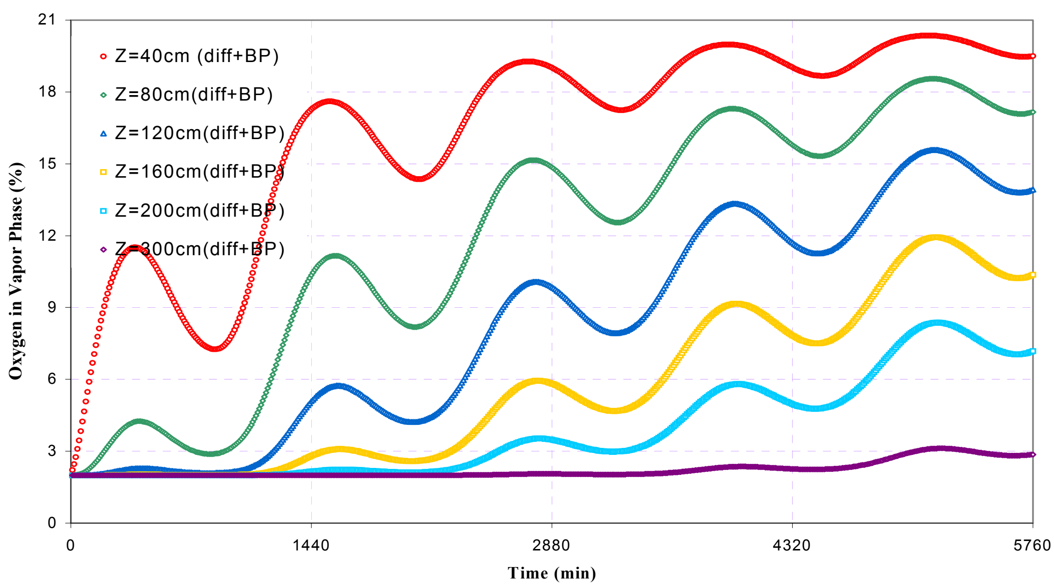

Figure 4. Oxygen Induced by Barometric Pumping and Diffusion in Shallow Vadose

Figure 4 indicates that the oxygen induced to shallow vadose zone by air diffusion and barometric pumping is significant. However, this significance of oxygen recovery due to air diffusion and barometric pumping appears damped with soil depth and becomes minimal when reaches 300 cm deep under the simulated conditions.

To demonstrate the use of the numerical model in interpretation of field observed or apparent respiration rates, field data collected from a bioventing site at F.E. Warren Air Force Base are used for model simulation. Input data used for simulation are summarized in Table 1. These data were used as input to simulate oxygen concentration in soils over time at various depths as a function of oxygen respiration rate. Field data were then used to identify predicted rates which allowed calibration to these measured data.

Table 1. Input Field Data for Oxygen Concentration Simulation

Depth (feet)	Moisture (%)	Soil Temperature (C^o)	Porosity
1.5	20	22	0.4
3.0	20	21	0.4
4.5	25	20	0.4
5.5	26	20	0.3
6.5	28	18	0.3
7.0	34	18	0.3
8.0	35	18	0.3

These predicted rates, accounted for oxygen diffusion into the soil, are listed in Table 2 and are compared to field measured data at soil depths of 90 cm, 170 cm, and 250 cm, respectively.

The results show that the corrected oxygen utilization rates by microbial metabolism are greater than the actual field observed rate at all three soil depths.

Table 2. Field Observed Respiration Rate versus Predicted Values

Soil Depth (cm)	Field Measured Respiration Rate (%/hr)	Corrected Respiration Rate (%/hr)
90	0.25	0.42
170	0.07	0.15
250	0.13	0.24

Reference:

Hinchee, R. E., S. K. Ong, R. N. Miller, D. C. Downey, and R. Frandt. 1992. Test Plan and Technical Protocol for a Field Treatbility Test for Bioventing, Rev. 2. U.S. Air Force Center for Environmental Excellence, Brooks Air Force Base, TX.