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Calculations on the Distribution of the Loss of BeO Through Volatilization from the Walls of a High Temperature Pile Channel having a Large Temperature Gradient

These calculations give the penetration per month due to volatilization as a function of the position of the oxide surface in the structure. The following assumptions are used.

1. It is assumed that the steam is saturated with oxide vapor at every point.
2. It is assumed that Brewer's free energy equation is correct for the transition

   Solid Oxide $\longrightarrow$ Gaseous oxide.

3. It is assumed that the temperature gradient is linear from the bottom of the structure to the top.
4. It is assumed that the pressure gradient is linear also.
5. It is assumed that the steam is in thermal equilibrium with the oxide surface at every point.

The following quantitative values are used.

1. 330 holes, 5 ft (152.4 cm) long and 2 in. in diam. (circumference of 15.96 cm).
2. 330 rods, 5 ft (152.4 cm) long and 1.5 in. in diam. (circumference of 11.97 cm).
3. 4500 lbs/min of water used (2.041×10^6 gm/min).
4. 6 atm. entrance pressure, 5 atm. exit pressure.
5. 150°C entrance temperature, 1500°C exit temperature.
6. Oxide density of 2.5 gm/cc.

The following equations result for T, P, and V of the steam as a function of the height (h cm) from the bottom of the structure.

$$T = 425 + 8.858\ h \qquad \text{(deg K)}$$

$$P = 6 - 0.00656\ h \qquad \text{(atm.)}$$

$$V = 9.304 \times 10^3\ \frac{T}{P} \qquad \text{(liters/min)}$$

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If g represents the weight of oxide present in the steam and p is the vapor pressure of the oxide at temperature T (p in mm of Hg), then

$$g = \frac{25.02}{62.36} \quad \frac{pV}{T} = 0.4012 \frac{pV}{T}$$

$$\frac{dg}{dh} = \text{weight of oxide lost from oxide surface at height h}$$

$$\frac{dg}{dh} = \frac{\partial g}{\partial p}\frac{dp}{dh} + \frac{\partial g}{\partial V}\frac{dV}{dh} + \frac{\partial g}{\partial T}\frac{dT}{dh} = 0.4012 \left[\frac{V}{T}\frac{dp}{dh} + \frac{p}{T}\frac{dV}{dh} - \frac{pV}{T^2}\frac{dT}{dh}\right]$$

From Brewer's free energy equation

$$\log_{10} p_{mm} = 10.377 - \frac{27.104}{T}$$

$$\frac{dp}{dh} = \frac{dp}{dT}\frac{dT}{dh} = \frac{27.104}{T^2}\, p\,(8.858) = \frac{2.401 \times 10^5\, p}{T^2}$$

$$\frac{dV}{dh} = \frac{5.203 \times 10^5}{p^2} \quad \text{liters/cm}$$

$$\frac{dT}{dh} = 8.858 \text{ deg/cm}$$

For later computation the equation for dg/dh is converted to

$$\frac{dg}{dh} = 0.4012 \left[\frac{V}{T}\frac{dp}{dh} + \frac{p}{T}\frac{dV}{dh} - 3.689 \times 10^{-5} V \frac{dp}{dh}\right]$$

The penetration per month (in inches) is given by

$$\frac{(60)\quad 24\quad (30)}{330\ (15.96 + 11.97)\quad 2.5\quad (2.54)} \frac{dg}{dh} = 0.7382 \frac{dg}{dh}$$

h (cm)	T°K	P	V (l)	p(mm)	$\frac{dp}{dh}$	$\frac{dV}{dh}$
0	423	6.0000	6.56×10^5	2.00×10^{-54}	2.69×10^{-54}	1.45×10^4
20	600	5.8688	9.52×10^5	1.66×10^{-35}	1.10×10^{-35}	1.51×10^4
40	777	5.7376	1.26×10^6	3.22×10^{-25}	1.28×10^{-25}	1.58×10^4
60	955	5.6064	1.58×10^6	9.57×10^{-19}	2.52×10^{-19}	1.65×10^4
80	1132	5.4752	1.93×10^6	2.66×10^{-14}	4.99×10^{-15}	1.74×10^4
100	1309	5.3440	2.28×10^6	4.66×10^{-11}	6.52×10^{-12}	1.82×10^4
120	1486	5.2128	2.65×10^6	1.37×10^{-8}	1.49×10^{-9}	1.92×10^4
140	1663	5.0816	3.05×10^6	1.20×10^{-6}	1.04×10^{-7}	2.02×10^4
152.4	1773	5.0000	3.30×10^6	1.23×10^{-5}	9.40×10^{-7}	2.08×10^4

h(cm)	$\frac{V}{T}\frac{dp}{dh}$	$\frac{p}{T}\frac{dV}{dh}$	$3.689\times10^{-5}V\frac{dp}{dh}$	$\frac{dg}{dh}$	penetration (in./month)
0	4.18×10^{-51}	6.84×10^{-53}	6.51×10^{-53}	1.68×10^{-51}	1.24×10^{-51}
20	1.75×10^{-32}	4.18×10^{-34}	3.86×10^{-34}	7.01×10^{-33}	5.18×10^{-33}
40	2.08×10^{-22}	6.55×10^{-24}	5.95×10^{-24}	8.36×10^{-23}	6.18×10^{-23}
60	4.19×10^{-16}	1.66×10^{-17}	1.47×10^{-17}	1.69×10^{-16}	1.25×10^{-16}
80	8.49×10^{-12}	4.08×10^{-13}	3.54×10^{-13}	3.43×10^{-12}	2.53×10^{-12}
100	1.14×10^{-8}	6.51×10^{-10}	5.49×10^{-10}	4.62×10^{-9}	3.40×10^{-9}
120	2.66×10^{-6}	1.77×10^{-7}	1.46×10^{-7}	1.08×10^{-6}	7.97×10^{-7}
140	1.91×10^{-4}	1.46×10^{-5}	1.17×10^{-5}	7.78×10^{-5}	5.74×10^{-5}
152.4	1.75×10^{-3}	1.44×10^{-4}	1.15×10^{-4}	7.15×10^{-4}	5.27×10^{-4}

The following calculations are made to determine whether the amount of oxide lost as vapor is determined by its equilibrium vapor pressure or by its rate of vaporization.

n = moles striking surface of area, a, per second and therefore the number of moles evaporating from surface of area a cm^2 per second if the accommodation coefficient is unity.

p = pressure in mm of Hg.

M = molecular weight

T = temperature in deg. K.

w = gm of material evaporating from a cm^2 per sec.

$$n = \frac{pa}{\sqrt{2\pi RMT}}$$

$$w = \frac{\sqrt{M}\,pa}{\sqrt{2\pi RT}} = 5.83\times10^{-2}\sqrt{\frac{M}{T}}\quad pa$$

Since the area of surface per cm height = 330 (27.928) = 9.216×10^3 cm^2, the grams of oxide evaporating per cm height per minute, w', is given by

$$w' = 5.83\times10^{-2}\,(5.002)\,9.216\times10^3\,(60)\,\frac{p}{\sqrt{T}}$$

$$= 1.613\times10^5\,\frac{p}{\sqrt{T}}$$

w' as here defined corresponds to dg/dh as used in the first calculation (p.2) if evaporation is the limiting factor.

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h (cm)	$\sqrt{T}$	w'	$\frac{dg}{dh}$
0	20.57	1.57×10^{-50}	1.68×10^{-51}
20	24.50	1.09×10^{-31}	7.01×10^{-33}
40	27.88	1.86×10^{-21}	8.36×10^{-23}
60	30.90	5.00×10^{-15}	1.69×10^{-16}
80	33.64	1.28×10^{-10}	3.43×10^{-12}
100	36.18	2.08×10^{-7}	4.62×10^{-9}
120	38.55	5.74×10^{-5}	1.08×10^{-6}
140	40.78	4.75×10^{-3}	7.78×10^{-5}
152.4	42.11	4.71×10^{-2}	7.15×10^{-4}

Since w' is considerably greater than dg/dh, it is not the limiting factor. Instead, the limiting factors are the equilibrium vapor pressure and the degree of saturation of vapor in the exit gas. Since the exit gas will probably not be saturated, such calculations as these will give the maximum penetration.

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